ADVANCES IN AGRICULTURAL & ENVIRONMENTAL SUSTAINABILITY

Dr. Mudasir Ali
Ms. Khumanthem Babina Devi
Ms. Kshetrimayum Manishwari Devi
Er. Bilal Ahmad Langoo
Mr. Dibyajyoti Nath

Advances In Agricultural
&
Environmental Sustainability

EMPYREAL
PUBLISHING HOUSE

India | UAE | Nigeria | Uzbekistan | Montenegro | Iraq |
Egypt | Thailand | Uganda | Philippines | Indonesia
www.empyrealpublishinghouse.com

Advances In Agricultural
&
Environmental Sustainability

Edited By:

Dr. Mudasir Ali
Assistant Professor & Head at Division of Renewable Energy Engineering
COAE&T, SKUAST-Kashmir

Ms. Khumanthem Babina Devi
Ph.D Research Scholar in Environmental Science
Mizoram University

Miss Kshetrimayum Manishwari Devi
Ph.D Research Scholar at Department of Agronomy
College of Agriculture, Central Agricultural University, Imphal

Er. Bilal Ahmad Langoo
Assistant Professor,
College of Agricultural Engineering, SKUAST-Kashmir, Shalimar Srinagar

Mr. Dibyajyoti Nath
Ph.D Research Scholar in Soil Science
Dr. Rajendra Prasad Central Agricultural University (RPCAU), Pusa, Bihar

First Impression: October 2023

ADVANCES IN AGRICULTURAL & ENVIRONMENTAL SUSTAINABILITY

ISBN: 978-81-965655-8-9

Rs. 1000/- ($80)

DISCLAIMER

Information contained in this book has been published by Empyreal Publishing House and has been obtained by the editors from sources believed to be reliable and correct to the best of their knowledge. The editors are solely responsible for the contents of the articles compiled in this book. Responsibility of authenticity of the work or the concepts/views presented by the author through this book shall lie with the author and the publisher has no role or claim or any responsibility in this regard. Errors, if any, are purely unintentional and readers are requested to communicate such error to the author to avoid discrepancies in future.

Published by:
Empyreal Publishing House

Preface

The agricultural sector and scientists have a significant and moral responsibility in ensuring food, nutritional, economical and sustainable development in any country. Population explosion is a cause of serious concern, as world population is growing at the rate of 2% per year. A common consensus is that sustainable farming is the most realistic way to feed growing populations. In order to successfully feed the population of the planet, farming practices must consider future costs–to both the environment and the communities they fuel. Energy is one the major inputs for the economical development of any country. In case of the developing countries, the energy sector assumes a critical importance in view of ever-increasing energy needs requiring huge investments to meet them. Energy is also important from the environmental viewpoint. Most of the energy issues, such as greenhouse effect and acid rain, are associated with energy production. Ironically, the improvement of environment usually needs additional energy input. In this sense, energy and environment represent the two sides of a coin: new technologies to produce energy without pollution and new technologies to control environment with minimum energy. The various present and advance methods of agriculture, environment and energy sustainability are the indispensable parts of this book. The present book would not have been completed without the great endeavor of its authors and co-editors. I would like to express my sincere thanks to the co-editors, Ms. Khumanthem Babina Devi, Ms. Kshetrimayum Manishwari Devi, Er. Bilal Ahmed langoo and Mr. Dibyajyoti Nath for their tremendous efforts to edit this book. Deep gratitude is also expressed to the authors of this volume who contributed excellent manuscripts keeping in view the need for sustainable future for all.

About the Editors

Dr. Mudasir Ali is presently working as Assistant Professor & Head at Division of Renewable Energy Engineering, COAE&T, SKUAST-Kashmir. Dr. Ali has completed B.Tech Agril. Engg. from Allahabad Agricultural Institute, Naini Allahabad (Prayagraj) in 2007, M.Tech. in Farm Machinery and Power from IGKV-Raipur in 2009 and PhD in Farm Machinery & Power Engineering from Punjab Agricultural University, Ludhiana in 2020. Dr. Ali is recipient of academic Gold Medal from IGKV-Raipur during 2009-10. He has received best PhD thesis award during 2022 by ICAR-IGFRI and ICAR-NAHEP, BAU Ranchi, best international paper award at 4th international conference on Renewable Energy, Sustainable Environment and Agri-Technological innovation, December 2022, at WUT, Warsaw, Poland. He has also received best Team Research Award from ISAE-India during 2014-15. Dr Ali is having 13 years of Teaching and research experience with specialization in Horticultural Mechanization, waste management and rural energy. He has published more than 20 research papers in national and international reputed journals.

Ms. Khumanthem Babina Devi (M.Sc Gold medalist) completed her B.Sc. (hons) Forestry from College of Horticulture & Forestry, Pasighat, CAU in 2018 and M.Sc. (Environmental Science) from NEHU, Shillong in 2020 and currently she is pursuing her PhD degree in Environmental Science from Mizoram University through DST INSPIRE fellowship programme . She has qualified SLET in the year 2021 and UGC NET three times in the year 2020, 2021 and 2022. She has been awarded best poster presentation at Mizoram Science Congress 2022. She has also awarded young researcher award in the year 2023 at international conference. She has one research paper (published) and one book chapter. She has been awarded with NEC scholarships and NFOBC for higher studies. She has presented many papers and posters in seminars and conferences at national and international level. Her research interest fields are forest ecology and diversity, tree seed treatments, biodiversity conservation and environmental sustainability.

Miss Kshetrimayum Manishwari Devi is a Ph.D research scholar at Department of Agronomy, College of Agriculture, Central Agricultural University, Imphal. She has completed her graduation in B.Sc. (Agri.) from HNBGU, Dehradun and M.Sc. (Agri.) Agronomy from College of Agriculture, Central Agricultural University, Imphal. She has qualified the ICAR (Ph.D.) entrance exam with an all-India UPS rank of 9th and has also qualified ASRB/ICAR-NET in various numbers. She has published various scientific papers, popular articles and seven book chapters. She has been awarded the Best Research Scholar Award 2022, the Best Article Award 2022, the Budding Young Agronomist Award, and is also a life member of the prestigious Indian Society of Agronomy. She has a work experience of about 5 years in the IWMP Project.

Er. Bilal Ahmad Langoo is currently working as Assistant Professor, Division of Processing and Food Engineering at College of Agricultural Engineering, SKUAST-Kashmir, Shalimar Srinagar. Er. Langoo has done M.Tech in Processing and Food Engineering from AAI-Allahabad (Prayagraj) in 2012. He has qualified ICAR-NET in 2016 and has published 10 research papers in national and international reputed journals. His field of specialization is Agricultural Processing and Product Development. Presently Er. Bilal is pursuing PhD in Process and Food Engineering from GBPUAT-Pantnagar.

Dibyajyoti Nath, presently pursuing his Ph.D. in Soil Science at Dr. Rajendra Prasad Central Agricultural University (RPCAU), Pusa, Bihar. He completed his B.Sc. (Hons.) in Agriculture from College of Agriculture, Central Agricultural University (CAU), Imphal, Manipur in 2020 and pursued his M.Sc. (Ag.) in Soil Science and Agricultural Chemistry from Tamil Nadu Agricultural University (TNAU), Coimbatore in 2022. He has qualified ASRB ICAR-NET (Soil Science). He has published few research papers, few book chapters and abstracts. He has been awarded with Best M.Sc. Thesis Award, Young Researcher Award, Young Fellow Award and Best Oral Presentation Award at various International Conferences. He has participated in many national and international conferences, seminars, workshops, certificate courses and training programs conducted by different organizations.

Table of Contents

 ISBN: 978-81-965655-8-9

CHAPTER 1

AGROFORESTRY TO PROTECT AND IMPROVE BIODIVERSITY

Khumanthem Ronaldo Singh[1], Khumanthem Babina Devi[2*] Dr. Raj Bahadur[3], Dr. Anuradha Singh[4]

[1]M.Sc. Department of Environmental Science, IGNOU Maidan Garhi, New Delhi–110068

[2]Ph. D Scholar, Department of Environmental Science, Mizoram University, Aizawl-796004, Mizoram.

[3]Associate Professor, Department of Agronomy, Acharya Narendra Deva University of Agriculture & Technology (ANDUA&T) Kumarganj, Ayodhya-224229, UP

[3]Associate Professor, Department of Botany, Meerut College, Meerut-250001, UP

ABSTRACT

Agroforestry is one of the solutions to sustainable agricultural expansion. It is a system in which both tree and non-tree crops are planted in the same region simultaneously. Agroforestry can also be the answer to biodiversity loss due to forest conversion. It also contributes to carbon sequestration, soil fertility, ecosystem services, reduction of biodiversity loss, etc. It further improves the air quality of an area by acting as air filters and windbreaks. Agroforestry practices are essential for sustainable growth and development of agriculture. Moreover, it leads to greater yield of agricultural products along with conserving and enhancing biodiversity. Many agroforestry practices have been successfully established in different parts of the world resulting in better yield along with biodiversity conservation. Therefore, agroforestry practices should be adopted and promoted to mitigate forest conversion and achieve sustainable development.

Key words: Agroforestry, forest conversion, sustainable development, biodiversity conservation

INTRODUCTION

In the middle of the 1960s, a new agricultural approach—commonly referred to as the "Green Revolution"—was put into place to achieve self-sufficiency in the production of food grains. HYV (high yielding variety) seeds, chemical fertilizers, irrigation systems, improved farm tools, and crop protection techniques were all used in this strategy. It was successful, and self-sufficiency in food was established. Food grain crops are now being grown on more land thereby decreasing the area of natural ecosystem. For instance, Punjab and Haryana produced 3% of the nation's food grains before the Green Revolution but after it they produced 20%. Since 1960–1961, the total area irrigated has nearly doubled (Singh, 1997; Kumar and Pasricha, 1999).

The most significant causes of land-use change and biodiversity loss in tropical areas are often described as substantial forest conversion and agricultural intensification (Sala *et al*., 2000; Wright, 2005). According to estimates, compared to the 1990s, deforestation rates in some tropical regions have increased after the turn of the century (FAO 2007). Additionally, the fact that some of the world's poorest people reside in the tropics adds to the strain on land use. In some tropical nations, up to 86% of the population is thought to be subsistence farmers (Fisher and Christopher 2007). Additionally, these areas are experiencing population growth that is far faster than the global average (Cincotta *et al*., 2000). Therefore, it is crucial to promote and practice any agricultural practices that give less stress on the environment.

The international conservation community is challenged to identify strategies that can minimize forestation and enhance rural livelihoods while still preserving biodiversity as deforestation rates climb in many tropical regions. Agroforestry, which is the deliberate management of trees

ISBN: 978-81-965655-8-9

for shade together with agricultural products, has the potential to connect nature reserves, create habitats outside of officially protected land, and lessen resource-use pressure on conservation areas (Bhagwat *et al*., 2008).

What is Agroforestry?

Agroforestry, according to Brazilian law, is "land use systems in which woody perennials are managed in association with herbaceous plants, shrubs, trees, agricultural crops, and forage species in the same management unit, according to spatial arrangement and temporal, with high species diversity and interactions between these components" (do brasil *et al*., 2009).

Fig 1: Agroforestry practice of coffee plantation under native tree (Bhagwat *et al*., 2008).

Agroforestry is the practice of growing both trees and non-tree crops or animals on the same plot of land. When resources from one crop are used to benefit another, the crops can be produced simultaneously, in rotation, or even in separate plots. This straightforward description, however, ignores the integrated ideas behind agroforestry, which may make this method of land management the most self-sufficient and environmentally sound of all agricultural systems. A second definition of agroforestry would therefore be the blending of trees, plants, and animals in conservative, sustainable, and fruitful systems. Agroforestry might be viewed more as a strategy than as a finished product. Although many complete systems have been developed and examined such technology would need to be adjusted for certain circumstances. One benefit of the agroforestry system is its adaptability (Martin and Sherman, 1998).

An agroforestry system is one that involves growing trees along with other field agricultural activities like growing crops and caring for animals. The sequestration of atmospheric carbon into soil is a promising potential benefit of the sustainable land use system known as agroforestry (Abbas *et al*., 2017).

Both in the tropics and in temperate regions, agroforestry is frequently viewed as a potential means of enhancing socioeconomic and environmental sustainability (Alavalapati *et al*., 2004; Nair, 2001).

 ISBN: 978-81-965655-8-9

Roles of Agroforestry

Carbon Sequestration

Through physical or biological processes, carbon can be removed from the atmosphere and stored in carbon sinks (such soils, vegetation, or oceans). In comparison to a monoculture field of agricultural plants or pasture, the quantity of carbon sequestered can increase with the inclusion of trees or shrubs in agroforestry systems (Sharrow and Ismail 2004; Kirby and Potvin, 2007).

Soil quality

It is well known how important agroforestry is for improving and preserving long-term soil sustainability and productivity. In tropical agroforestry systems, the integration of plants and trees that can organically fix nitrogen is rather typical. By incorporating considerable amounts of above- and below-ground organic matter as well as releasing and recycling nutrients in agroforestry systems, non-N-fixing trees can also improve the physical, chemical, and biological aspects of soil (Young, 1997; Buck *et al*., 1998; Jose ,2009).

Air Quality

Agroforestry techniques like windbreaks and shelterbelts are hailed for their many advantages. Among these advantages are the ability to effectively protect roads and buildings from drifting snow, cost savings in livestock production due to lower wind chills, protection of crops, creation of habitat for wildlife, production of oxygen from atmospheric carbon dioxide removal, reduction of noise pollution, and mitigation of odour from concentrated livestock operations. In recent years, there has been a lot of interest in utilising shelterbelts as a viable strategy to cope with livestock odour. Most chemicals and substances that cause odours are carried on aerosols (particulates). By eliminating dust, gas, and microbiological components, vegetative buffers can purge airstreams of particles (Tyndall and Colletti 2007).

Summary of agroforestry benefits (Martin and Sherman,1998)

- Increased year-round production of goods that people may use and buy.
- Better utilisation of labour and resources all year long.
- The preservation and enhancement of water resources as well as soils, particularly when legumes are used.
- More effective use of the land.
- The cost of planting trees is covered in the short term by increased food output.
- Providing shade for plants that need it or can handle it, such as vegetables or other crops.
- Fruits are produced during the long and medium terms.
- Long-term fuel and timber production.
- An increase in overall food or retail production.

Agroforestry for Conserving Biodiversity

Several writers (Schroth *et al*. 2004; McNeely, 2004; McNeely and Schroth, 2006; Harvey *et al*., 2006; Jose, 2009) have investigated the methods through which agroforestry systems contribute to biodiversity. Agroforestry generally fulfills five key functions in biodiversity preservation:

- Agroforestry provides habitat for species that can withstand a certain amount of disturbance;
- Agroforestry aids in the preservation of sensitive species' genetic material;

 ISBN: 978-81-965655-8-9

- Agroforestry slows the rate of conversion of the natural habitat by offering a more efficient, sustainable alternative to traditional agricultural systems that may involve destroying natural habitats;
- Agroforestry promotes connectivity by building pathways between habitat remnants that may support the biodiversity between flora and fauna; and
- By supplying additional ecosystem services like erosion control and water recharge, agroforestry aids in the conservation of biological variety by reducing the deterioration and loss of nearby habitat.

It has been established that various agroforestry systems are crucial for the preservation of species and habitats outside of formally designated protected areas (Bhagwat *et al*., 2008).

Williams-Guillen and colleagues discovered that mantled wailing monkeys, *Alouatta palliata*, can use shade coffee plantations in Nicaragua as alternate wildlife habitats and as corridors between forest remnants (Williams-Guillen *et al*., 2006).

Similar studies on bird populations on Khao Luang Mountain in southern Thailand have revealed that 38-48% of bird species living in nearby woods may also be found in mixed fruit plantations (Round *et al*., 2006).

In Ecuador, the hymenopteran communities of various habitat types, such as coffee agroforests and native forest fragments, overlapped noticeably. This finding suggests that even intensively managed land can contribute significantly to the general biodiversity of the landscape mosaic (Tylianakis *et al*., 2005). The habitat and landscape scale variability are maintained through agroforestry systems (Bhagwat *et al*., 2008).

Forest reserves under formal protection are less impacted by trees in agroforestry environments (Bhagwat *et al*., 2008). The availability of forest resources in mixed gardens and village woodlands in the northern Kerinci Seblat National Park and discovered that households with mixed gardens had a significantly lower reliance on park resources than those with just wetland rice fields (Murniati *et al*.,2001).

Recent studies have demonstrated the crucial role that agroforestry plays in the fight to preserve biodiversity around the world. Compared to conventional farming methods, the agroforestry system of shade coffee offers considerable promise for enhancing biodiversity (Perfecto *et al*., 1996).

Similarly, multistrata cacao (*Theobroma cacao*) agroforestry arrangements which involve timber, fruit, and indigenous forest species also aid in the preservation of biodiversity by supplying habitat for avian, mammalian, and other species, enhancing landscape connectivity, and minimising edge effects between forest and agricultural land. For instance, in the indigenous reserves of Talamanca, Costa Rica, bat and bird groups occurring in forests, two different types of agroforestry systems (cacao and banana), and plantain monocultures. In addition to having bat assemblages that were as (or more) diversified, prolific, and species-rich as forests do, agroforestry systems also have a higher proportion of nectarivorous bats than forests do (Harvey and Gonzalez, 2007).

Evidences of Biodiversity Conservation through Agroforestry

In Thailand, the world's largest producer of rubber, a survey was conducted for birds, fruit-eating butterflies, and reptiles in 25 monocultural and 39 agroforest smallholder rubber plots. Each plot's management and vegetation structure data were gathered, and the plots' surroundings' landscape composition was measured. For a different set of 34 monocultural and 47 agroforest rubber plots in the same area, rubber yield data were gathered. Since reported rubber yields did not differ between agroforests and monocultures, agroforestry should not

 ISBN: 978-81-965655-8-9

increase the need for natural rubber-producing land in this situation. Greater butterfly diversity was found in agroforests, and butterfly diversity grew as natural forest cover expanded throughout the terrain. Agroforests and monocultures both had comparable bird and reptile richness, but the height of herbaceous vegetation inside rubber plots increased the bird richness. While the species composition of birds was influenced by the height of herbaceous vegetation within plots, the density of non-rubber trees within plots (representing agroforestry complexity), and the extent of natural forest in the landscape, the species composition of butterflies varied between agroforests and monocultures and in response to natural forest extent. The amount of open habitat and canopy cover in the landscape increases the composition of the reptile population. Rubber did not promote the conservation of birds that depend on forests (Warren-Thomas *et al*., 2020).

Fig 2: Monoculture rubber plantation (Warren-Thomas et al., 2020).

Fig 3: Agroforest rubber plantation (Warren-Thomas *et al*., 2020).

 ISBN: 978-81-965655-8-9

Shaded cocoa systems have been managed for more than 250 years in the south of Bahia and in some areas of Esprito Santo state (May *et al*., 2008). Since the original "cabruca" method is implemented by thinning the understory to plant cocoa trees while conserving the canopy of larger trees, it is categorised as a genuine "static" agroforestry system. Some of the original forest's qualities, including some of its biodiversity, are preserved through this method. Due to the ability to maintain fertility, output can last longer without the use of outside resources (Ruf and Schroth, 2004).

CONCLUSION

One of the major causes of biodiversity loss is decrease in forest cover. With the increase in human population, food demand also increases which leads to agricultural expansion which further leads to forest conversion. Decrease in forest cover may have a severe impact on the environment. So, it is high time to develop and promote any agricultural practices that give less stress on forest and environment. In this context, sustainable agriculture may be the better option. From the study, it is concluded that agroforestry practices sequester carbon, improve soil quality, preserve species, control erosion, provide ecosystem services, etc. Moreover, it also promotes diversity as compared to monoculture. To maximise the advantages of agroforestry, better design on agroforestry systems and more research are recommended for a better future. In the end, agroforestry may be one of the promising tools for diversifying production systems and conservation of biodiversity.

REFERENCES

- Abbas, F., Hammad, H. M., Fahad, S., Cerdà, A., Rizwan, M., Farhad, W., ... & Bakhat, H. F. (2017). Agroforestry: a sustainable environmental practice for carbon sequestration under the climate change scenarios—a review. *Environmental Science and Pollution Research*, *24*, 11177-11191.
- Alavalapati, J. R., Shrestha, R. K., Stainback, G. A., & Matta, J. R. (2004). Agroforestry development: An environmental economic perspective. In *New Vistas in Agroforestry: A Compendium for 1st World Congress of Agroforestry, 2004* (pp. 299-310). Springer Netherlands.
- Bhagwat, S. A., Willis, K. J., Birks, H. J. B., & Whittaker, R. J. (2008). Agroforestry: a refuge for tropical biodiversity? *Trends in ecology & evolution*, *23*(5), 261-267.
- Buck, L. E., Lassoie, J. P., & Fernandes, E. C. (Eds.). (1998). *Agroforestry in sustainable agricultural systems*. CRC Press.
- Cincotta, R. P., Wisnewski, J., & Engelman, R. (2000). Human population in the biodiversity hotspots. *Nature*, *404*(6781), 990-992.
- do Brasil, F., à Desertificação, C., da Agrobiodiversidade, U. S., de Bacias Hidrográficas, P. C., Sustentáveis, R. P., Urbanos, R. S., & Ecológico-Econômico, Z. (2009). Ministério do Meio Ambiente. *Available online: mapas. mma. gov. br/i3geo/datadownload. htm (accessed on 10 October 2019)*.
- FAO (2007) State of the World's Forests. Food and Agriculture Organisation of the United Nations (http://www.fao.org/docrep/009/ a0773e/a0773e00.htm)
- Fisher, B., & Christopher, T. (2007). Poverty and biodiversity: Measuring the overlap of human poverty and the biodiversity hotspots. *Ecological economics*, *62*(1), 93-101.
- Harvey, C. A., Gonzalez, J., & Somarriba, E. (2006). Dung beetle and terrestrial mammal diversity in forests, indigenous agroforestry systems and plantain monocultures in Talamanca, Costa Rica. *Biodiversity & Conservation*, *15*, 555-585.

- Harvey, C. A., & González Villalobos, J. A. (2007). Agroforestry systems conserve species-rich but modified assemblages of tropical birds and bats. *Biodiversity and Conservation*, *16*, 2257-2292.
- Jose, S. (2009). Agroforestry for ecosystem services and environmental benefits: an overview. *Agroforestry systems*, *76*, 1-10.
- Kirby, K. R., & Potvin, C. (2007). Variation in carbon storage among tree species: Implications for the management of a small-scale carbon sink project. *Forest Ecology and Management*, *246*(2-3), 208-221.
- Kumar, R., & Pasricha, N. S. (1999, April). Land use and land cover changes in the Indus plains of Punjab in the post Green Revolution period 1965–1995. In *Proceedings of the International Seminar on Historical Perspectives of Land-use/Land-cover Change in South Asia for the Study of Global Change*.
- MARTIN, D. F. W., & Sherman, S. (1998). Agroforestry principles. *Field Guide to Appropriate Technology*, 365.
- MAY, P. H., TROVATTO, C. M., Deitenbach, A., & Floriani, G. S. (2008). Manual agroflorestal para a Mata Atlântica. *Brasília: Ministério do Desenvolvimento Agrário*, *195*.
- McNeely, J. A. (2004). Nature vs. nurture: managing relationships between forests, agroforestry and wild biodiversity. In *New Vistas in Agroforestry: A Compendium for 1st World Congress of Agroforestry, 2004* (pp. 155-165). Springer Netherlands.
- McNeely, J. A., & Schroth, G. (2006). Agroforestry and biodiversity conservation–traditional practices, present dynamics, and lessons for the future. *Biodiversity & Conservation*, *15*, 549-554.
- Murniati, Garrity, D. P., & Gintings, A. N. (2001). The contribution of agroforestry systems to reducing farmers' dependence on the resources of adjacent national parks: a case study from Sumatra, Indonesia. *Agroforestry Systems*, *52*(3), 171-184.
- Nair, P. K. R. (2001). Agroforestry in our fragile world: challenges and opportunities for sustainable development. Forerunner to the encyclopedia of life support systems, Chapter 1.25. *vol. I. UNESCO/EOLSS, Paris/Oxford*, 375-393.
- Perfecto, I., Rice, R. A., Greenberg, R., & Van der Voort, M. E. (1996). Shade coffee: a disappearing refuge for biodiversity: shade coffee plantations can contain as much biodiversity as forest habitats. *BioScience*, *46*(8), 598-608.
- Round, P. D., Gale, G. A., & Brockelman, W. Y. (2006). A comparison of bird communities in mixed fruit orchards and natural forest at Khao Luang, southern Thailand. *Biodiversity & Conservation*, *15*, 2873-2891.
- Ruf, F., & Schroth, G. (2004). Chocolate forests and monocultures: a historical review of cocoa growing and its conflicting role in tropical deforestation and forest conservation. *Agroforestry and biodiversity conservation in tropical landscapes. Island Press, Washington*, 107-134.
- Sala, O. E., Stuart Chapin, F. I. I. I., Armesto, J. J., Berlow, E., Bloomfield, J., Dirzo, R., ... & Wall, D. H. (2000). Global biodiversity scenarios for the year 2100. *science*, *287*(5459), 1770-1774.

- Schroth, G., Da Fonseca, G. A., Harvey, C. A., Gascon, C., Vasconcelos, H. L., Izac, A. M. N., ... & Wilkie, D. S. (2004). Conclusion: agroforestry and biodiversity conservation in tropical landscapes. *About Island Press*.
- Sharrow, S. H., & Ismail, S. (2004). Carbon and nitrogen storage in agroforests, tree plantations, and pastures in western Oregon, USA. *Agroforestry systems*, *60*, 123-130.
- Singh, R. B. (1997). Impact of agriculture and land use/cover change on soil and water resources and ecosystem sustainability: a case study of Punjab. *Sustainability of Rural System in the Context of Global Change. University of New England, Armidale*.
- Tylianakis, J. M., Klein, A. M., & Tscharntke, T. (2005). Spatiotemporal variation in the diversity of Hymenoptera across a tropical habitat gradient. *Ecology*, *86*(12), 3296-3302.
- Tyndall, J., & Colletti, J. (2007). Mitigating swine odor with strategically designed shelterbelt systems: a review. *Agroforestry systems, 69*, 45-65.
- Warren-Thomas, E., Nelson, L., Juthong, W., Bumrungsri, S., Brattström, O., Stroesser, L., ... & Dolman, P. M. (2020). Rubber agroforestry in Thailand provides some biodiversity benefits without reducing yields. *Journal of Applied Ecology*, *57*(1), 17-30.
- Williams-Guillén, K., McCann, C., Martínez Sánchez, J. C., & Koontz, F. (2006). Resource availability and habitat use by mantled howling monkeys in a Nicaraguan coffee plantation: can agroforests serve as core habitat for a forest mammal? *Animal Conservation*, *9*(3), 331-338.
- Wright, S. J. (2005). Tropical forests in a changing environment. *Trends in ecology & evolution*, *20*(10), 553-560.
- Young, A. (1997). *Agroforestry for soil management* (No. Ed. 2). CAB international.

CHAPTER 2

NANO FERTILIZERS FOR SECOND GREEN REVOLUTION

Suchibrata Chamuah[1*], Rituraj Dutta[2], William Haokip[3] and Shreedhar Beese[4]

[1]Ph.D. Scholar, Department of Vegetable Science, College of Horticulture and Forestry, CAU (I), Pasighat

[2]M.Sc. Student, Department of Vegetable Science, College of Horticulture and Forestry, CAU (I), Pasighat

[3]Ph.D. Scholar, Department of Fruit Science, College of Horticulture and Forestry, CAU (I), Pasighat

[4]Ph.D. Scholar, Department of Floriculture & Landscape Architecture, Dr. Y S Parmar University of Horticulture & Forestry, Nauni Solan (HP)

ABSTRACT

Contemporary farming practises have played devastation on the formerly bountiful soil, relentlessly draining its key nutrients and causing catastrophic damage to the fragile equilibrium of the surrounding nature. This is a frightening illustration of agriculture extravagance. The overuse of these fertilisers degrades the state of the soil, contaminates the surroundings, disturbs agro ecosystems, and produces deposit on farming goods. Additionally, a sizeable amount of the soil's nutrients, such as nitrogen, phosphate and potassium are lost (50–70%) prior to being used. Contrarily, nanofertilizers utilise nanoparticles to regulate the dispersion of nutrients, which makes them less expensive and more effective than conventional fertilisers. A novel category of fertilisers called nanofertilizers uses modern nanotechnology to give crops with an efficient and environmentally friendly technique of fertilisation. They are made to release plant-based nutrients in a precise way, making sure that their contents circulated progressively over a long period of time and giving the crops an ongoing supply of vital nutrients. Because it requires less frequent distribution and uses less fertiliser overall, the controlled-release technology is more effective than standard fertilisers. These nanoparticles are perfect for preserving and dispensing nutrients because they have a substantial dimension compared to volume proportion. Nanotechnology has mostly been applied to agricultural system to boost crop output while reducing crop damage and stimulating crop protection responses towards bugs, diseases, and other environmental hazards. Additionally, using nanofertilizers can improve ecological sustainability by lowering runoff and leaching of nutrients into the surroundings. It may additionally boost the effectiveness of fertiliser use, which increase the productivity of crops and lowers the total expense of applying fertiliser. With less negative effects on the surroundings, nanofertilizers may serve as an easier and less costly method to fertilise plants. These innovations are the result of potential novel innovations that could assist in addressing a growing need for nourishment and enhancing the long-term viability of agriculture. As a result, nanofertilizer can be viewed as an asset for the fertiliser sector and it might be used as a tool to spark a second green revolution.

Keywords: Controlled-release, environmental hazards, nanofertilizer, nanotechnology

INTRODUCTION

To keep up with the soaring population's demand for food and nutrition, agricultural production systems indiscriminately used chemical fertilisers, which had a negative effect on ecological services and the quality of the environment. For this purpose, researchers are currently looking into new ways to boost crop output while using less fertiliser. Synthetic fertilisers are defined as inorganic fertilisers that contain all three of the vital nutrients- nitrogen, phosphorus and potassium (N, P, and K) in the proper concentrations for a variety of cultivars and growing circumstances. For the advancement as well as development of plants, NPK-synthetic fertilisers are essential. While P (phosphorus) promotes root, flower, and fruit formation, K (potassium) boosts stem and development of roots as well as the synthesis of proteins, N (nitrogen) encourages the development of leaves and is a component of proteins and chlorophyll. Yet, plants just utilise around 30–60%, 10–20%, and 30–50% of the supplied doses of N, P, and K accordingly, and the remaining amounts are lost to the surroundings, seriously contaminating the ground and waterways, resulting in significant monetary and environmental losses.

Consequently, a different system must be created to improve agricultural output and to safeguard the environment. The drawbacks of conventional fertilisers made from chemicals can be alleviated with a nanohybrid construction such as nanofertilizers (NFs). Smart fertilisers, also known as nanofertilizers, are created employing nanosized particles that serve as fertiliser carriers and carriers for controllable delivery (Calabi-Floddy et al. 2018). Considering its numerous underlying attributes, such as its extensive surface area, greater capacity for adsorption, additional permeation capability, and its suitable and controlled kinetics for delivering nutrients at the intended locations with little loss, employing nanofertilizers as a carrier substance for promoting a smarter and environmental friendly farming is an appealing option (Janmohammadi et al. 2016). They feed nutrients to crops in an effective manner, demonstrating their superiority over bulkier synthetic fertilisers when it comes to crop output and ecological responsibility. Based on the techniques for use and the characteristics of the particulates, crops may take in NFs via their roots or foliage. The capacity of plants to tolerate biotic and abiotic stressors is improved by NFs. It lowers the expense to produce and lessens the impact on the surroundings as a whole.

Owing to the special characteristics that nanoparticles possess, nanofertilizers are frequently utilised in farming practises to improve nutritional usage effectiveness. Nanomembrane encapsulation of fertiliser nanoparticles enables the diffusion of nutrients consistently and gradually throughout an extended period of time, resulting in minimal degradation of nutrients throughout plant fertilisation and providing plants with adequate nourishment (Shebl et al. 2019). Micronutrient insufficiency in relation to macronutrients causes a decline in production and nourishment of plants. Additionally, eating foods low in micronutrients has a significant impact on a person's well-being. By encapsulating the nutrients in nanomaterials, coating them with a thin protecting film, delivering them as formulations or nanoparticles, or applying nanotechnology to conventional fertilisers, it is possible to minimise these drawbacks and use the majority of the chemical dose applied.

NANOFERTILIZERS

Nutrient carriers with a size between 1 and 100 nm are known as nanofertilizers. The term "nano" denotes one millionth of a millimetre or one billionth of a metre. As the size is shrunk, the surface area has dramatically risen. The fertilisers known as "nanofertilizers" are nano-structured formulations which distribute nutrients to the soil steadily and under regulated conditions. Utilising slow-release or controlled-release fertilisers with nanotechnology can boost the effectiveness of the absorption of nutrients and substantially decrease nutrient loss. By creating compositions, which are coated, encapsulated, or embedded in the nanomaterials, the nanomaterials may be delivered either in the soil nutrition or by foliar application. Due to their huge surface area compared to their size, nano fertilisers can penetrate plant tissue more readily than other conventional fertilisers. A novel type of fertilisers called nano fertilisers will increase nutrient utilisation efficiency from 30% to as much as 80%. A key criterion for evaluating the advancement of better nutrition management is the efficacy of the utilisation of nutrients (NUE). Additionally, the active element of agricultural inputs is released at specific sites under controlled conditions, which reduces the volume and expense of fertiliser borne by farmers

 ISBN: 978-81-965655-8-9

(Mukhopadhyay, 2014). Due to their small size, nanofertilizers have various characteristics that are not present in ordinary fertilisers. These attributes are-

1. Greater surface area: Due to their lower particle size, nanofertilizers have a very large surface area. The responsiveness of nanofertilizers is increased by their larger surface area.
2. Greater solubility: Nanofertilizers allow efficient delivery of insoluble & reacting materials to plants in accessible forms and have better solubility in various solvents.
3. Encapsulation: By encapsulation in enveloping kinds of membranes that are semi-permeable covered with resin-polymer, waxes, and sulphur, the rate of release and releasing patterns can be precisely controlled.
4. Controlled Release: When used in large quantities, bulk fertilisers are efficient for a limited time; however, by utilising nanofertilizers, the release of nutrients is prolonged.

Nanofertilizers' advantages against regular fertilisers

The nutrients are necessary for the nourishment as well as growth of plants. Whenever the soil itself can no longer provide nourishment owing to ongoing farming or naturally low content, fertilisers are administered. It is typically discovered that the fertilisers used on plants possess very little nutritional effectiveness. N, P, and K fertilisers typically have use efficiencies of approximately 30 %, 20%, and 40%, accordingly. Consequently, a sizable amount of the fertiliser supplied ends up going to the atmosphere or retained in the soil itself in forms that are unavailable. According to estimates, 40–70% of administered N fertilisers, 80–90% of administered P fertilisers and 50–60% of administered K fertilisers fail to meet goals. This results in both monetary losses and deterioration of the environment. In order to meet agricultural needs, a lot of fertiliser must be administered to the ground, that could have major negative effects on the natural world and the well-being of humans. The surroundings does not suffer by nanofertilizers, on the reverse side. As nanofertilizers possess substantial proportion of nutrients in crop accessible way, it would give nutrient extremely effectively as well as on targeted way for prolonged duration. This characteristic of nanofertilizers lowers the amount of fertiliser that needs to be administered. Additionally, this lowers farming expenses and boosts the earnings of farmers. All of them will raise the nutritional significance of crops and flavouring excellence. It increase plants stabilisation by preventing bending and deep-rooting crops to increase plant stabilisation while accelerating the advancement of plants. These nutritional compositions could therefore replace conventional fertilisers by ensuring controlled and prolonged nutritional delivery. Nanofertilizers affects on crop well being by enhancing root and shoot development, increasing activity of antioxidants, boosts the amount of photosynthetic pigments, enhances nutrient transport and absorption, lower the volatilization of nutrients,boosts microbial activity and water retention capacity. Yet there may be certain important limitations to the widespread usage of nanofertilizers for agricultural purposes that need to be taken into account. It is necessary to look into the harmful effects and biological compatibility of nano fertilisers.

Nanofertilizer Compositions

The efficiency of nanofertilizers is affected differently through various compositions. Urea, ammonia, peat, and other artificial fertilisers can be used to create nanoparticles.To create nanofertilizers, ammonium humate, peat, and various other artificial substances are being combined. Mesoporous silica nanoparticles are good nanofertilizers because they may hold urea. By integrating nanosized colloidal particles to formulations, nano-emulsions are created. A while ago, IFFCO created liquid nano-urea with particulates that are 30 nm in dimension. Also nano-DAP was also released recently which supplies both Phosphorus and Nitrogen in specified concentrations thus reducing the cost of the bulky inorganic fertilizers. The procedure listed below is used to create various formulations:

 ISBN: 978-81-965655-8-9

1. Nanomaterials of various natures and chemical properties are enclosed with nutrients for plants.
2. A thin covering of nano-coated artificial chemicals coverings, such as polymers and sulphur coatings, are applied on nutritional particle.
3. The delivery of essential nutrients may take the form of nanoparticle emulsions.

System of Absorption of Nanofertilizers

Nanofertilizers possess a larger area of contact and smaller particle dimensions than the tiny openings in leaves and roots. Nanotechnology can enhance the effectiveness of the nano fertilizer's assimilation and nutrient use by encouraging entry within the plant's tissues from the treated area. A fertiliser with smaller particles has greater number of particles per unit area and a greater amount of specific surface area, which increases its potential for interaction with nano-fertilizers and boosts nutritional accessibility and uptake (Liscano *et al.*, 2000). According to Flischer *et al.,* (1999), the cell wall's pores have a diameter of 5 to 50 nm. The only nanoparticles or nanoparticle complexes that can easily penetrate via the cellular barrier and enter the plasma membrane are those whose diameter is less than the cellular walls pore dimensions (Moore, 2006). For instance, nano urea particles, which range in size from 20 to 50 nanometers, have 10,000 times greater surface area per unit of volume than granulated urea. Once penetrating the tissues of the plant by plasmodesmata which is 40 nm in diameter and phloem cells, they are transferred to various crop portions. Via aquaporin, ion channels, and endocytosis, these are capable of binding to protein carriers (IFFCO, 2022). Additionally, the efficiency of foliar application is determined by "nano urea's ultra-small dimension and greater surface attributes, which get readily utilised by the crops whenever sprayed on their leaflets."

According to Eichert and Goldbach (2008), nanoparticles less than 5 nm travel down the cuticular route, while those larger than that adopt the stomatal route and are eventually carried to the conducting mechanism, which aids in the leaves' rapid and straightforward uptake of nutrients because the molecules are 100% soluble (Fernandez and Eichert, 2009). An apoplastic route allows nanoparticles to reach the cell's intercellular gaps. The symplastic (through cytoplasm) approach, in contrary, is thought to be a more controlled and organised mechanism for the migration of designed nanoparticles into crops, according to Rico *et al.,* 2011. After entering the stomata, these nanoparticles are moved by the phloem network. Active vascular cells make up the phloem, which transports photosynthetic materials including sucrose, protein, and certain mineral ions enabling plant growth. They are subsequently released in a controlled way as they reach the area of the crop where nutrient is required. The active component's site-specific, controlled discharge prevents eutrophication, residual pollution and excessive outflow.

Application Techniques for Nanofertilizers

Three of the main techniques for applying nanofertilizers are foliar, seed nanopriming, and soil application.In the foliar application, nanofertilizers are sprayed directly over the leaves of plants, enabling quick uptake of nutrients via the leaf surfaces. The technique works especially well when fertilisers are needed immediately or in areas with poor fertility in the soil.Nevertheless, the effectiveness of absorption of nitrogen is impacted by foliar spray, which is subject to climatic conditions including moisture, humidity, temperature, and wind. Prior planting, the seeds are coated with or soaked in a mixture comprising nanofertilizers. Speedy germination, sturdier seedlings, and improved absorption of nutrients during the plant's lifespan are all facilitated by the technique. It is particularly useful wherever adverse soil conditions exist or in situations where speedy growth of plants is required. To prevent toxicity to plants a suitable nanofertilizer dosage need to be established. Integrating nano fertilizers onto the soil through broadcasting, layering or banding or targeted application is known as soil treatment. By ensuring a gradual and regulated diffusion of nutrients, the technique prevents nutrients from

 ISBN: 978-81-965655-8-9

being lost by leaching or volatilization. Locations that have excellent nutrient absorption capabilities and climates with regular precipitation cycles are best suitable for treatment of soils. To avoid environmental damage or nutritional disparities, the usage needs to be meticulously monitored. The right way to apply nanofertilizers is essential for optimum plant growth because it differs based on the environment and soil type.The selection is based on factors such as the state of the soil, accessibility of nutrients, and environment that have an impact on the absorption of nutrients and utilisation. Considering these elements and choosing the best approach can increase crop output, lessen ecological damage and produce more environmentally friendly methods of farming.

Impacts of various nanofertilizers on crops

To introduce nanofertilizer into the plant systems, *in vitro* and *in vivo* techniques are used. Methods for *in vitro* delivery might be applied to the cultivated soil or on the leaves. The distribution of nutrients by soil application is unmatched when utilizing organic and synthetic fertilizers. Foliar application is more efficient than soil application (Taiz and Zeiger, 2010). The agricultural systems have a great deal of potential to be transformed by nanotechnology. It provides a platform that is used to create an innovative, safe, and safe delivery system for agrochemicals. According to Dimkpa and Bindraban (2016), encapsulated nanoparticles improve the effectiveness of applied fertilizer, restore plant health, and simultaneously lower soil toxicity, agroecological degradation, and environmental pollution. When fertilizer particles are coated with nanomembranes, nutrients may be released regularly and gradually over a long period of time, resulting in little loss of minerals during crop fertilisation and giving crops a balanced diet (Shebl *et al.*, 2019). Micronutrient insufficiency in relation to macronutrients causes a decrease in the production and nutrition of crops. Additionally, eating food that is lacking in micronutrients has a significant impact on human health. A method to improve the gradual and controlled release of certain micronutrients into the plant system for effective absorption was developed to address this problem (Monreal *et al.*, 2015). By enabling more effective absorption of soil nutrients, nenofertilizers can aid in enhancing crop yields. By reducing fertilizer runoff and leaching, they can also aid in reducing environmental contamination. Additionally, nenofertilizers promote higher nutrient absorption in plants, enhancing crop quality, production, and resiliency while also improving water efficiency (Yadav, 2023). More vital nutrients can enter the crops due to the smaller dimensions of nanoparticles compared to the pore size of leaves and roots. By making more nano/micronutrients available to the plant, illness, nutrient shortage, and abiotic and biotic stressors can be avoided. This aids in improving agricultural characteristics and getting improved food items fit for both human and animal use. The improved capacity of nanofertilizer to spread the insoluble nutrients is one of its most valued advantages over conventional fertilizer.

Impacts of nano urea

The environmental advantages of nano urea outweigh its high nitrogen utilization efficiency. This fertilizer is sometimes referred to as "smart fertilizer" since it reduces nitrous oxide emissions, which are largely accountable for contaminating soil, air, and water bodies. Additionally, it minimizes global warming. A 500 ml bottle of nano urea, which is the liquid form of solid urea, has 40,000 ppm of nitrogen, giving nitrogen feeding similar to that of a bag of conventional urea. Conventional urea effectively supplied 30–40% nitrogen to plants; however, the remaining portion is lost as a result of evaporation, chemical changes in water and soil movement, erosion, and other issues. In comparison, the nano urea liquid's efficiency is around 80% (IFFCO, 2022). IFFCO Nano Urea is easily absorbed by plants when sprayed on leaves due to its ultra-fine structure and surface characteristics. These particles go to the parts of the plant where nitrogen is needed. This liquid urea has been demonstrated to be useful and efficient for plant nutrition, boosting output while enhancing nutrient quality, which improves

 ISBN: 978-81-965655-8-9

crop quality. Nano urea use has the potential to increase crop production by an additional 8%. With less input, more output is produced. without impacting the yield, a reduction in urea or other nitrogenous fertilisers. It cuts down on the need for urea by at least 50% (Tomar *et al.*, 2023).

Impacts of potassium nanofertilizers

One of the three macronutrients most commonly used in agriculture is potassium (K), which is also the most abundant cation inside plant cells and essential for osmoregulation, the activation of numerous enzymes, and the transportation of nutrients through membranes. Potassium deficiency affects key plant development processes like photosynthesis and protein synthesis, which in turn reduces crop production (Marschner, 2011; Wang and Wu, 2013). Application of K nanoparticles in lucerne plants (*Medicago sativa* L.) increases growth, mineral content, and response mechanisms to stress-related issues (ElSharkawy *et al.*, 2017). In contrast, substantial variations in biomass production, water absorption, and anthocyanin content was found in the petals of daffodil plants (*Narcissus tazatta* L.) after applying a K nano fertilizer to them. Although there aren't many publications that employ K as a nanofertilizer, supplies in the form of K nanofertilizers are currently available. Adding K boosts photosynthetic activity, and the more K is added, the higher the net photosynthetic activity will be. Application of 150 and 300 kg ha^{-1} of K_2O to cotton plants boosted net photosynthesis in both normal and water-stressed conditions. When used under stress, K can help protect the structure of chlorophyll, which can have a good impact on the amount of chlorophyll present as well as other factors pertaining to the physiological growth of the plants.(Marquez *et al.*, 2022).

Impacts of boron nanofertilizers

Boron (B), one of the micronutrients, is crucial for the physiological growth of plants since it makes up a crucial portion of the cell wall's structural elements. Additionally, it takes part in pollination, fruiting, sugar transfer, uracil synthesis, and photosynthesis. While its lack impacts fruit production, photosynthetic activity, chlorophyll content, and nitrate reductase enzyme activity (Shireen *et al.*, 2018; Moreno *et al.*, 2016). The range between a nutrient's deficit and toxicity is quite small for B, which plants need in amounts between 10 and 100 mg kg^{-1} (Reguera, 2009). B nanoparticles boost the root and aerial biomass of lettuce and zucchini plants, increase pomegranate tree productivity, and improve fruit quality when paired with zinc nanofertilizer. When B nanoparticles are applied topically to mung bean (*Vigna radiata* L.) plants, there are noticeable variations in plant height, pod count, and overall yield. Green beans that have been treated with B nanoparticles have increased biomass accumulation, yield, nitrate reductase enzyme activity, photosynthetic activity, stomatal conductance, and photosynthetic pigment activity (Franco *et al*., 2023).

Impacts of zinc oxide nanoparticles

Chemical fertilizers must contain zinc oxide (ZnO), which is used in place of zinc sulphate. In order to grow crops and fruit trees, ZnO has also been sprayed into the soil directly. On the other hand, zinc nanoparticles are growing in popularity and are now thought to have remarkable optical, physical, and antibacterial qualities, which makes them a significant player in agriculture. Although concentrations as high as 2000 ppm had an inhibitory effect, peanuts treated with varying concentrations of Nano-zinc oxide (ZnO NPs) and chelated bulk zinc sulphate ($ZnSO_4$) are reported to have flowered early and produced a yield of 34%. Wheat has been grown with bulk zinc, nano Zinc oxide, and Titanium dioxide (TiO_2). While the nano zinc boosted the protein content of the seeds and elevated the chlorophyll level of the shoots, the bulk zinc had no discernible impact on the wheat. Application of zinc nanoparticles to *Amaranthus cruentus* at the required 500 mg/l level results in increasing vegetative growth with height and leaf width (Mfon *et al*., 2022).

 ISBN: 978-81-965655-8-9

Impacts of molybdenum nanoparticles

One of the specific roles of this vital micronutrient is to form a structural part of the enzyme nitrate reductase, which is crucial for the assimilation of nitrogen. Additionally, it is an essential component of the molybdenum cofactor (Moco), an organic pterin complex that binds to molybdoenzymes in the majority of biological systems. Molybdenum deficit lowers the activity of molybdoenzymes, which has a detrimental effect on primary nitrogen absorption and activity in legume nodules, according to a number of studies. In addition to playing a significant role in the metabolism of sulphur amino acids, molybdenum is directly involved in the manufacture of abscisic acid and the conversion of sulfite to sulphate carried out by sulfite oxidase and aldehyde oxidase in legumes. Green beans' biomass, yield, nitrate reductase enzyme activity, chlorophyll content, nitrogen use efficiency (NUE), and total nitrogen accumulation (TNA) all rise as a result of foliar NanoMo treatment. The improvement in the growth and output of green bean plants is attributable to both their excellent response to low-dose ammonium nitrate fertilisation and the additional foliar fertilisation with NanoMo at doses that allowed for the rapid absorption of Mo and, in turn, the adequate assimilation of N. The same outcome was also attained with lentil and chickpea. Molybdenum can be thought of as playing a crucial role in nitrogen metabolism in terms of yield, even if it isn't involved directly. This is because it is a component of the enzymes nitrate reductase and nitrogenase, which fix nitrogen (Munoz-Marquez *et al*., 2022).

Impacts of other important metal nanoparticles and their oxides

Numerous scientists working in this field have reported on the effective usage of copper oxide nanoparticles in the creation of nanofertilizers as well as their function as additives for soil clean-up and plant growth regulators. Intake of copper at modest levels (10 mg) promotes plant development, but high dosages of the same have a significant negative impact on biomass, slow plant growth, and disrupt plant physiology (Xiong *et al*., 2017). By raising the amount of Cu-NPs by more than 0.4 ppm, it was found that all growth metrics of the Millat-2011 wheat cultivar crop, with the exception of fresh weight, had significantly decreased. This can be because excessive buildup and absorption of nanoparticles might have phytotoxic consequences (Hafeez *et al*., 2015). The harmful and toxic effects of copper nanoparticles are caused by the continuous oxidation and reduction processes of copper ions through their interactions with other substances when released directly inside the plant cell, as well as the solubility of copper nanoparticles in different medium of application. The CuO NPs, which have been shown to have antibacterial capabilities, have a favourable impact on the microbial response in soil. The photosynthetic activity of plants is positively impacted by CuO nanoparticles, despite the fact that many experimental results show that CuO NPs are much more harmful than copper nanoparticles. (Mathur *et al*.,2022).

Iron-based nanofertilizers are used to provide the crops with the required quantity of iron since they are very stable and track iron release across a wide pH range (pH: 3–11). A further benefit of iron-based nanofertilizers increasing its usage in agricultural fields is the prevention of early senescence and ageing due to the absence of ethylene-based compounds in their structure (Moghadam *et al*., 2012). Excessive use of Fe_3O_4 is also linked to minor inhibitory effects that have been seen as detrimental to plant development. For instance, the use of Fe_3O_4 nanoparticles at greater concentrations hindered some plant’s ability to produce Chlorophyll a. After employing fluids containing Fe_3O_4 nanoparticles at greater concentrations, plantlet’s growth was also negatively impacted, resulting in the development of brown patches on the leaves (Mathur *et al*., 2022).

In order to create nanofertilizer, which is used to regulate nutrient intake and sustain the productivity of crops in agricultural systems, titanium dioxide (TiO_2) nanoparticles are synthesised organically. TiO_2 nanoparticles improve the absorption of essential metal nutrients

 ISBN: 978-81-965655-8-9

for greater agricultural output. TiO_2 increases the content of carotenoids, anthocyanins, and chlorophyll (a and b) at concentrations of 0.01% and 0.03%, improving crop output. Ti (titanium) is used to enhance the performance, quality, and yield of crops by stimulating certain enzymes, promoting the mobilisation of nutrients, and tolerating abiotic and biotic stress conditions. It was discovered through a field experiment that doses of TiO_2 nanoparticles at specific stages and concentrations have a substantial impact on morphological characteristics like the dry weight of maize and the number and yield of maize. The mineralized form of titanium dioxide (TiO_2) that is metastable improves root's capacity to absorb nutrients and water while also boosting their strength. Rubisco carboxylase (an enzyme) activity was increased by more than 2.67 times when Nanoanastase TiO_2 was applied as compared to control in *Spinacia oleracia*, which also boosted the absorption of carbon dioxide (CO_2) (Gao *et al.*, 2006).

Use of nanoparticles in vegetable cultivation

An increase in tomato plant height, stem diameter, root length, larger stomatal openings in leaves, mineral content on leaves, fruit size, total yield per plant, vitamins, moisture, ash, protein, fibre, fat, carbohydrate, energy contents, and finally antioxidant properties can all be attributed due to foliar application of mixed nanofertilizers (Rahman *et al.*, 2021). Numerous parameters of cabbage were shown to be impacted by the application of nano-DAP at varied concentrations. Nano-DAP affects head compactness, the quantity of wrapped and unwrapped leaves harvested, the chlorophyll content of the leaves, shelf life, and NPK levels in the soil and leaves (Chamuah *et al.*, 2023). In case of faba bean also, combining organic inputs with various nenofertilizer levels led to effects on yield, vitamin B2 content, nitrogenase enzyme activity, chlorophyll content, and vitamin B1 content (Jassim *et al.*, 2020).

CONCLUSION

Any constraints on agricultural output have an impact on both the financial system and the lives of people, either directly or through indirect means.With numerous benefits over traditional fertilisers, nanofertilizers are emerging as an intriguing option for environmental friendly farming and worldwide nutritional stability. These benefits comprise decreased water and nutrient losses, precise distribution, plant development stimuli, and regulated discharge. Nanofertilizers have the ability to reduce the major agricultural productivity constraint. It is more efficient to use and requires lower quantity. However, very few research have examined the potential harmful impacts of nanofertilizers on crops up to this point. Considering the prospective benefits, further investigation is necessary to create accessible and affordable manufacturing processes as well as to optimise the chemical makeup and releasing amounts of nanomaterials. By overcoming these obstacles, producers everywhere will have accessibility and are able to purchase nanofertilizers, particularly in emerging economies wherein nutrition and ecologically sound farming are of the utmost importance. Despite the prospective advantages of nanofertilizers, it is crucial to tackle any dangers connected to their use, such as those related to natural, ecological, and wellness issues. As technologies develop, it is going to be essential to continually track and evaluate the effects of nanofertilizers on crop productivity, the condition of soil, and the surroundings in order to take information-based choices and modifications which will maximise the positive effects of nanofertilizers while minimising their adverse impacts.

BIBLIOGRAPHY

- Calabi-Floddy, M., Medina, J., Rumpel, C., Condron, L. M., Hernandez, M. D. & Luz Mora, M. D. L. (2018). Smart fertilizers as a strategy for sustainable agriculture. *Adv. Agron.,* 147:119–57.
- Chamuah, S., Gogoi, S., Bhattacharjee, D., Barman, D., Dutta, S., Sharma, S., and Das, K. (2023). Effect of Nano-DAP on Soil Characteristics and Qualities of Cabbage. *Int. j. plant soil sci.*, *35*(13): 52-59.

- Dimkpa, C. O., and P. S. Bindraban. (2016). Fortification of micronutrients for efficient agronomic production: A review. *Agron. Sustain. Dev.,* 36 (1):1–7.
- Eichert, T., & Goldbach, H. E. (2008). Equivalent pore radii of hydrophilic foliar uptake routes in stomatous and astomatous leaf surfaces—further evidence for a stomatal pathway. *Physiol. Plant.*, 132: 491-502.
- El-Sharkawy, M. S., El-Beshsbeshy, T. R., Mahmoud, E. K., Abdelkader, N. I., Al-Shal, R. M., & Missaoui, A. M. (2017). Response of alfalfa under salt stress to the application of potassium sulfate nanoparticles. *Am. J. Plant Sci.,* 8(8):1751-1773.
- Fernandez, V., & Eichert, T. (2009). Uptake of hydrophilic solutes through plant leaves: Current state of knowledge and perspectives of foliar fertilization. *Crit. Rev. Plant Sci.*, 28: 36-68.
- Fleischer, A., O'Neill, M. A., & Ehwald, R. (1999). The pore size of nongraminaceous plant cell walls is rapidly decreased by borate ester crosslinking of the pectic polysaccharide rhamnogalacturonan II. *Plant Physiol.*, 121(3):829-838.
- Franco-Lagos, C. L., Sanchez, E., Palacio-Marquez, A., Perez-Alvarez, S., Terrazas-Gomez, M., Villalobos-Cano, O., & Ramirez-Estrada, C. A. (2023). Efficacy of the application of boron nanofertilizer on biomass, yield, nitrogen assimilation and photosynthetic activity in green beans. *Not. Bot. Horti. Agrobot. Cluj. Napoca.*, 51(1): 12795-12795.
- IFFCO, 2022. Environment friendly IFFCO Nano Urea (liquid) fertilizer for precision and sustainable agriculture. (Website: https://nanourea.in/en/nano-urea retrieved on dated 04-01-2022.
- Janmohammadi, M., Amanzadeh, T., Sabaghnia, N., & Dashti, S. (2016). Impact of foliar application of nano micronutrient fertilizers and titanium dioxide nanoparticles on the growth and yield components of barley under supplemental irrigation. *Acta Agric. Slov.*, 107 (2):265–76. doi:10.14720/aas.2016.107.2.01.
- Jassim, R. A., Al-Burky, H. N., & A-Jubory, A. K. (2020). Evaluation of nano fertilizer and abstract of organic matter and method of application on some quality properties and yield of faba bean (*Vicia faba* L.). *Int. J. Agric. Stat. Sci.,* 3899: 16-1479.
- Liscano, J.F., Wilson, C.E., Norman, R.J. & Slaton, N.A. (2000). AAES Res Bulletin, 963, 1:31
- Marquez-Prieto, A. K., Palacio-Marquez, A., Sanchez, E., Macias-Lopez, B. C., Perez-Alvarez, S., Villalobos-Cano, O., & Preciado-Rangel, P. (2022). Impact of the foliar application of potassium nanofertilizer on biomass, yield, nitrogen assimilation and photosynthetic activity in green beans. *Not. Bot. Horti. Agrobot. Cluj. Napoca.*, 50(1): 12569-12569.
- Marschner, H. (2011). Marschner's mineral nutrition of higher plants. Academic Press, pp 178-189.
- Mathur, S., Pareek, S., & Shrivastava, D. (2022). Nanofertilizers for Development of Sustainable Agriculture. *Commun. Soil Sci. Plant Anal.*, 53(16): 1999-2016.
- Mfon, R. E., Al Amri, Z., Mfon, W. E., & Odiaka, N. I. (2022). Effect of biosynthesized zinc oxide nanoparticles on the vegetative growth of *Amaranthus cruentus* plants. *J. Sci. Educ. Technol.,* 9(1): 58-71.

- Moghadam, A. L., Vattani, H., Baghaei, N., & N. Keshavarz. (2012). Effect of different levels of fertilizer nano_iron chelates on growth and yield characteristics of two varieties of spinach (*Spinacia oleracea* L.): Varamin 88 and Viroflay. *Res. J. Appl. Sci. Eng. Technol.*, 4(48):13–18.
- Moore, M. N. (2006). Do nanoparticles present ecotoxicological risks for the health of the aquatic environment. *Environ. Int.*, 32(8):967-976.
- Moreno, D. L., Quiroga, I. A., Balaguera-Lopez, H. E., Magnitskiy, S. (2016). El estrés por boro afecta la fotosíntesis y la síntesis de compuestos antioxidantes en plantas. Una revisión [Boron stress affects photosynthesis and synthesis of antioxidant compounds in plants. A review]. *Rev. Colomb. Estad.*,10(1):137-148.
- Mukhopadhyay, S. S. (2014). Nanotechnology in agriculture: prospects and constraints. *Nanotechnol. Sci. Appl.*, 7:63.
- Munoz-Marquez, E., Soto-Parra, J. M., Noperi-Mosqueda, L. C., & Sanchez, E. (2022). Application of molybdenum nanofertilizer on the nitrogen use efficiency, growth and yield in green beans. *Agronomy*, 12(12): 3163.
- Rahman, M. H., Hasan, M. N., Nigar, S., Ma, F., Aly Saad Aly, M., & Khan, M. Z. H. (2021). Synthesis and characterization of a mixed nanofertilizer influencing the nutrient use efficiency, productivity, and nutritive value of tomato fruits. *ACS omega*, *6*(41), 27112-27120.
- Reguera, M. (2009). Papel central del boro en el diálogo molecular de la simbiosis Rhizobium-Leguminosas y en procesos de organogenesis [Central role of boron in the molecular dialogue of Rhizobium-Leguminosae symbiosis and in organogenesis processes]. Tesis Doctoral. Universidad Autónoma de Madrid.
- Rico, C.M., Majumdar, S., Duarte-Gardea, M., Peralta-Videa, J.R., & Gardea-Torresdey, J. L. (2011). Interaction of nanoparticles with edible plants and their possible implications in the food chain. *J. agric. food chem.*, 59(8):3485-3498.
- Shebl, A., Hassan, A. A., Salama, D. M., Abd El-Aziz, M. E., & Abd Elwahed, M. S. A. (2019). Green Synthesis of nanofertilizers and their application as a foliar for *Cucurbita pepo*. L. *J. Nanomater.*, 4:1–11. doi:10.1155/2019/3476347.
- Shireen, F., Nawaz, M. A., Chen, C., Zhang, Q., Zheng, Z., Sohail, H., & Bie, Z. (2018). Boron: functions and approaches to enhance its availability in plants for sustainable agriculture. *Int. J. Mol. Sci.*, 19(7):1856.
- Taiz, L., & Zeiger, E. (2010). Plant physiology, 781. 5th edn ed. Massachusetts: Sinauer Associates Inc.
- Tomar, M., Choudhary, R., & Patidar, R. (2023). Chapter-1 Nano Urea-A Bliss for Agriculture or Not. Recent Trends in Agriculture, 1.
- Wang Y, Wu. W. H. (2013). Potassium transport and signaling in higher plants. *Annu. Rev. Plant Biol.*, 64:451- 476.
- Xiong, T. T., Dumat, C., Dappe,V., Vezin, H., Schreck, H., Sahid, M., Pierart, A., & Sobanksa, S. (2017). Potential contamination of copper oxide nanoparticles and possible consequences on urban agriculture. *Environ. Sci. Technol.*, 78(57): 74–82.
- Yadav, A., Yadav, K., & Abd-Elsalam, K. A. (2023). Exploring the Potential of Nanofertilizers for a Sustainable Agriculture. *Plant Nano Biology*, 100044.

 ISBN: 978-81-965655-8-9

- Yadav, A., Yadav, K., & Abd-Elsalam, K. A. (2023). Nanofertilizers: Types, Delivery and Advantages in Agricultural Sustainability,. Agrochem., , *2,* 296–336. https://doi.org/10.3390/agrochemicals202001.

 ISBN: 978-81-965655-8-9

CHAPTER 3

IOT AND SENSORS IN SMART ENVIRONMENT MONITORING SYSTEM

Mriganko Kakoti[1]*, Bipasha Borkotoky[2], Akash Paul[3], Hridesh Harsha Sarma[4]
[1]Department of Agricultural Meteorology, Assam Agricultural University, Jorhat-785013
[2]Department of Soil Science, Assam Agricultural University, Jorhat-785013
[3]Department of Agronomy, Assam Agricultural University, Jorhat-785013
[4]Department of Agronomy, Assam Agricultural University, Jorhat-785013

ABSTRACT

The combination of Internet of Things (IoT) and sensor technologies has ushered in a new era of tackling urgent environmental issues. In the face of rising environmental concerns, such as pollution and resource depletion, as well as the looming threat of climate change, a paradigm shift towards smart environment monitoring (SEM) systems is required. These IoT and sensor-powered systems provide fast, data-driven solutions for comprehensive environmental monitoring and optimisation. This chapter digs into the complex terrain of IoT and sensors in SEM, investigating various sensor types, communication protocols, data processing approaches, and real-world applications. From monitoring air and water quality to precision agriculture and disaster response, these technologies promise unparalleled insights and actionable data for ensuring the well-being of our planet. However, challenges such as data security, interoperability, and cost must be navigated to fully unlock the potential of IoT and sensors in revolutionizing our approach to environmental conservation. Striking this balance is pivotal in our collective endeavour towards a more sustainable and resilient world. In this chapter, we will go through the extensive impact of IoT and sensor technologies on smart environment monitoring (SEM) systems. We reveal the revolutionary potential of this convergence by digging into a complicated terrain including many sensor kinds, communication protocols, data processing approaches, and real-world applications. From monitoring air and water quality to enabling precision agriculture and improving disaster response, these technologies promise unparalleled insights and actionable data that are critical for ensuring the well-being of our planet. However, these promises are accompanied by problems, such as worries about data security, interoperability, and cost-effectiveness. To fully realise the potential of IoT and sensors in revolutionising our approach to environmental conservation and ensuring a more sustainable and resilient world, we must overcome these obstacles.

INTRODUCTION

In an era defined by unprecedented environmental challenges, the convergence of Internet of Things (IoT) and sensor technologies has emerged as a powerful change agent, reshaping how we perceive, interact with, and protect our surroundings. The twenty-first century confronts humanity with a daunting array of environmental issues, ranging from rising pollution levels and depleting natural resources to the ever-increasing threats of climate change (IPCC, 2021). Addressing these challenges necessitates a paradigm shift in our approach to monitoring and managing our environment, one that goes beyond traditional methods and embraces the concept of smart environment monitoring (SEM) system (Tadejk, 2017). This game-changing approach uses IoT and sensor technologies to build responsive, data-driven systems capable of comprehensively assessing and optimising the health of our environment. As this chapter progresses, we will go deep into the heart of this technological revolution, investigating the critical roles of sensors and the IoT ecosystem in developing intelligent, adaptable, and sustainable solutions for environmental monitoring. This chapter unravel the intricate tapestry of IoT and sensors in smart environment monitoring (SEM) systems through a journey that spans diverse sensor types, communication protocols, data processing techniques, and real-

 ISBN: 978-81-965655-8-9

world applications, shedding light on their profound impact on how we safeguard our planet's well-being.

The Environmental Imperative

The state of our environment has emerged as a critical issue in the twenty-first century. Humanity has witnessed alarming trends in environmental degradation over the last few decades, driven by factors such as population growth, industrialization, and urbanisation (Chu and Karr, 2017). The consequences of these trends are far-reaching, ranging from deteriorating air and water quality to biodiversity loss and the looming threat of climate change. Our surroundings are more than just a backdrop to our lives; they are the very foundation on which our well-being is built. Clean air, safe water, and a stable climate are critical for human health, economic prosperity, and the survival of numerous species. Recognising the importance of these interdependencies, societies around the world are increasingly embracing the need to protect and preserve our environment. Nonetheless, as we face these complex environmental challenges, we have unprecedented opportunities for innovation and transformation. Technology, particularly the Internet of Things (IoT) and sensor technologies, has emerged as a powerful weapon in our arsenal, allowing us to monitor, analyse, and act on environmental data with unprecedented precision and speed (Truong, 2022).

The IoT Revolution

The Internet of Things, or IoT, is at the heart of the smart environment monitoring revolution. The Internet of Things represents a fundamental shift in how we connect to, interact with, and value the physical world. It is a vast and interconnected network of devices, sensors, and objects, all of which are capable of autonomously collecting, exchanging, and processing data. The Internet of Things ecosystem is diverse, encompassing a wide range of devices and sensors, each tailored to specific applications and environments. These unobtrusive and compact devices serve as the sensory and data-gathering instruments of the IoT, continuously collecting information from their surroundings. What distinguishes IoT sensors is their ability to seamlessly transmit data, often in real-time, to a central processing unit or a cloud-based platform. Consider a city that has a comprehensive network of air quality sensors. These sensors continuously monitor pollutants like carbon dioxide (CO_2) and particulate matter (PM2.5). The information they collect is instantly transmitted to a centralised database and analysed in real time (Moursi *et al.*, 2021). Residents can access this information through a mobile app, allowing them to make informed decisions about outdoor activities and take precautions when air quality deteriorates.

The Role of Sensors

Sensors are the unsung heroes of the Internet of Things revolution. They are the foundational elements, frontline warriors, and sentinels that allow the IoT ecosystem to work smoothly. These small, often unassuming gadgets come in a variety of shapes and sizes and serve a variety of functions based on the unique demands of the area being monitored.

- **Environmental Sensors:** Theses are at the forefront of smart environmental monitoring. They are designed to measure a wide range of atmospheric, soil, and water characteristics. Temperature sensors detect minute temperature differences, allowing us to better understand climatic trends and the health of ecosystems. Humidity sensors measure moisture levels, which is critical for forecasting weather patterns and assessing indoor air quality. Pollutants are detected by air quality sensors, which provide critical data for public health and environmental protection. Noise level sensors provide information on acoustic pollution, which aids in urban planning and noise management. Radiation sensors detect ionising radiation, which is critical in preventing nuclear disasters and guaranteeing the safety of radiation therapy in healthcare (Butt et al., 2022).

 ISBN: 978-81-965655-8-9

- **Energy Sensors:** Another key aspect of environmental sustainability is energy use. Energy sensors track energy, gas, and water consumption, providing insight into resource consumption patterns. Individuals, organisations, and communities can use these sensors to uncover inefficiencies and implement energy-saving initiatives. Understanding energy usage patterns allows us to lower our carbon footprint and waste resources, so contributing to a more sustainable future.
- **Weather Sensors:** Also known as meteorological sensors, are specialised devices that measure different atmospheric factors and weather conditions. These sensors include anemometers for measuring wind speed and direction, barometers for measuring atmospheric pressure, hygrometers for measuring humidity levels, thermometers for measuring temperature, and rain gauges for measuring precipitation. Sensors for monitoring solar radiation, ultraviolet (UV) radiation, and even atmospheric gases may be included in more complex weather sensors. These sensors are used in weather stations, drones, satellites, and other meteorological instruments to capture real-time data for weather forecasting, climate research, and environmental monitoring. Weather sensors contribute considerably to our understanding of the Earth's atmosphere and its ever-changing circumstances by continuously monitoring these crucial meteorological parameters, assisting in both day-to-day weather predictions and forecasting.
- **Motion and Presence Sensors:** Motion and presence sensors are critical in smart environments. These sensors detect movement as well as the presence of persons or objects in a specific area. They are critical for security, occupancy monitoring, and optimising lighting and HVAC (Heating, Ventilation, and Air Conditioning) systems. Significant energy savings can be gained by managing these systems based on real-time occupancy data. When motion sensors detect that a room is empty, they can automatically modify the lighting and temperature settings to save energy.
- **Camera and Image Sensors:** Visual data is a valuable ally in a wide range of smart environment monitoring applications. Images and videos are captured by cameras and image sensors and can be analysed for a variety of purposes such as surveillance, tracking, and visual inspection. Image sensors are used in industrial settings for quality control, process monitoring, and even robotics. Drones equipped with cameras and image sensors can monitor crop health and detect pests and illnesses in agriculture, allowing for focused interventions and minimising the need for chemical treatments.
- **Water Quality Sensors:** The quality of water is a critical concern in various contexts, from drinking water safety to aquaculture and industrial processes. Water quality sensors are designed to measure parameters such as pH, turbidity, dissolved oxygen levels, and the presence of contaminants. In wastewater treatment plants, these sensors ensure that effluent meets regulatory standards before release into natural water bodies. In aquaculture, they help maintain optimal conditions for aquatic life, while in research, they assist in monitoring the health of aquatic ecosystems.
- **Other Specialised Sensors:** A variety of specialised sensors can be used depending on the specific environment and monitoring objectives. Gas sensors, for example, can detect specific gases such as methane or volatile organic compounds (VOCs), which is critical for industrial safety and environmental protection. Soil sensors provide information about soil moisture and nutrient content, allowing for precision agriculture (Yin et al., 2021). Sensors are used in structural health monitoring to analyse the status of infrastructure such as bridges and dams, hence ensuring their safety and longevity.

ISBN: 978-81-965655-8-9

Data as the cornerstone for monitoring and survey

The foundation of smart environment monitoring is data. It is the raw material from which insights are extracted, judgements are made, and actions are begun. Sensor data is rich in information, reflecting the dynamic nature of the environment and the various interactions that occur within it. The true strength of IoT-enabled sensors is their capacity to collect data in real time. Traditional monitoring approaches frequently rely on manual measurements or sporadic data collection, which can lead to the omission of critical events or trends. In contrast, IoT sensors collect data continually and autonomously, allowing for fast responses to changing situation. As an illustration, consider a forest fire monitoring system. Traditional monitoring may include sporadic patrols or visual inspections, which increases the danger of missing early symptoms of a fire. In contrast, in a forest, an IoT-based system outfitted with temperature and humidity sensors may identify rising temperatures and decreasing humidity levels in real time. This early warning can prompt quick responses such as the dispatch of firefighting personnel or aerial water drops, perhaps averting a disastrous wildfire.

Data Processing and Analysis for smart environment monitoring (SEM)

The sheer number and complexity of data collected by sensors, on the other hand, might be daunting. Sophisticated data processing and analysis techniques are required to make sense of this data and translate it into actionable insights.

- **Real-time Data Processing:** Real-time data processing is vital in smart environment monitoring systems for quickly identifying and responding to key events. In the context of air quality monitoring, for example, a sudden increase in pollution levels can prompt automatic warnings to notify authorities and citizens, allowing for timely responses to protect public health.
- **Machine Learning Algorithms:** Machine learning algorithms are critical in detecting hidden patterns and anomalies in data. These algorithms can forecast future trends and detect potential problems by analysing historical data. In agriculture, for example, machine learning models can estimate crop yields based on environmental data, assisting farmers in optimising planting and harvesting periods.
- **Anomaly detection:** These systems can detect departures from typical behaviour, indicating potential concerns. These algorithms are used in industrial settings to detect equipment breakdowns or aberrant process conditions, minimising costly downtime and assuring safety.
- **Data Visualisation:** Another important part of data analysis is data visualisation. Visual data representations, such as charts, graphs, and maps, assist stakeholders in quickly interpreting complicated data sets. Interactive dashboards provide a user-friendly interface for real-time monitoring of the environment and access to previous data.
- **Web based dashboards:** Dashboards on the web are often used to provide sensor data to consumers. These interfaces give users with real-time access to environmental data, allowing them to monitor conditions, track trends, and receive alarms. Residents of a city, for example, can use a mobile app to monitor air quality levels before engaging in outside activities.
- **Mobile Applications:** Accessing environmental data on smartphones and tablets is made easier by mobile applications. These apps frequently include extra features such as personalised alerts and location-based information. Before embarking on an outdoor expedition, a hiker, for example, can use a mobile app to check real-time weather conditions and path recommendations.

 ISBN: 978-81-965655-8-9

- **Customizable Alerts and messages:** Keeping stakeholders informed requires timely alerts and messages. Users can configure alert levels and preferences to get notifications when certain conditions are met, or odd events occur. In agriculture, for example, a farmer can receive alerts about anticipated frost conditions that could injure crops, allowing him or her to take precautionary steps (Tudi et al., 2021).

Automation and Control of Data

Data analysis insights not only inform decisions, but also drive automation and control systems. Smart environment monitoring systems enabled by IoT can take activities based on real-time data, improving efficiency and resource optimisation.

- **Integration with Control Systems:** To automate actions based on sensor data, IoT systems can be smoothly connected with control systems. Data from occupancy sensors, for example, can trigger the automatic adjustment of lighting, heating, and cooling systems in a smart building to optimise energy usage and comfort. This automation not only saves energy but also increases tenant pleasure.

- **Energy Efficiency:** A main focus of IoT-enabled smart environment monitoring is energy efficiency. Many sensors are energy-efficient, including low-power modes that extend battery life. Energy harvesting systems, such as solar panels, can be used to power sensors at remote or inaccessible places, assuring their ongoing operation.

Real-world Applications of IoT and sensors

In smart environment monitoring systems, real-time IoT and sensor applications are at the forefront of attempts to improve environmental sustainability, public health, and resource management. These apps use IoT devices and sensors to collect, interpret, and act on data in real time, allowing for proactive reactions to environmental changes and obstacles. We go over several major real-time applications in various sectors below:

I. Air Quality Monitoring: IoT- enabled air quality sensors in smart cities continuously monitor pollutants such as PM2.5, PM10, nitrogen dioxide (NO_2), sulphur dioxide (SO_2), and ozone (O_3). Through mobile apps and websites, real-time data is used to build air quality indices and give inhabitants with up-to-date information about air quality in their area. In industries, sensors track emissions in real time and detect abnormal pollutant levels. When emissions exceed allowable limits, automated alarms are sent, allowing for quick corrective actions to minimise environmental impact.

II. Water Quality Monitoring:

- Water Treatment Plants: IoT sensors in water treatment plants monitor parameters like turbidity, pH levels, dissolved oxygen, and chlorine levels. Real-time data ensures that water quality standards are met, and any deviations trigger immediate alerts for corrective measures.

- Natural Water Bodies: Sensors deployed in rivers, lakes, and oceans continuously measure water quality and detect pollutants, harmful algal blooms, or changes in temperature. These systems provide early warnings of contamination events and protect aquatic ecosystems.

III. Energy Management:

- Building Energy Efficiency: IoT sensors in smart buildings monitor occupancy, temperature, lighting, and energy consumption. Real-time data analysis allows for automated adjustments to heating, cooling, and lighting systems, optimizing energy usage while ensuring occupant comfort.

 ISBN: 978-81-965655-8-9

- Smart Grids: Sensors integrated into the electricity grid detect power outages, line faults, and voltage fluctuations in real-time. This information helps utilities respond promptly to maintain grid stability and minimize downtime.

IV. Disaster Monitoring and Response:

- Early Warning Systems: In regions prone to natural disasters such as earthquakes, floods, and wildfires, IoT sensors detect early warning signs in real-time. Alerts are broadcast to authorities and residents, allowing for timely evacuations and emergency responses.
- Wildfire Detection: IoT-based wildfire detection systems use sensors to monitor temperature, humidity, wind speed, and smoke concentration. When critical thresholds are exceeded, automated alerts are sent to firefighting agencies, enabling rapid response to contain wildfires.

V. Agriculture and Precision Farming:

- Crop Monitoring: Soil moisture sensors, weather stations, and crop health sensors provide real-time data to farmers. This information enables precise irrigation, optimal fertilization, and pest control measures, maximizing crop yields while conserving resources.
- Livestock Monitoring: IoT-enabled sensors track the health and location of livestock. Real-time data can alert farmers to issues such as illness, distress, or unauthorized movement, facilitating prompt intervention.

VI. Wildlife Conservation:

Animal Tracking: IoT-enabled GPS and sensor-equipped collars or tags are used to monitor the movements and behaviour of endangered species. Real-time tracking data helps conservationists protect wildlife and combat poaching.

VII. Weather Forecasting:

IoT weather stations collect real-time meteorological data, including temperature, humidity, wind speed, and barometric pressure. This information is vital for weather forecasting, severe weather alerts, and climate research.

These real-time applications demonstrate the transformative power of IoT and sensors in smart environment monitoring systems. By providing timely and actionable data, these systems enable more efficient resource management, enhanced environmental protection, improved public safety, and a higher quality of life for communities around the world. As technology continues to advance, the potential for real-time monitoring and response will only grow, further contributing to our ability to address pressing environmental challenge.

Table 1. Different types of SEM systems

SEM systems	Purpose	Methods/ Device used
IoT based SM	Soil monitoring for farming	Wireless sensors
IoT based air pollution	Air pollution monitoring	Gas sensor and IoT
Air quality	Air quality monitoring	Geomatics sensors and IoT
Sensor based Air Quality Monitoring (AQM)	Air pollution monitoring system	Gas sensor and LASER sensor
LoRa technology for climate monitoring	Climate and ecology monitoring	LoRa technology and sensor network
Multi-agent supervising system	e-health monitoring system due to temperature and radiation changes around the surroundings	Supervising system and AI
Radiation	Radiation monitoring	HPXe chamber

(Source: Ullo and Sinha, 2020)

ISBN: 978-81-965655-8-9

The benefits and challenges of sensors and IoT in smart environmental monitoring (SEM)

Sensors and the Internet of Things (IoT) in smart environmental monitoring represent a paradigm shift in our approach to understanding and conserving the natural world. The advantages of this convergence are numerous, since it enables us to take proactive measures towards environmental sustainability and resilience. One of the key benefits is the ability of sensors linked into IoT networks to capture real-time, high-resolution data (Pamula *et al.*, 2022). These sensors continuously collect data on a variety of environmental parameters, such as air and water quality, temperature, humidity, soil conditions, and so on. This fine-grained data enables us to detect even slight changes in the environment, offering early warning systems for possible problems. In urban locations, for example, air quality sensors can quickly detect spikes in pollution levels, allowing authorities to issue health advisories and implement remedial steps to improve air quality. Water quality monitors in rivers and lakes, for example, can identify pollution episodes, thereby preserving aquatic ecosystems. Furthermore, IoT-powered environmental monitoring encourages resource efficiency, which is crucial in a society plagued by water scarcity and climate change. Soil moisture sensors and meteorological data integration enable precision irrigation in agriculture, optimising water usage while increasing crop yields. Sensors manage lighting, heating, and cooling systems in smart buildings and cities based on occupancy and environmental conditions, lowering energy usage and greenhouse gas emissions.

These achievements of IoTs, however, are not without hurdles. Concerns about data security and privacy are crucial, especially when working with sensitive environmental data. It is critical to ensure the integrity and security of sensitive information in order to avoid unauthorised access and potential exploitation. Additionally, the interoperability of various sensor systems and data formats remains a challenge, hindering seamless integration into comprehensive monitoring networks (Noaman *et al.,* 2022). Another factor to consider is cost, as building and maintaining sensor networks can be costly, particularly in distant or resource-constrained areas. Furthermore, it is vital to ensure the quality and dependability of sensor data. Calibration, routine maintenance, and quality assurance methods are vital for avoiding misleading information, especially in sensitive applications such as catastrophe monitoring or public health protection. While the advantages of sensors and IoT in smart environmental monitoring are obvious in terms of increased awareness, resource efficiency, and early response to environmental concerns, tackling the associated challenges is critical. Striking a balance between exploiting these technologies' revolutionary potential and reducing their disadvantages is critical in our continued efforts to protect and preserve the environment, ultimately contributing to a more sustainable and resilient world.

CONCLUSION

The combination of Internet of Things (IoT) and sensor technologies represents a breakthrough possibility for tackling our time's most critical environmental concerns. The twenty-first century has ushered in an era in which the state of our environment is a major issue, with pollution, climate change, and resource depletion all looming big. IoT is at the centre of the smart environment monitoring revolution, with its huge network of sensors and gadgets. These sensors are critical in a variety of industries, including environmental monitoring, energy management, disaster response, agriculture, wildlife protection, and weather forecasting. Real-time data collection and analysis enable us to make informed decisions and automate actions, allowing us to optimise resource consumption and improve environmental protection. However, this paradigm shift, however, is not without problems, such as data security and privacy, interoperability, cost, and data quality. It is critical for a sustainable and resilient future to strike a balance between leveraging the potential of these technologies and solving these difficulties. In this fast changing context, IoT and sensor technologies provide us with a formidable arsenal for ensuring the well-being of our planet and meeting the environmental imperatives of our time.

 ISBN: 978-81-965655-8-9

REFERENCES

- Atzori, L., Iera, A., and Morabito, G. (2010). The internet of things: A survey. *Computer networks*, 54(15): 2787-2805.
- Butt, M. A., Voronkov, G. S., Grakhova, E. P., Kutluyarov, R. V., Kazanskiy, N. L., and Khonina, S. N. (2022). Environmental monitoring: A comprehensive review on optical waveguide and fiber-based sensors. *Biosensors*, 12(11): 1038.
- Chen, P., Smith, R., and Johnson, S. (2020). IoT Devices and Communication Protocols: A Comprehensive Overview. *Journal of IoT Research*, 32(1): 45-58.
- Chu, E. W., and Karr, J. R. (2017). Environmental impact: Concept, consequences, measurement. *Reference Module in Life Sciences*.
- IPCC. (2021). Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, et al. (eds.)]. Cambridge University Press.
- Jones, P., Smith, J., and Anderson, M. (2019). The Impact of Urbanization on Ecosystems. *Urban Ecology Review*, 12(1): 45-58.
- Moursi, A. S., El-Fishawy, N., Djahel, S., and Shouman, M. A. (2021). An IoT enabled system for enhanced air quality monitoring and prediction on the edge. *Complex & Intelligent Systems*, 7(6): 2923-2947.
- Noaman, M., Khan, M. S., Abrar, M. F., Ali, S., Alvi, A., & Saleem, M. A. (2022). Challenges in integration of heterogeneous internet of things. *Scientific Programming*, 2022.
- Pamula, A. S., Ravilla, A., and Madiraju, S. V. H. (2022). Applications of the Internet of Things (IoT) in Real-Time Monitoring of Contaminants in the Air, Water, and Soil. *Engineering Proceedings*, 27(1): 26.
- Razzaque, M. A., Milojevic-Jevric, M., Palade, A., and Clarke, S. (2016). Middleware for internet of things: A survey. *IEEE Internet of Things Journal*, 3(1): 70-95.
- Smith, R. (2020). Global Population Growth and Its Environmental Implications. *Population and Environment Journal*, 63(5): 789-802.
- Tadejko, P. (2017). Environmental monitoring systems using internet of things-standards and protocols. *Ekon. I Srodowisko*.
- Truong, T. C. (2022). The impact of digital transformation on environmental sustainability. *Advances in Multimedia*, 2022: 1-12.
- Tudi, M., Ruan, H. D, Wang, L., Lyu, J., Sadler, R., Connell, D., Chu. C. and Phung, D. T. (2021). Agriculture development, pesticide application and its impact on the environment. *International journal of environmental research and public health*, 18(3): 1112.
- Ullo, S. L., and Sinha, G. R. (2020). Advances in smart environment monitoring systems using IoT and sensors. *Sensors*, 20(11); 3113.
- Yin, H., Cao, Y., Marelli, B., Zeng, X., Mason, A. J., and Cao, C. (2021). Soil sensors and plant wearables for smart and precision agriculture. *Advanced Materials*, 33(20): 2007764.

ISBN: 978-81-965655-8-9

CHAPTER 4

MULCHING: ENHANCING SOIL ENVIRONMENT

Manish Kumar Maurya[1*], Kishore Jyoti Bhuyan[2], Debasmita Nath[3], Dimpi Dutta[4]
[1, 2]M.Sc. Scholar, [4]Ph.D. Scholar, Department of Agronomy, Assam Agricultural University, Jorhat, Assam-785013 (India)
[3]M.Sc. Scholar, Department of Plant Breeding and Genetics, Assam Agricultural University, Jorhat, Assam-785013 (India)

ABSTRACT

The significance of soil as a non-renewable natural asset crucial to sustainable development is increasingly acknowledged. This chapter's focus lies in evaluating soil health within an agricultural context, with particular attention on mulching as a sustainable approach to bolstering soil fertility and productivity in arable systems. While soil health is integral to sustainable development, actual sustainability is realized through a combination of resource conservation, socio-cultural support, commercial competitiveness, and environmental friendliness. Mulching has proven its effectiveness in enhancing the soil environment by curbing evaporation, augmenting moisture retention, maintaining temperature equilibrium, boosting nutrient accessibility and root uptake, suppressing weed growth, reducing salinity, and fostering biological activity. Although organic mulch materials are commonly employed in arable systems to enhance the soil environment, the use of inorganic plastic mulch has gained substantial global significance in recent years. Nevertheless, it is crucial to comprehend the intricate ways in which mulching influences the soil environment.

Keywords: Organic mulch, Evaporation, Solarization, Soil chemical, Allelochemical

1. INTRODUCTION

The term "mulch" has its origins in the German word "*molsch*," meaning "prone to decay." Throughout history, mulches have been extensively employed in the cultivation of vegetables, a practice dating back to ancient times (Lightfoot, 1994). Mulch refers to a layer of diverse materials placed between the soil surface and the atmosphere. Mulching, in turn, involves the deliberate application of this layer with the goal of bringing about positive changes in the soil's environment. Mulch can take on an organic form (such as crop residues and stubble) or an inorganic one (like plastic sheets and gravel). It can either be naturally produced on-site, such as leaving previous crop residue mulch on the soil surface, generated through cover crops, or even involve living mulch like perennial legume growth. Alternatively, it can be cultivated elsewhere and brought in for application in the field – examples include straw, sawdust, and plastic products. The practice of mulching has a longstanding history as a strategic tool, utilized for generations across various ancient civilizations. Notably, the Great Plains region of the USA, once plagued by the Dust Bowl, was transformed into a global agricultural hub by embracing conservation tillage – the practice of letting crop residues remain as surface stubble or flattened straw mulch.

Mulch delivers a buffering effect, countering the impact of environmental elements on the soil. The extent of this buffering effect hinges on factors such as the quality, quantity, and durability of the mulch material, the soil's composition, and the prevailing climatic conditions. Mulching has an impact on the soil's hydrothermal dynamics by influencing factors like radiation balance, the pace of heat and water vapor transfer, and the soil's heat capacity. This practice bolsters the physical state of the soil by enhancing its structure, aiding in water conservation by reducing evaporation, promoting better infiltration, and curbing runoff. Furthermore, it positively alters the soil's thermal characteristics, curbs erosion, and enhances the chemical milieu and biological

 ISBN: 978-81-965655-8-9

activity within the soil. The microclimate changes brought about by mulching facilitate the emergence of seedlings and the growth of roots while inhibiting weed proliferation. As organic mulches decompose due to microbial activity, they introduce nutrients into the soil and contribute to carbon sequestration. The favorable soil conditions under mulch foster improved crop yields, greater efficiency in resource utilization, and reduced environmental pollution. From a conservation standpoint, mulch replicates the effects of plant cover. It proves particularly valuable as a substitute for cover crops in arid regions where inadequate rainfall hinders the establishment of ground cover before heavy rains or strong winds, or where cover crops vie with the main crop for moisture. However, incorrect mulch application can lead to the creation of anaerobic conditions during heavy rainfall, resulting in nitrogen loss due to denitrification. It may also lead to disease and pest infestations, and certain allelopathic substances found in crop residues could hinder crop growth. Therefore, an appropriate, site-specific approach is necessary, accounting for diverse soil, crop, and climate conditions, to ensure efficient mulch management that supports sustainable crop production.

2. Mode of Action of Mulches

i) Organic mulches play a significant role in conserving soil and water by maintaining high infiltration rates while reducing runoff and its speed.

ii) Mulches capture the energy of raindrops, lessening their impact on soil particle breakup. This reduction in particle breakup lowers soil pore clogging and sustains a prolonged high infiltration rate. Additionally, they disrupt surface water movement, decreasing runoff velocity and allowing more time for water to infiltrate.

iii) Organic mulches curtail evaporation by decreasing energy absorption by the soil and the air just above it.

iv) The influence of mulches on soil temperature depends on their impact on albedo, control over celestial radiation, moisture content, evaporative cooling, and heat conduction. Reflective mulches, like white ones, lower soil temperature, while direct contact with black plastic increases it.

v) Strip mulches that retain higher soil moisture and reduce evaporation around the seed area contribute to lowering soil salinity.

vi) Mulches impede weed germination and restrict weed biomass. Firstly, they block sunlight needed for seed germination, leading to cooler soil temperatures and reduced day-night temperature fluctuations. As a result, fewer weed seeds sprout compared to uncovered soil. Secondly, mulches serve as barriers, hindering the emergence of any germinated weeds.

3. How Does Mulching Affect the Soil Environment?

Mulching brings about positive changes in the physical, chemical, and biological aspects of soil. Under mulch, the soil experiences improved hydrothermal conditions, enhanced aggregation to prevent erosion and soil loss, and an overall better physical state. The benefits of mulching on the soil's chemical environment and biological activities are mainly a result of increased soil organic matter due to organic mulching and improved soil conditions resulting from both organic and inorganic mulches (refer to Figure 1).

3.1 Soil Moisture Management

Mulching has a positive impact on the soil's moisture levels by managing factors like soil surface evaporation, enhancing water infiltration and retention, and aiding water condensation during cooler nights due to temperature changes (Acharya *et al.*, 2005).

 ISBN: 978-81-965655-8-9

3.1.1 Controlling evaporation from soil surface

The process of water evaporation directly from the soil surface is crucial, especially for bare soils or regions that practice summer fallow. Mulching reduces this evaporation from the soil surface by slowing down the impact of radiation and wind speed on the mulched area. Its effectiveness is most noticeable during the initial phase when energy drives the drying process. However, mulching's ability to control evaporation diminishes during the subsequent stages, such as the falling rate or supply-controlled stage of evaporation. During this phase, the soil surface beneath the mulch dries, and inhibiting the transfer of water vapor to the atmosphere is primarily due to the dry soil rather than the vegetative mulch above it. A higher density of mulch further curbs the energy reaching the soil surface, thus limiting evaporation during the constant rate stage. Slowing down initial evaporation can also improve the process of internal drainage, allowing more water to move downwards into the deeper layers of the soil profile. This leads to longer water conservation and reduces the likelihood of evaporation loss. Mulching also impacts the evaporation pattern by creating resistance to the movement of water vapor from the soil surface to the atmosphere. Additionally, it increases the thickness of a less turbulent air zone above the soil, thereby altering the conditions at the boundary layer between soil and air. The extent of evaporation reduction due to different mulch densities is significantly more pronounced when there is high evaporative demand. The degree of maximum evaporation reduction and when it occurs depend on mulch density, soil type, evaporative demand, and residue application method.

The orientation of residue, whether flat or standing, affects the layer's porosity and thickness, thus influencing the rate of soil surface evaporation. With increasing standing residue, higher wind speeds are required to initiate water loss through evaporation. Furthermore, the rate of water loss at a given wind speed decreases with greater amounts of standing residue. The position of residue also influences soil temperature, impacting the evaporation rate through its effect on the vapor pressure of soil water. The effectiveness of water conservation through mulching is most significant in regions with frequent rainfall. However, during extended dry periods, mulch might maintain soil surface moisture for a prolonged period, extending the initial evaporation phase without actually saving water.

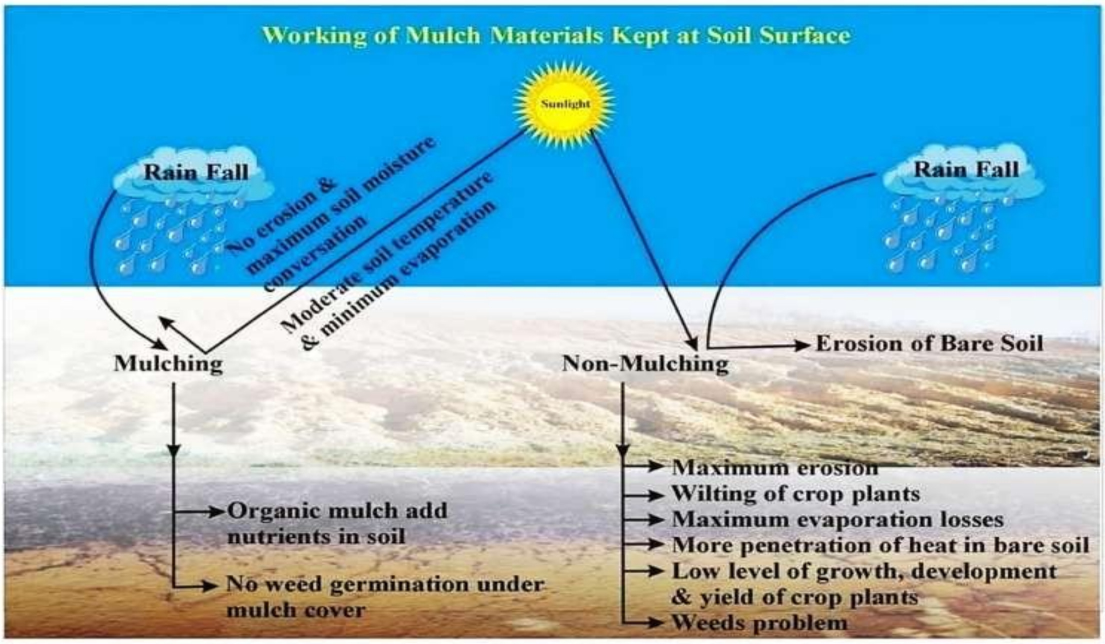


Figure 1. Potential effect of mulch (source: El-Beltagi *et al*., 2022; Iqbal *et al*., 2020)

 ISBN: 978-81-965655-8-9

3.1.2 Improving infiltration rate

Organic mulching enhances the rate of infiltration by acting as a barrier against runoff, providing more time for water to seep into the soil. Additionally, mulch intercepts rainwater and shields the soil from erosion caused by raindrop impact. It prevents the formation of crusts due to clogged soil pores, thereby increasing the rate of infiltration. Moreover, organic mulches contribute to the improvement of macro porosity and stability of soil structural aggregates. This, in turn, enhances water transmission properties, facilitating improved infiltration and recharge of the soil profile (Lal, 1987). The application of straw mulch enhances soil water storage and efficiency. The volume of water stored in the soil profile, along with its efficiency, total water utilization, and water use efficiency for dryland crops, all increase as the mulch rate rises (Unger, 1990). In some scenarios, the increase in infiltration resulting from mulching is even more crucial for water conservation within the profile than its impact on reducing evaporation.

3.1.3 Soil moisture retention

Mulching enhances the soil's ability to retain moisture by influencing pore size distribution and soil structure. A higher mulch rate has a greater impact on increasing soil water retention, particularly at lower suctions (Lal, 1987). This is due to the rise in macro-pores and inter-aggregate pores resulting from elevated soil organic matter content and increased activity of soil organisms like earthworms and termites in areas with mulch.

3.1.4 Water condensation at night

Stone and gravel mulches create a horizontal flow of heat and vapor, potentially leading to water accumulation beneath the stones due to nighttime vapor condensation. This collected water might be substantial enough to function as a water source for specific desert plant species and soil organisms.

3.2 Controlling runoff and soil erosion

Mulching consistently leads to a reduction in soil erosion and frequently contributes to the decrease of both runoff rate and volume. The presence of mulch covering safeguards the soil against the impact of raindrops and the formation of surface seals. This protection results in an increased infiltration rate and a lowered speed of runoff, achieved by creating a physical barrier that resists the flow of water. Generally, the loss of water through runoff experiences an exponential decline with the increase in mulch density (Erenstein, 2002). While there are certain soil types for which mulching may not significantly lower runoff, it often brings about a substantial reduction in soil erosion. The runoff water, when filtered through the mulch, tends to be clear with minimal sediment content. Through the safeguarding effect of crop residues against raindrops, mulching reduces the concentration of sediment in runoff water.

Experimental findings demonstrate that a suitable amount of crop residue mulch can counteract the impact of slope degree in reducing runoff and soil loss. Moreover, mulching effectively mitigates wind-induced soil erosion by diminishing wind velocity at the soil surface. This is achieved by securely anchoring the mulch to the soil to prevent wind displacement. Standing crop residues act as barriers against wind and prove more efficient than flattened surface mulches in curtailing wind erosion. The efficacy of standing crop residues hinges on the plant density of the harvested crop and the height of the plants above the ground.

3.3 Regulation of soil thermal regime

Mulching exerts a regulating effect on the thermal conditions of the soil, and this impact varies based on factors such as soil types, climate, the type of mulch materials used, and the rate of application. It elevates soil temperature in cooler weather conditions and conversely reduces it during hot periods. In general, mulch dampens the extent of daily fluctuations in soil temperature. Organic mulching results in higher soil temperatures during the nighttime and early morning hours, while lowering daytime temperatures compared to areas without mulch.

 ISBN: 978-81-965655-8-9

Transparent polyethylene mulch increases the maximum soil temperature, whereas organic mulches like pine needles and grass have a cooling effect. However, black polyethylene mulch has relatively minimal influence on the maximum soil temperature. The presence of straw mulch can decrease the maximum soil temperature due to factors such as the interception of incoming solar radiation, its high reflectivity, and low heat conductivity. The degree of this effect depends on factors like soil moisture, incidental radiation, the rate of mulch application, and the time of year (Prihar, 1986). Lowering the maximum soil temperature through straw mulching, particularly in the early growth stages of sugarcane, can lead to significant improvements in crop yield.

3.4 Soil aeration in soil

Crop residue mulch enhances soil aeration by facilitating the unrestricted exchange of gases between the soil and the atmosphere. This is achieved through the improvement of structural stability, overall porosity, macro porosity, and the reduction of surface crusting, along with enhanced soil drainage. Oxygen diffusion rates are higher in mulched conditions compared to areas without mulch. The composition of soil air under mulch is influenced by factors like the mulch material's nature (including its C/N ratio), the rate of its decomposition, the soil moisture levels, and the prevailing climate conditions. In contrast, plastic mulch acts as a barrier to carbon dioxide (CO_2), a gas vital for photosynthesis. This leads to a significant buildup of CO_2 beneath the plastic cover, as the film doesn't allow for its dissipation. CO_2 finds its way through the holes made in the plastic for the plants, creating a "chimney effect" that results in concentrated pockets of abundant CO_2 around actively growing leaves. This concentrated CO_2 encourages accelerated crop growth.

3.5 Improvement in soil structural

Mulching contributes to the enhancement of soil structural properties both directly and indirectly by stimulating biological activity. Organic mulching has a positive impact on various structural aspects such as total porosity, macro porosity, and the mean weight diameter of water-stable aggregates. This improvement is attributed to the introduction of organic matter that decomposes over time. The stability of soil aggregates is found to increase as the mulch rate rises (Lal, 1987). Generally, under mulched conditions, the soil's bulk density is lower compared to situations without mulch. Furthermore, bulk density tends to decrease as the rate of residue mulch increases. One reason behind this decline in bulk density with higher mulch rates is the elevated activity of earthworms in areas with mulch.

3.6 Improving soil chemical environment

Both organic and living mulches offer a range of advantageous effects on the soil's chemical environment. However, the influence on soil chemical properties-whether they increase, decrease, or remain unaffected-is determined by factors such as the material type, soil characteristics, and prevailing climatic conditions. Mulching notably impacts soil organic matter, leading to subsequent enhancements in soil physical, chemical, and biological attributes as the material decomposes. Organic mulches, rich in organic matter content, contribute to improved soil organic matter levels upon application. On the other hand, inorganic mulches have a low percentage of organic matter but expedite its decomposition, leading to benefits such as soil moisture retention and amplified microbial growth.

In addition to organic carbon, other soil chemical properties like cation exchange capacity and electrical conductivity (Chen *et al.*, 2021), total nitrogen, total sulfur, available phosphorus, and exchangeable potassium (Rahmani *et al.*, 2021) experience positive improvements. The breakdown of organic mulch releases organic acids, which can lead to a decrease or even an increase in soil pH, potentially enhancing the bioavailability of micronutrients such as Mn, Zn, Cu, and Fe. Over time, the mineralization of organic nitrogen results in elevated concentrations of mineral N (NO_3 and NH_4^+) in the soil, thereby increasing the availability of soil nitrogen.

 ISBN: 978-81-965655-8-9

Under plastic mulch, the breakdown of organic materials releases soluble nutrients like NO_3, NH_4^+, Ca_2^+, Mg_2^+, K^+, and fulvic acid into the soil. This process augments the availability of soil nutrients, contributing to improved soil nutrient content.

3.7 Improving soil microbial environment

Within an agro-ecosystem, the diversity of soil microbes assumes a crucial role in nutrient cycling and maintaining soil structural stability. In essence, the composition of soil microbial communities is a determining factor in the long-term viability of soil ecosystems. Organic mulches, rich in carbon content, serve as abundant food sources for microbes. This stimulates their growth, leading to rapid multiplication and the breakdown of organic matter. Consequently, essential plant nutrients are released in readily available forms through mineralization, thus enhancing overall soil quality (Mehraj *et al.,* 2014). Additionally, the combined effects of moisture retention and the temperature-regulating impact of mulching create a favorable environment for microbial development in the soil. This heightened microbial activity plays a significant role in processes like biological nitrogen fixation and soil pH regulation, facilitated by the improved soil nutrient status resulting from organic matter decomposition (Hamza *et al.,* 2017). Plastic mulches, although non-degradable, induce rapid decomposition by promoting microbial activity, primarily due to their ability to elevate soil temperatures (Kasirajan and Ngouajio, 2012). The processes of decomposition, nutrient mineralization, and soil carbon sequestration are all notably influenced by the physicochemical attributes of the soil. The presence of a high microbial biomass and activity frequently translates to optimal nutrient availability for crops.

4. Application methods of mulching materials

In agricultural environments, an array of mulching materials is utilized in various manners and configurations, as depicted schematically in Figure 2.

4.1. Flat Mulching

One conventional mulching technique is referred to as flat mulching, which entails covering the uppermost layer of soil with a variety of mulching materials, whether organic, inorganic, or a combination of both. When using organic mulching materials, the thickness of the layer can be adjusted according to the desired purpose. Another variation of flat mulching involves partially covering the topsoil, as seen in plastic mulching with perforations. This particular type of mulching enhances both soil aeration and the penetration of rainfall, offering an improvement over the traditional flat mulching approach (Kader, M.A. 2016).

4.2. Ridge Shape Mulching

In this type, a plastic film covers the ridge to effectively guide rainwater into furrows or reduce runoff, thereby improving water utilization efficiency (WUE). The raised portion of the field, known as the ridge, is where crops like corn are commonly cultivated and covered with mulch. Additionally, crops can be planted in the furrows, which have the option of being mulched or left uncovered (Zhao *et al.,* 2014).

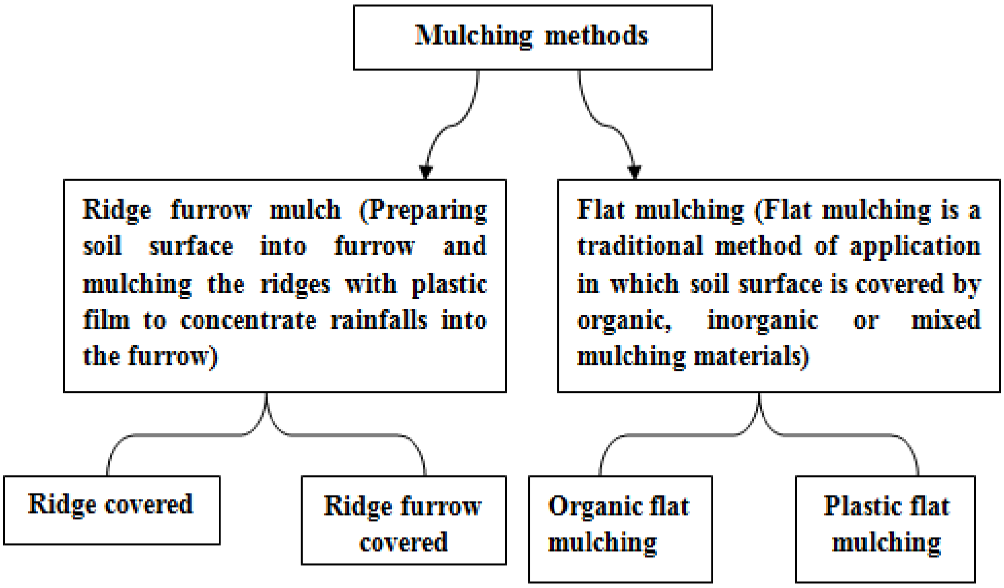


Figure 2. Application methods of mulches

5. Limitation for use of mulches

5.1 Acidifying the soil pH

Uncovered soil exhibits the highest level of acidity compared to soil covered with inorganic mulch, and among the various treatments investigated in the study conducted by Iles and Dosmann in 1999, soil mulched with organic materials displays the mildest acidifying tendencies. The utilization of woody materials for nursery production can result in the generation of acidic compounds like phenolic acids during the decomposition process. However, when applied in field conditions, the impact of woody materials on soil acidity is minimal or negligible due to the localized nature of acid production. In practical scenarios, the introduction of mulches does not significantly contribute to soil acidity, as highlighted in Chalker-Scott's work in 2007.

5.2 Allelopathic effects

Allelopathy is the process wherein the germination of seeds and the growth of plants are hindered due to the discharge of allelochemicals originating from plants themselves or occasionally from living organic mulches. Organic mulch materials can release allelochemicals such as Juglone, 1, 8-cineol, Heliannuols, Tricin, and Momilactone B. These allelochemicals have an impact on various aspects including seed germination, impeding seedling growth, hindering plant establishment, and reducing overall dry matter production.

5.3 Flammability

Divergent opinions exist concerning the burning behavior of rapid-fire mulch, with certain mulch types igniting more quickly than others. A research investigation was undertaken to assess the swift flammability of various mulches, as documented in the study by Steward *et al.* in 2003. The outcomes of this study indicated that within the mulches examined, rubber mulch exhibited a greater propensity for rapid combustion compared to the other mulch varieties employed in the experiments.

5.4 Selection of mulch

The effectiveness of achieving mulching objectives is primarily contingent upon the choice of mulch type. Incorrect selection of mulch types can have repercussions on both the soil

 ISBN: 978-81-965655-8-9

environment and the growth of plants. To illustrate, thin and transparent films are typically employed for soil solarization purposes, while black mulch is utilized for weed control in cultivated fields with sandy soil. White film is chosen for areas where summer crops are grown and silver-colored film serves as an insect repellent.

5.5 Nitrogen deficiency

There is a misconception surrounding the application of organic mulches, suggesting that they lead to a shortage of nitrogen for plants when utilized in thriving crop plants or around trees. This misconception arises from the fact that woody materials possess a substantial carbon-to-nitrogen (C/N) ratio. Microorganisms consume the nitrogen present, leaving carbon in the soil. As a consequence, nitrogen scarcity can develop in the soil, a condition often evidenced by chlorosis in plants.

5.6 Weed infestation

There is a belief that certain types of mulches can inadvertently transport a multitude of weed seeds. This notion is based on the idea that composts and remnants utilized as mulch, when insufficiently decomposed, might harbor seeds from a range of weed species. High-quality mulch possesses attributes like depth, which effectively suppresses weed growth while concurrently enhancing the vitality of plants and soil.

6. CONCLUSION

By serving as a safeguarding barrier between the soil's surface and the surrounding atmosphere, mulching represents a deliberate effort to enhance the soil's ecosystem. This practice exerts a profound influence on diverse facets of soil dynamics, spanning from the equilibrium of hydrothermal processes to the enrichment of nutrients. The strategic choice of appropriate mulch varieties, whether natural like crop residues or synthetic such as plastic sheets, directly shapes the soil's ability to counteract environmental stressors. Mulching adeptly alleviates the detrimental impacts of factors like erosion, evaporation-induced water loss, and the rampant growth of unwanted plants. By establishing a microenvironment conducive to the sprouting of seedlings and the expansion of roots, mulch significantly aids in cultivating robust plant populations and achieving elevated crop yields. Furthermore, the integration of decomposing organic mulch into the soil introduces vital nutrients and contributes to the sequestration of carbon, effectively addressing concerns about long-term sustainability.

REFERENCES

- Acharya, C.L., Hati, K.M. and Bandyopadhyay, K.K. (2005). Mulches. In. (Hillel, D., Rosenzweig, C., Powlson, D.S., Scow, K.M., Singer, M.J., Sparks, D.L. and Hatfield, J. eds.) *Encyclopedia of Soils in the Environment*. 521-532. Elsevier Publication
- Chalker-Scott, L. (2007). Impact of mulches on landscape plants and the environment - a review. *J. Environ. Hortic.* 25:239–249
- Chen, N., Li, X., Šim unek, J., Shi, H., Hu, Q. and Zhang, Y. (2021). Evaluating the effects of biodegradable and plastic film mulching on soil temperature in a drip-irrigated field. *Soil Tillage Res*. 2021, 213, 105116
- Dosmann, M.S. and Iles, J.K. (1999). Effect of organic and mineral mulches on soil properties and growth of 'Fairview Flame R' red maple trees. *J. Arboric*. 25: 163–167
- El-Beltagi, H.S., Basit, A., Mohamed, H.I., Ali, I., Ullah, S., Kamel, E.A.R., Shalaby, T.A., Ramadan, K.M.A., Alkhateeb, A.A. and Ghazzawy, H.S. (2022). Mulching as a Sustainable Water and Soil Saving Practice in Agriculture: A Review. *Agronomy, 12,* 1881

- Erenstein, O. (2002). Crop residue mulching in tropical and semi-tropical countries: An evaluation of residue availability and other technological implications. *Soil Till. Res.* 67: 115-133
- Hamza, T.A., Hussein, Z., Mitku, R., Ayalew, P., and Belayneh, T. (2017). Isolation and characterization of nitrogen fixing bacteria from rhizosphere soil collected from shell mele agricultural center, Southern Ethiopia. *Journal of Agricultural Science and Food Technology*. Vol 3 No 7 Pages 117-124
- Iqbal, R, Raza, M.A.S, Valipour, M, Saleem M.F, Zaheer, M.S, Ahmad, S., Toleikiene, M., Haider, I., Aslam, M.U and Nazar, M.A. (2020). Potential agricultural and environmental benefits of mulches- a review. *Bulletin of the National Research Centre* (2020) 44:75
- Kader, M.A. (2016). Mulching material effects on soil moisture and temperature of soybean (*Glycine max*) under effective rainfall. Master's Thesis, Gifu University, Gifu, Japan, 2016
- Kasirajan, S. and Ngouajio, M. (2012). Polyethylene and biodegradable mulches for agricultural applications: a review. *Agronomy for Sustainable Development*. Vol 32 No 2 Pages 501-529
- Lal, R. (1987). Farming systems. In: Lal R (ed.) Tropical Ecology and Physical Edaphology, pp 618-685. *Wiley-Interscience Publication*
- Lightfoot, D.R. (1994). Morphology and ecology of lithic-mulch agriculture. *Geo. Rev.* 25:172-185
- Mehraj, S., Qurtulane Peer, F.A., Bisati, I.A., Mir, M.M. and Hassan, S., (2014). Effect of organic and inorganic mulches on TSS, acidity, TSS/Acidity, yield efficiency, soil hydrothermal conditions and leaf nutrient content under temperate conditions. *Ecology, Environment and Conservation*. Vol 21 No 3 Pages 2015-1331
- Prihar, S.S. (1986). Fertilizer and water use efficiency through the aid of mulching. In: Proceedings of Seminar Organized by Fertilizer Association of India (Northern Region) at Dehradun, India, May 10-11, 1986. pp 31-44
- Rahmani, W., Salleh, M.N., Hamzah, M.H., Abdu, A., Ishak, M.F., Khadir, W.R.W.A., Mohd, Awang, R., Ibrahim, Z., Majid, A.F.A., Salleh, M.S.A., Anuar, A. and Alias, M.A.B. (2021). Effect of different types of mulching on soil properties and tree growth of *magnolia champaca* planted at the montane rainforest in Cameron Highlands, Pahang, Malaysia. *International Journal of Forestry Research* Volume 2021, Article ID 5517238, 11 pages
- Steward, L.G, Sydnorand T.D, and Bishop, B. (2003). The ease of ignition of 13 landscape mulches. *J. Arboric*. 29:317–321
- Unger P.W. (1990). Conservation tillage systems. *Advances in Soil Science*, 13, 27-68
- Zhao, H., Wang, R.Y., Ma, B.L., Xiong, Y.C., Qiang, S.C. and Wang, C.L. (2014). Ridge-furrow with full plastic film mulching improves water use efficiency and tuber yields of potato in a semiarid rain-fed ecosystem. *Field Crops Res*. 161, 137–148

ISBN: 978-81-965655-8-9

CHAPTER 5

SMART SENSORS AND SYSTEMS: AN INNOVATION TOWARDS CLIMATE SMART FARMING

[1*]Dimpi Dutta, [2]Debasmita Nath, [3]Kishor Jyoti Bhuyan, [4] Manish Kumar Maurya
[1] Ph.D. Scholar, Assam Agricultural University
[2.3.4] MSc. Scholar, Assam Agricultural University

INTRODUCTION

The world community has shifted its interest towards the era of digitization for different aspects in both developed as well as developing countries. Among different factors, agriculture plays a significant role in the global economy over the entire globe. The change in climatic conditions and decline in cultivated areas along with the burgeoning population created pressure on the world food supply and agricultural market. Climatic condition plays a crucial role in cultivation and having insufficient knowledge of climate greatly affects the quantity and quality of the crop produced. The changes in rainfall intensity, temperature and carbon dioxide concentration due to global warming significantly affect plant growth. Climatic changes will impact soil moisture, occurrence of drought or flood, decrease in soil fertility and change in water level in different areas (Allen et al., 2004). Climate change affects global agriculture production through direct or indirect means. Farm production requires soil and plant monitoring, environmental monitoring, transportation, supply chain management, infrastructure management, animal monitoring, insect control etc., (Nayyar and Puri, 2016). Annually, the demand for cereals and livestock would rise by one billion tons and two hundred million tons, respectively (Krishnan et al., 2020). The conventional method of cultivation was not able to meet the insufficiency of food. Hence, there is a need to increase global food production without hampering the environment through the introduction of revolutionary digital technologies viz., Artificial intelligence (AI), Internet of things (IoT), smart sensors, big data analysis, cloud computing, remote sensing etc., for modernizing the agriculture (Ferrandez-Pastor, 2016). Various initiatives have been taken by the Food and Agriculture Organization (FAO) to elevate crop productivity, efficiency and sustainability through resilient agricultural food systems. The main aim of FAO is to coordinate with the UN Sustainable Development Goals (SGDs) to build a new era of smart farming with zero percentage of hunger by 2030 (Kumari et al., 2021). This objective might be fulfilled by the use of digital agricultural technologies.

1. Smart Farming

Smart farming means the use of modern information and technologies for farm management and the improvement of produce quality. The different smart sensors with wireless or web applications are deployed by the farmers to monitor the crop ecosystem in the field and to provide precise and reliable information on different plant parameters and associated abnormal conditions, like the low quality of the crop, the appearance of pests, diseases and weeds, inappropriate irrigation and imbalance of soil chemical components. The farmers were able to optimize their crops and were updated regarding the changes in the factors of the environment and ecosystem. With the help of sensors, they were capable of preventing or protecting the crop from environmental challenges. So, the world is advancing towards the objective of smart agriculture where sensors and cameras will be used to monitor crop growth and assess unfavorable condition, real- time data assembled from these sensors will be processed and provided to the farmer's smartphones or devices in the form of alerts and analysis reports. The technologies included in the smart farming are (Figure 1):

 ISBN: 978-81-965655-8-9

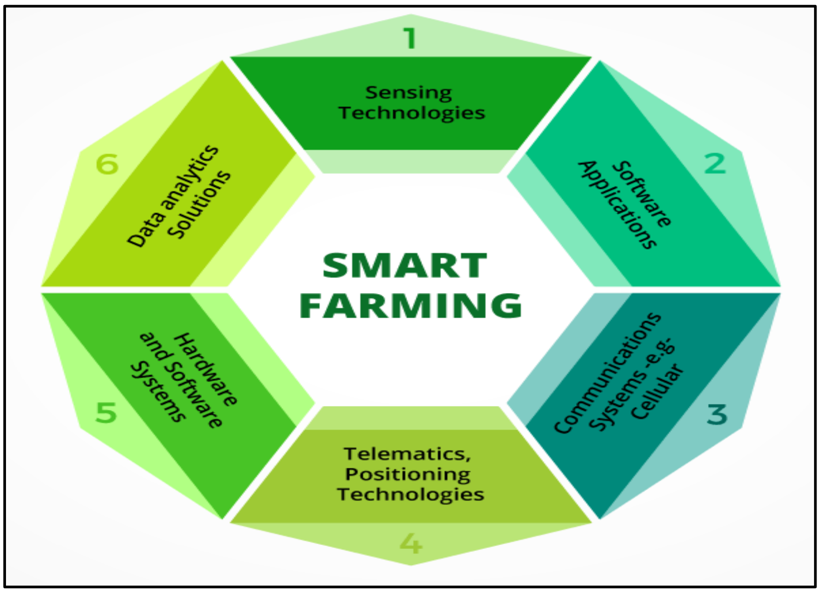


Figure 1: Technologies under smart farming

Smart farming provides farmers with precise data and good resources for managing plants, machinery, and data. Smart farming is one of the solutions to the problems faced in conventional farming. The differences between conventional and smart farming are presented in Table I.

Table I: The differences between conventional and smart farming

Conventional farming	Smart farming
Fertilizer and pesticide application throughout the field	Application of fertilizer and pesticide in the affected region
Detection of zone and geo-tagging are not possible	Satellites help the detection of zone in the farms
Weather prediction not possible	Weather analysis can be possible
The same set of methods used for planting of a crop throughout the area	A different set of methods for planting of crops and optimized the requirement of water.

Smart Farming Cycle

Types of sensors used in Smart farming

1. **Optical Sensor**

   It utilizes light to determine the properties of the soil like soil texture, organic matter and moisture content of the soil. These sensors are attached to satellites, vehicles, drones or robots to collect the data on soil reflectance. It can also check the plant's health based on its leaf (Hu et al., 2015).

2. **Electrochemical Sensors**

   It provides data on soil nutrient status and pH by utilizing an ion-selective electrode. The electrodes can sense the active ions present in the soil and based on this soil configuration is determined (Yew et al., 2014).

3. **Location Sensors**

   It estimates the range, distance and height of any object within the concerned area. Global Positioning System (GPS) is used for this purpose (Hu et al., 2015).

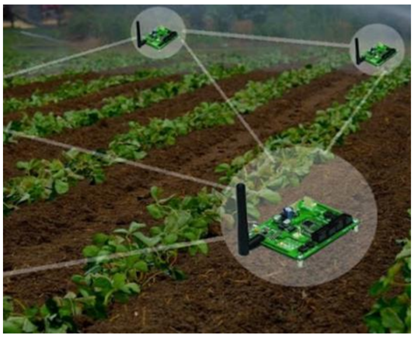
 ISBN: 978-81-965655-8-9

Optical sensors in agriculture

Electrochemical sensors for soil nutrient detection

Mechanical soil sensors for agriculture

Dielectric soil moisture sensors



Location sensors in agriculture

Electronic sensors

Airflow sensors

Agriculture sensors IOT

Source: Types of smart sensors in agriculture for farming in India. Agriculture. Tractor junction

 ISBN: 978-81-965655-8-9

4. **Mechanical Sensors**
   It determines the soil compaction or soil mechanical resistance. It is based on the force required by the plant roots for water absorption and helps in an effective irrigation schedule (Yurui et al., 2007).

5. **Soil electrical resistivity sensors**
   These sensors are useful to determine the changes in soil resistance due to variations in soil moisture level. They can also identify the frictional angle of soil and the soil's physical characteristics (Sai and Hemalatha, 2017).

6. **Agricultural Weather Station**
   These are the environmental monitoring devices installed in the field to measure different weather parameters. They are equipped with many sensors for measuring temperature, relative humidity, location, solar radiation and wind speed (Math and Dharwadkar, 2018).

Advantages of using smart sensors for climate-smart farming

1. Promoting collective agriculture with smart sensors:

Smart sensors play a pivotal role in promoting collective farming, especially in rural and remote regions. It can facilitate the creation of services that enable rural agricultural communities to collectively store farm information, share data, and enhance communication between farmers and agricultural experts. Mobile applications have proven invaluable in disseminating IoT-related information such as the appropriate tools, fertilizers, and weather forecasts. This data can be effortlessly shared among rural residents through both free and paid mobile services.

2. Security concerns in agriculture:

The challenges within the agriculture sector extend beyond simply increasing food production; they also encompass ensuring the safety, security, and quality of the food supply. Numerous issues have been reported regarding the quality of food supplied to the market, including problems like food adulteration, counterfeiting and artificial manipulation of the size of vegetables and fruits. These issues raise significant health concerns and can have adverse effects on the economy. Some aspects of food fraud, such as product authenticity, process integrity, human factors, and data integrity, can be addressed using smart sensors.

3. Advantages of competition:

The growing demand for increased food production and the adoption of innovative technologies are transforming agriculture into a more competitive sector. This development facilitates a framework in which the sharing of information through smart sensors within the agricultural sector olds the potential to bring about fresh opportunities in marketing, monitoring, and management. By minimizing costs and reducing wastage in farm inputs such as fertilizers and pesticides, it becomes possible to enhance food productivity. The utilization of real-time data for decision-making purposes becomes essential in managing competition effectively, especially for farmers who embrace smart sensors.

4. Creating and distributing prosperity:

The adoption of smart sensors can introduce fresh opportunities for job creation, benefiting farmers by bypassing the various exploitative practices of middlemen. This enables farmers to directly engage with customers, resulting in greater profits.

5. Cost-efficiency and minimizing damage:

One of the significant advantages of smart sensors lies in their ability to remotely monitor devices and equipment placed at a distance. In agriculture applications, smart sensors prove invaluable in terms of cost and time savings by efficiently surveying vast areas of land, which would otherwise require human intervention and the use of farmers' vehicles.

 ISBN: 978-81-965655-8-9

Disadvantages of using smart sensors for climate-smart farming

Certainly, smart sensor platforms come with their fair share of challenges and issues. Here are some of the problems faced in various sections such as business prototypes, technological issues, and regional challenges:

1. Security and Privacy:

Data Security: Smart sensors connected to IoT devices are susceptible to hacking and data breaches. Ensuring the security of data transmitted between devices and stored in the cloud is crucial.

Privacy Concerns: Smart sensors often collect vast amounts of personal data, raising privacy concerns. Striking a balance between data collection for functionality and protecting user privacy is challenging.

2. Authority and Governance:

Lack of Standardization: The absence of standardized protocols and regulations across different smart sensors and platforms makes it difficult to ensure interoperability and data consistency.

Regulatory Compliance: Complying with various regional and international regulations regarding data protection and smart sensor usage can be complex and costly.

3. Data Management and Merging:

Data Integration: Smart sensors often involve diverse data sources with different formats. Integrating and merging this data for meaningful insights can be a significant challenge.

Data Quality: Ensuring data accuracy and reliability is essential for decision-making, but data generated by smart sensors can be noisy and incomplete.

4. Lack of Association:

Contextual Understanding: Smart sensors may struggle to understand the context of the data they collect, making it challenging to provide relevant and meaningful information to users.

5. Diversity in smart sensors devices:

Compatibility: Managing a wide variety of smart sensors devices with different communication protocols and hardware can be complex. Compatibility issues can hinder the seamless operation of the systems.

Device Management: Scaling smart sensors deployments and managing a large number of devices efficiently is a logistical challenge.

6. Technological Challenges:

Scalability: As smart sensors networks grow, scalability becomes a significant concern in terms of infrastructure, data processing, and device management.

Energy Efficiency: Many smart sensors devices operate on battery power, making energy efficiency a critical consideration for their long-term viability.

Latency and Reliability: Some smart sensors applications, such as real-time monitoring and control, require low latency and high reliability, which can be challenging to achieve.

7. Regional Challenges:

Connectivity: Smart sensor deployments may face connectivity issues in remote or underserved regions, limiting their effectiveness.

Cultural and Language Differences: Adapting smart sensor solutions to different regions and cultures can be complex due to language, cultural norms, and user behavior variations.

 ISBN: 978-81-965655-8-9

Addressing these challenges requires collaboration among technology companies, policymakers, and stakeholders to develop robust solutions and establish a regulatory framework that ensures the responsible and secure use of smart sensors technologies.

Future thrust:
The future scope of smart sensors in agricultural applications is promising and is expected to play a significant role in transforming the agriculture industry. Here are some key areas where smart sensors are expected to have a substantial impact:

1. Precision Agriculture:
Smart sensors and devices can collect real-time data on soil conditions, weather, crop health, and equipment performance. Farmers can use this data to make data-driven decisions, optimize resource usage (water, fertilizer, pesticides), and increase crop yields while reducing costs.

2. Livestock Monitoring:
Smart sensors enabled wearable devices for animals can track their health, location, and behavior. This data helps farmers in early disease detection, ensuring animal welfare, and improving breeding practices.

3. Smart Irrigation:
Smart sensors can monitor soil moisture levels and weather conditions. Automated irrigation systems can adjust water delivery in real time, reducing water wastage and increasing efficiency.

4. Crop Monitoring:
Drones equipped with smart sensor technology can capture aerial images and collect data on crop health and growth. Machine learning algorithms can analyze this data to identify disease outbreaks or nutrient deficiencies.

5. Supply Chain Management:
Smart sensors can track the movement and storage conditions of agricultural products from farm to market.

This ensures the quality and safety of food products and reduces spoilage and waste.

6. Pest and Disease Management:
Smart sensors-based pest monitoring systems can detect the presence of pests or diseases in crops. Integrated pest management strategies can be implemented to minimize the use of pesticides.

7. Farm Equipment Automation:
Smart sensors enabled tractors and machinery can perform tasks autonomously or with remote monitoring. This reduces labour costs, increases efficiency, and minimizes the risk of human error.

8. Environmental Monitoring:
Smart sensor devices can monitor environmental factors like air quality, temperature, and humidity. This information is valuable for assessing the impact of agriculture on the environment and making sustainable farming decisions.

9. Market Access:
Smart sensors can connect farmers directly with consumers and markets through online platforms and mobile apps. This can help farmers get fair prices for their produce and improve market access.

 ISBN: 978-81-965655-8-9

10. Data Analytics and AI:

Smart sensors generated data can be processed using artificial intelligence and machine learning to provide valuable insights for decision-making. Predictive analytics can help farmers plan for the future and mitigate risks.

11. Climate Change Adaptation:

Smart sensor technology can assist farmers in adapting to changing climate patterns by providing real-time weather data and recommendations for adapting farming practices.

12. Rural Development:

Smart sensors in agriculture can contribute to the development of rural areas by creating job opportunities and improving the overall economic landscape.

The adoption of smart sensors in agriculture is still in its early stages, but as technology continues to advance and become more affordable, its impact on the industry is expected to grow significantly. Farmers and agribusinesses that embrace smart sensor solutions can benefit from increased efficiency, sustainability, and profitability while addressing the challenges of feeding a growing global population.

REFERENCES

- Ferrandez-Pastor, F.J.; Garcia-Chamizo, J.M.; Nieto-Hidalgo, M.; Mora-Pascual, J.; MoraMartinez, J. (2016). Developing ubiquitous sensor network platform using Internet of Things: Application in precision agriculture. Sensors. 16(7): 1141.
- Hu, P., Chen, Y. and Sonkusale, S. (2015). Low-cost spectrometer accessory for cell phone based optical sensor. IEEE Virtual Conference on Applications of Commercial Sensors (VCACS), Raleigh, NC. pp. 1-5.
- Math, R. K. M. and Dharwadkar, N. V. (2018). IoT-based low-cost weather station and monitoring system for precision agriculture in India. 2nd International Conference on 1-SMAC (IoT in Social, Mobile, Analytics and Cloud), Palladam, India. pp. 81-86.
- Nayyar. A. and Puri, V. (2016). Smart Farming: IoT Based Smart Sensors Agriculture Stick for Live Temperature and Moisture Monitoring using Arduino, Cloud Computing and Solar Technology. The International Conference on Communication and Computing Systems (ICCCS-2016). Pp:673-680.
- Sai, V. V. and Hemalatha, T. (2017). Computational methods for simulating soil parameters using electrical resistivity technique. 8th International Conference on Computing, Communication and Networking Technologies (ICCCNT), Delhi. pp. 1-7.
- Weber, R. H. (2010). Internet of Things–New security and privacy challenges. Computer Law and Security Review. 26(1): 23-30.
- Yew, T. K., Yusoff, Y., Sieng, L. K., Lah, H. C., Majid, H. and Shelida, N. (2014). An electrochemical sensor ASIC for agriculture applications. 37th International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO), Opatija. pp. 85-90.
- Yurui, S., Qingmeng, Z., Zhaolong, Z. and Lammers, P. S. (2007). Measuring Soil Physical Properties by Sensor Fusion Technique. 2nd IEEE Conference on Industrial Electronics and Applications, Harbin. pp. 142-146.

CHAPTER 6

ROLE OF ORGANIC MANURE ON PHYTOREMEDIATION

Priyobarta Singh Khumukcham
Ph.D Scholar, Department of Soil Science, Assam Agricultural University, Jorhat-785013, Assam, India

ABSTRACT
Phytoremediation, the use of plants to remediate environmental contaminants, holds great promise for sustainable pollution cleanup. This paper explores the potential of organic manure as a valuable tool in phytoremediation. The synergistic combination of organic manure and phytoremediation enhances pollutant uptake, improves soil health, and stimulates microbial activity. This approach offers several advantages, including increased remediation efficiency, reduced environmental footprint, and long-term soil restoration. Research gaps and avenues for future innovation are identified, emphasizing the holistic and eco-friendly nature of organic manure-enhanced phytoremediation. The broader implications for sustainable environmental management, including reduced greenhouse gas emissions and enhanced community well-being, underscore the significance of this approach in addressing environmental challenges. Organic manure-enhanced phytoremediation serves as a model for responsible and effective pollution management in a changing world.

Keywords: Phytoremediation, organic manure, sustainability, environmental management, soil health, pollution cleanup, microbial activity, sustainable agriculture, climate change mitigation, community well-being

INTRODUCTION
Environmental pollution poses a significant challenge to the well-being of both ecosystems and human populations. Toxic contaminants, such as heavy metals, organic pollutants, and radioactive substances, are often released into the environment through industrial activities, mining, agriculture, and various other human-related sources. These contaminants can have adverse effects on soil, water, and air quality, as well as on the health of living organisms.

Phytoremediation is an innovative and sustainable approach to addressing environmental pollution. It is a specialized technique that utilizes plants to remove, detoxify, or immobilize contaminants from the soil, water, or air. This natural, eco-friendly process harnesses the inherent abilities of certain plants to absorb, accumulate, or break down pollutants. Phytoremediation offers a promising alternative to traditional remediation methods, which often involve costly and environmentally damaging procedures.

The importance of phytoremediation in environmental management cannot be overstated. Here are several key reasons why this approach is gaining prominence:

- **Sustainability:** Phytoremediation is an environmentally sustainable technique that relies on the natural processes of plants and microorganisms. It reduces the need for energy-intensive, chemical-based remediation methods, thereby minimizing the carbon footprint associated with pollution cleanup.
- **Cost-Effectiveness:** Phytoremediation is often more cost-effective than conventional remediation methods. It can be less expensive to implement and maintain, making it an attractive option for remediating contaminated sites, particularly in resource-constrained areas.

 ISBN: 978-81-965655-8-9

- **Minimal Disruption:** Unlike traditional remediation methods that may involve excavation and removal of contaminated soil, phytoremediation can be less disruptive to the environment. It allows for in-situ treatment, reducing habitat destruction and disturbance.
- **Versatility:** Phytoremediation is a versatile technique that can be adapted to address a wide range of contaminants, including heavy metals, organic pollutants, and even radionuclides. Different plant species exhibit varying degrees of tolerance and efficacy in remediating specific pollutants.
- **Soil Restoration:** Phytoremediation not only removes contaminants but also improves soil quality. Certain plants can enhance soil structure, nutrient content, and microbial activity, leading to the long-term restoration of degraded landscapes.
- **Biodiversity Conservation:** The use of native plant species in phytoremediation can promote biodiversity conservation by creating habitat and food sources for local wildlife.
- **Public Health Protection:** Phytoremediation can reduce the risks associated with exposure to harmful pollutants, thereby safeguarding the health and well-being of nearby communities.
- **Regulatory Compliance:** Phytoremediation can help industries and landowners meet environmental regulations and remediation requirements while simultaneously demonstrating commitment to sustainable practices.

Need for Sustainable and Eco-Friendly Approaches to Remediate Contaminated Sites

Environmental contamination is a pressing global concern, with numerous sites worldwide being polluted by various hazardous substances, including heavy metals, industrial chemicals, petroleum products, and radioactive materials. Addressing these contaminated sites is imperative, but it must be done with a commitment to sustainability and eco-friendliness. Here are key reasons highlighting the need for sustainable and eco-friendly approaches to remediate contaminated sites:

- **Protecting Ecosystem Health:** Contaminated sites often disrupt local ecosystems, harming plants, animals, and microorganisms. Sustainable remediation approaches prioritize ecosystem health, aiming to restore the natural balance and biodiversity of affected areas.
- **Minimizing Environmental Footprint:** Traditional remediation methods often involve energy-intensive processes, such as excavation and incineration, which can exacerbate environmental damage. Sustainable methods, like phytoremediation and bioremediation, typically have lower energy requirements and reduce the overall environmental footprint.
- **Preventing Secondary Pollution:** Unsustainable remediation practices can inadvertently generate secondary pollution. For instance, incineration of contaminated materials can release toxic byproducts into the atmosphere. Sustainable methods focus on minimizing or eliminating such risks.
- **Long-Term Effectiveness:** Sustainable approaches tend to offer long-term solutions. By improving soil quality, reducing contaminants, and restoring ecosystems, these methods help prevent future contamination and ensure the lasting health of the environment.
- **Community Well-Being:** Contaminated sites often exist near communities, posing health risks to residents. Sustainable remediation not only addresses contamination but also considers the well-being of nearby communities, reducing health hazards and promoting a healthier living environment.
- **Compliance with Regulations:** Many regions and nations have stringent environmental regulations that require the responsible management and remediation of contaminated sites.

 ISBN: 978-81-965655-8-9

Sustainable approaches help organizations and governments comply with these regulations effectively.

- **Resource Conservation:** Unsustainable remediation can deplete valuable resources, such as freshwater for washing or treating contaminated soil. Sustainable methods often use renewable resources, like plants, to achieve remediation goals.
- **Promotion of Green Technologies:** Sustainable remediation promotes the development and adoption of green technologies and practices, fostering innovation in the field of environmental management.
- **Public Perception and Acceptance:** Communities and stakeholders often prefer eco-friendly and sustainable remediation methods. Adopting such approaches can lead to better public support and cooperation.
- **Resilience to Climate Change:** As climate change intensifies, sustainable remediation methods can help build resilience in ecosystems and communities. For example, restoring wetlands can mitigate flooding and act as carbon sinks.
- **Economic Viability:** Sustainable remediation can offer economic benefits by reducing the costs associated with energy, transportation, and disposal of contaminated materials.
- **Global Responsibility:** As global citizens, we have a shared responsibility to protect the environment for future generations. Sustainable remediation reflects our commitment to preserving the planet's health and resources.

Role of Organic Manure in Enhancing Phytoremediation Effectiveness

Phytoremediation, as discussed earlier, is a promising and eco-friendly approach to mitigate environmental pollution. It harnesses the unique abilities of plants to absorb, accumulate, or transform contaminants from soil, water, or air. While phytoremediation is effective on its own, the incorporation of organic manure can significantly enhance its efficiency and overall success. Here's a preview of how organic manure plays a crucial role in boosting the effectiveness of phytoremediation:

- **Improved Nutrient Availability:** Organic manure is rich in nutrients, such as nitrogen, phosphorus, and potassium, which are essential for plant growth. When added to contaminated soils, organic manure enhances the nutrient content, promoting healthier plant growth. This, in turn, increases the capacity of plants to absorb and translocate pollutants from the environment.
- **Enhanced Soil Structure:** Organic manure contributes to improved soil structure by enhancing its texture and water-holding capacity. This results in better aeration and root penetration, allowing plants to establish more robust root systems. Stronger roots enable greater pollutant uptake and help plants thrive in contaminated environments.
- **Stimulated Microbial Activity:** Organic manure contains organic matter that serves as a substrate for beneficial soil microorganisms. These microorganisms play a vital role in breaking down contaminants and making them more accessible to plants. The presence of organic manure fosters a healthy microbial community, accelerating the degradation of pollutants.
- **pH Buffering:** Some contaminants can alter soil pH levels, which can affect plant health. Organic manure acts as a pH buffer, helping to maintain a stable and favorable pH range for plant growth. This ensures that plants remain healthy and capable of efficient phytoremediation.

 ISBN: 978-81-965655-8-9

- **Increased Tolerance:** Organic manure can enhance the stress tolerance of plants. Contaminated environments often subject plants to various stress factors, including high levels of pollutants. Organic manure provides plants with the necessary nutrients and compounds to withstand these stressors, allowing them to continue their remediation efforts.
- **Bioaugmentation:** The introduction of specific microorganisms from organic manure can aid in the biodegradation of certain contaminants. This technique, known as bioaugmentation, can be especially effective in enhancing phytoremediation when applied in conjunction with organic manure.
- **Reduced Leaching and Runoff:** Organic manure helps bind pollutants in the soil, reducing the risk of leaching into groundwater or runoff into nearby water bodies. This containment minimizes the spread of contaminants and their potential impact on surrounding ecosystems.
- **Sustainable Approach:** The use of organic manure aligns with sustainable and environmentally friendly practices. It reduces the reliance on synthetic chemicals and promotes the recycling of organic waste materials, contributing to a more circular and sustainable approach to pollution management.

Phytoremediation process:

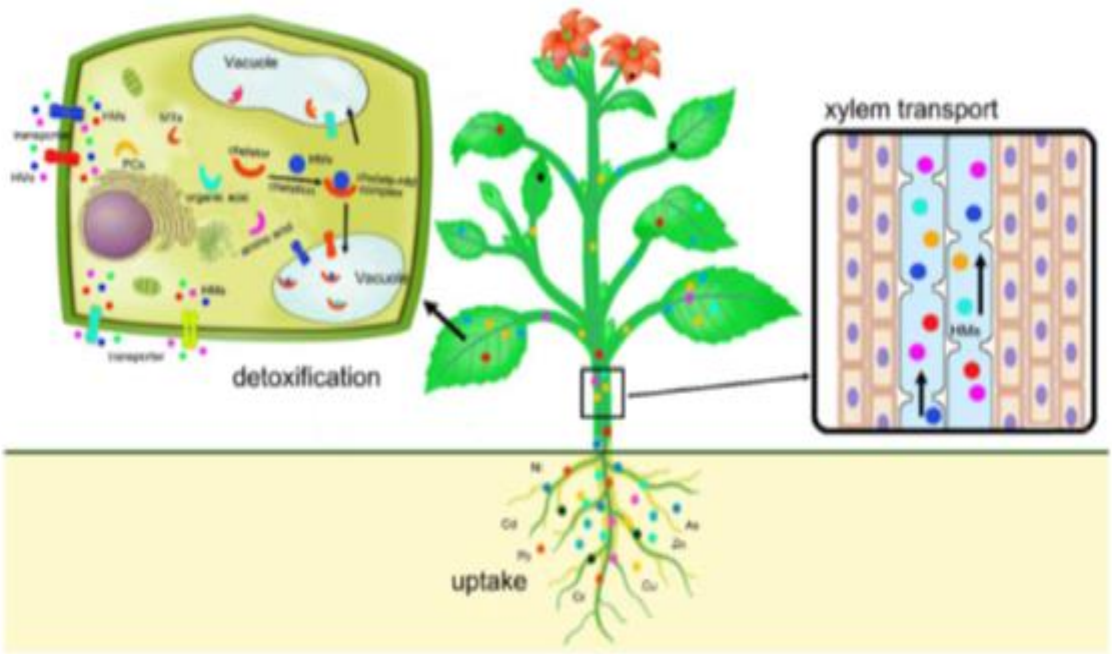


Fig: Schematic diagram shows the uptake, translocation and sequestration of heavy metals in plants

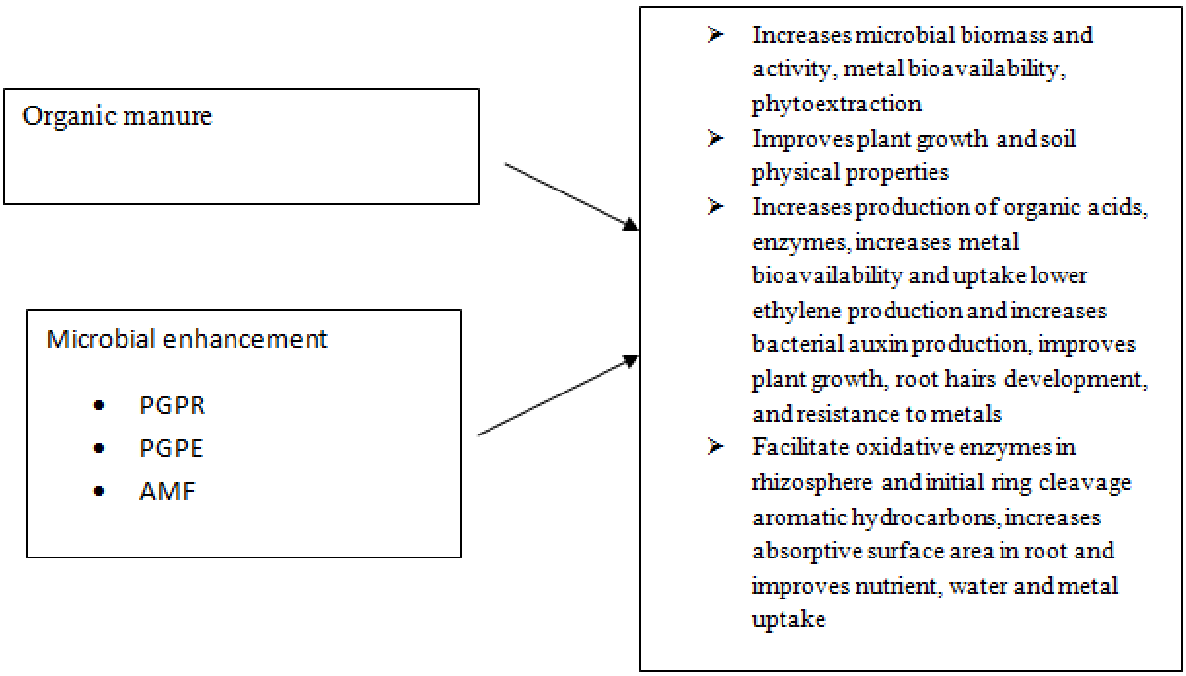
There are series of processes involved in accumulation of heavy metal in plants, including heavy metal mobilization, root uptake, xylem loading, root-to-shoot transport, cellular compartmentation, and sequestration. Heavy metal mostly exists as insoluble form in soil, which is not bioavailable to plants. Plants can increase their bioavailability by releasing a variety of root exudates, which can change rhizosphere pH and increase heavy metal solubility (Dalvi and Bhalerao, 2013). The bioavailable metal is sorbed at the root surface and moves across the cellular membrane into the root cells. The uptake of heavy metals into roots occurs mainly through two pathways, apoplastic pathway (passive diffusion) and symplastic pathway

 ISBN: 978-81-965655-8-9

(active transport against electrochemical potential gradients and concentration across the plasma membrane). The common uptake of heavy metals via symplastic pathway is an energydependent process mediated by metal ion carriers or complexing agents (Peer et al., 2005). After entering into root cells, heavy metal ions can form complexes with various chelators, such as organic acids. These formed complexes including carbonate, sulfate, and phosphate precipitate, are then immobilized in the extracellular space (apoplastic cellular walls) or intracellular spaces (symplastic compartments, such as vacuoles) (Ali et al., 2013). The metal ions sequestered inside the vacuoles may transport into the stele and enter into the xylem stream via the root symplasm (Thakur et al., 2016) and subsequently are translocated to the shoots through xylem vessels. Through apoplast or symplast, they are transported and distributed in leaves, where the ions are sequestered in extracellular compartments (cell walls) or plant vacuole, thereby preventing accumulation of free metal ions in cytosol (Tong et al., 2004).

There are a number of phytoremediation strategies that are applicable for the remediation of heavy metal-contaminated soils, including (i) phytostabilization—using plants to reduce heavy metal bioavailability in soil, (ii) phytoextraction—using plants to extract and remove heavy metals from soil, (iii) phytovolatilization—using plants to absorb heavy metal from soil and release into the atmosphere as volatile compounds, and (iv) phytofiltration—using hydroponically cultured plants to absorb or adsorb heavy metal ions from groundwater and aqueous waste (Salt et al., 1995; Ernst, 2005;Marques et al., 2009). Other phytoremediation strategies include phytodegradation and rhizodegradation, which are used for breakdown of organic pollutants.

Mechanism of organic manure impact on phytoremediation**:**



 ISBN: 978-81-965655-8-9

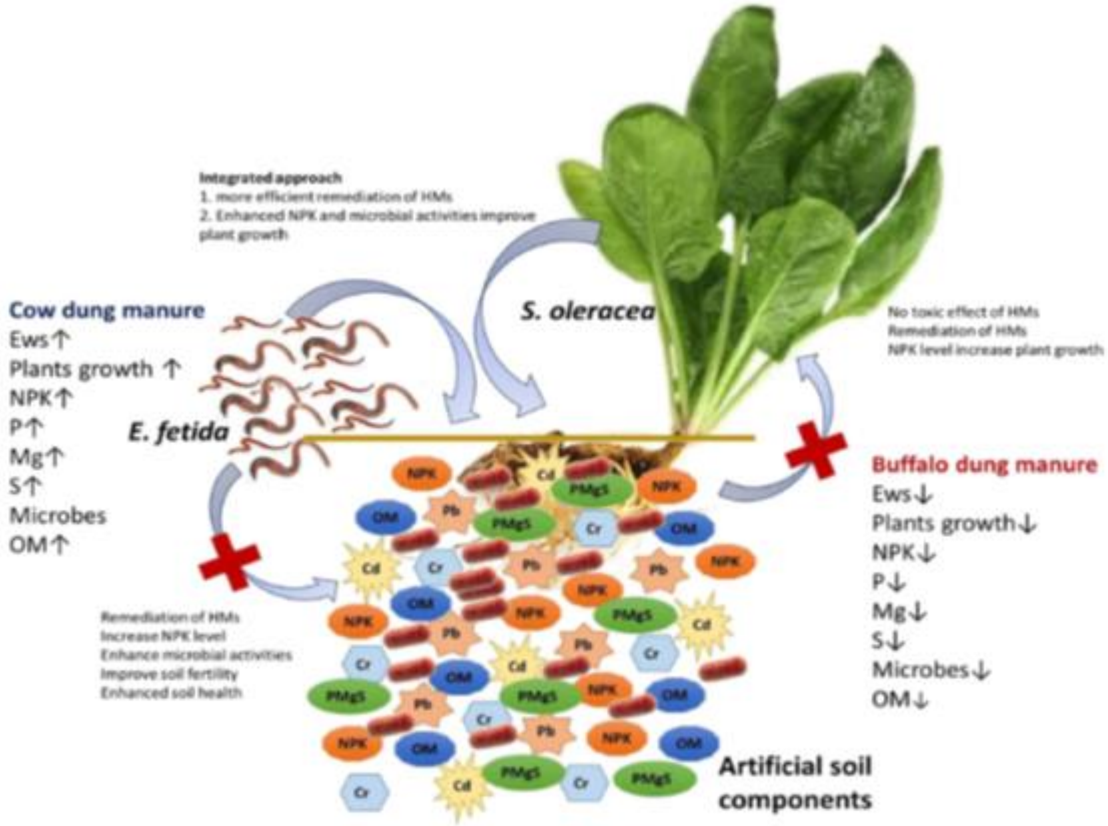


Fig: Impact of organic manure on phytoremediation

Impact:

Nutrient Supply:

Biochemical Mechanism: Organic manure is a source of essential nutrients such as nitrogen (N), phosphorus (P), and potassium (K), along with various micronutrients. These nutrients are vital for plant growth and metabolism.

- Physiological Impact: Adequate nutrient availability from organic manure improves plant vigor and vitality. Nutrient-rich plants have a stronger defense against stress, including exposure to contaminants. This enhanced growth allows plants to establish a larger root system, increasing their overall pollutant uptake capacity.

Improved Soil Structure:

Biochemical Mechanism: Organic manure contains organic matter that improves soil structure by binding soil particles together and enhancing soil aggregation.

- Physiological Impact: Enhanced soil structure promotes root development and aeration. Plants with well-developed root systems can access a larger volume of soil, increasing their contact with contaminants. Better aeration improves root health, ensuring that the plant remains vigorous and capable of pollutant uptake.

Microbial Activity Stimulation:

Biochemical Mechanism: Organic manure provides a substrate for beneficial soil microorganisms. These microorganisms feed on the organic matter, breaking it down into simpler compounds.

- Physiological Impact: Microbial activity in the rhizosphere, the area around plant roots, can be stimulated by organic manure. This microbial activity plays a crucial role in contaminant transformation and degradation. Microbes can convert certain contaminants into less toxic forms or immobilize them, reducing their availability to plants.

pH Buffering:
Biochemical Mechanism: Organic matter in manure acts as a buffer, helping to maintain a stable pH in the soil.

- Physiological Impact: Contaminated soils often exhibit pH imbalances that can affect plant health and contaminant availability. Organic manure helps keep the pH within a suitable range for plant growth, ensuring that plants remain healthy and capable of efficient phytoremediation.

Bioavailability of Contaminants:
Biochemical Mechanism: Organic matter in manure can complex with certain contaminants, reducing their solubility and bioavailability.

- Physiological Impact: Lower bioavailability of contaminants means that plants are exposed to lower levels of toxic substances. This can enhance their tolerance to pollutants, allowing them to grow and function effectively in contaminated environments.

Reduced Oxidative Stress:
Biochemical Mechanism: Organic matter contains antioxidants and compounds that can help reduce oxidative stress in plants caused by exposure to contaminants.

- Physiological Impact: Lower oxidative stress levels in plants lead to reduced damage to cellular structures and better overall health. This, in turn, supports a plant's ability to continue growing and remediating contaminants.

Organic matter is an important sorbent of heavy metals in soils and sediments. Decomposition of organic amend- ments leads to changes in soil chemical properties, which affects the soil metal mineralization, fractionation, its solubility and distribution (Premi et al., 2013). Organic matter released into the soil solution results in the subsequent release of heavy metals associated with that organic matter. The interactions of humic acid-metal with heavy accelerate aggregation which in turn also increases solubilization of heavy metal and also the extractable fraction. Organic matter influence the behavior of the heavy metals in the soil by: releasing heavy metals associated with the organic matter, extracting or mobilizing heavy metals from the complexes and improving soil microbial populations which affect heavy metal mobility and availability to the plant through release of chelating agents, acidification, phosphate solu- bilization and redox changes. Humic acid–metal interactions provoke flocculation that increases solubilization and extractable fraction of heavy metals. Thus, humic acid-rich materials can be a useful amendment for soil remediation involving phytoextraction. Heavy metals can be chelated by organic acids such as citric and malic acid, by metal-binding proteins such as metallothioneins. A co-solubilization of heavy metals such as Cu, Ni, and Pb, and the likely formation of organo-metal complexes, increases the potential for their migration and bioavailability. Phytoextraction requires uptake of heavy metals into harvestable biomass. The addition of the organic amendments results in higher plant biomass pro- duction. The efficiency of phytoextraction improves with higher biomass yield of the accumulator species as well as with higher concentration of the heavy metal in the har- vestable biomass. Organic supplements improve microbial populations which affect heavy metal mobility and availability to the plant through release of chelating agents, acidification, phosphate solubilization and redox changes. Hence, they have a good potential to enhance phytoremediation processes (Jing et al., 2007). FYM and vermicompost are also effective in improving root and shoots dry matter of mus- tard

 ISBN: 978-81-965655-8-9

in metal contaminated soil through solubilization and increases metal uptake (Jing et al, 2007 and Singh et al, 2007).

Some potential areas for future research and innovation:

I. **Manure Formulations:** Develop specialized manure formulations tailored for different contaminants and plant species. This could involve adjusting the nutrient content, microbial populations, and organic matter composition to maximize pollutant uptake and remediation efficiency.

II. **Plant Selection and Engineering**: Continue researching and selecting plant species with high phytoremediation potential and engineering them for improved pollutant uptake and tolerance. Genetic modifications can enhance plants' ability to thrive in contaminated environments.

III. **Manure-Derived Compounds:** Study the role of specific compounds present in organic manure (e.g., humic acids, enzymes) in facilitating contaminant sequestration, transformation, or plant uptake. This can lead to the development of targeted amendments.

IV. **Manure Quality Standards:** Establish quality standards for organic manure used in phytoremediation to ensure consistency in nutrient content, microbial activity, and contaminant-free sources.

V. **Long-Term Monitoring:** Conduct long-term field studies to assess the sustained effectiveness of organic manure-enhanced phytoremediation and the potential for contaminant re-release over time.

VI. **Ecosystem Services:** Investigate the broader ecosystem services provided by organic manure-enhanced phytoremediation, including carbon sequestration, improved soil health, and enhanced biodiversity.

VII. **Economic Viability and Scaling Up:** Analyze the economic feasibility of large-scale organic manure-enhanced phytoremediation projects and explore strategies for scaling up this approach for practical and cost-effective remediation.

VIII. **Regulatory Frameworks:** Collaborate with policymakers and regulatory agencies to develop guidelines and regulations for the safe and responsible use of organic manure in phytoremediation projects.

IX. **Stakeholder Engagement:** Involve local communities and stakeholders in the planning and implementation of phytoremediation projects that incorporate organic manure. Consider their concerns, preferences, and traditional knowledge.

X. **Climate Resilience:** Assess the impact of climate change on organic manure-enhanced phytoremediation and develop strategies to adapt to changing environmental conditions.

CONCLUSION

In conclusion, phytoremediation, the use of plants to mitigate environmental contamination, holds immense promise for sustainable and eco-friendly remediation efforts. When combined with organic manure, it becomes an even more potent tool for restoring contaminated ecosystems and improving soil, water, and air quality. Phytoremediation operates on a foundation of biochemical and physiological mechanisms that enable plants to absorb, accumulate, and detoxify contaminants. Organic manure enriches these processes by providing essential nutrients, enhancing soil structure, stimulating microbial activity, buffering pH, and reducing oxidative stress. This synergy between organic manure and phytoremediation not only improves the effectiveness of pollutant removal but also promotes the long-term health and resilience of ecosystems. While significant progress has been made in the field of phytoremediation, there are still research gaps and challenges that warrant further exploration. Investigating the use of organic manure in combination with phytoremediation opens up exciting avenues for future research and innovation. These endeavors may lead to more efficient and sustainable strategies for remediating contaminated sites, addressing multi-contaminant scenarios, and adapting to evolving environmental conditions. Ultimately, the integration of organic manure and phytoremediation represents a holistic and environmentally responsible approach to pollution management. By harnessing the power of nature, we can work towards cleaner, healthier environments, protect biodiversity, and contribute to a more sustainable future for our planet.

REFERENCE

- Premi OP, Kandpal BK, Rathore SS, Shekhawat K, Chauhan JS (2013) Green manuring, mustard residues recycling and fertilizer application affects productivity and sustainability of Indian mustard (Brassica juncea L.) in Indian semi arid tropics. Ind Crops Prod 41:423–429
- Jing Y, He Z, Yang X (2007) Role of soil rhizobacteria in phytoremediation of heavy metal contaminated soils. J Zhejiang Univ Sci B 8:192–207
- Singh G, Brar MS, Malhi SS (2007) Decontamination of chromium by farm yard manure application in spinach grown in two texturally different Cr-contaminated soils. J Plant Nutr 30:289–308
- Dalvi, A. A., and Bhalerao, S. A. (2013). Response of plants towards heavy metal toxicity: an overview of avoidance, tolerance and uptake mechanism. Ann. Plant Sci. 2, 362–368.
- Peer, W. A., Baxter, I. R., Richards, E. L., Freeman, J. L., and Murphy, A. S. (2005). "Phytoremediation and hyperaccumulator plants," in Molecular Biology of Metal Homeostasis and Detoxification, eds M. J. Tamas and E. Martinoia (Berlin: Springer), 299–340. doi: 10.1007/4735_100
- Ali, H., Khan, E., and Sajad, M. A. (2013). Phytoremediation of heavy metals-concepts and applications. Chemosphere 91, 869–881. doi: 10.1016/j. chemosphere.2013.01.075
- Thakur, S., Singh, L., Wahid, Z. A., Siddiqui, M. F., Atnaw, S. M., and Din, M. F. M. (2016). Plant-driven removal of heavy metals from soil: uptake, translocation, tolerance mechanism, challenges, and future perspectives. Environ. Monit. Assess. 188:206. doi: 10.1007/s10661-016-5211-9
- Tong, Y.-P., Kneer, R., and Zhu, Y.-G. (2004). Vacuolar compartmentalization: a second-generation approach to engineering plants for phytoremediation. Trends Plant Sci. 9, 7–9. doi: 10.1016/j.tplants.2003.11.009
- Salt, D. E., Blaylock, M., Kumar, N. P. B. A., Dushenkov, V., Ensley, B. D., Chet, I., et al. (1995). Phytoremediation: a novel strategy for the removal of toxic metals from the environment using plants. Nat. Biotechnol. 13, 468–474. doi: 10.1038/nbt0595-468
- Ernst, W. H. (2005). Phytoextraction of mine wastes–options and impossibilities. Chem. Erde Geochem. 65, 29–42. doi: 10.1016/j.chemer.2005.06.001
- Marques, A. P., Rangel, A. O., and Castro, P. M. (2009). Remediation of heavy metal contaminated soils: phytoremediation as a potentially promising clean-up technology. Crit. Rev. Env. Sci. Technol. 39, 622–654. doi: 10.1080/ 10643380701798272.

 ISBN: 978-81-965655-8-9

CHAPTER 7

METAGENOMICS: INSIGHTS INTO MICROBIAL COMMUNITIES FOR CROP ECOSYSTEMS

[1*]Debasmita Nath, [2]Dimpi Dutta, [3]Manish Kumar Maurya, [4]Kishor Jyoti Bhuyan
[1.3.4] MSc. Scholar, Assam Agricultural University
[2] Ph.D. Scholar, Assam Agricultural University

INTRODUCTION

The presence of microbial communities is crucial within the biosphere, as they serve a vital function in preserving soil and crop well-being, thus upholding the principles of sustainable agriculture. Microbes also has an essential role in the industrial sector as they produce metabolites in the form of enzymes (Jansson and Hofmockel, 2018). Majority of the microorganisms present in many environmental conditions are not culturable and hence not available for any research programme (Amann et al., 1995). Most of the microbial species cannot be identified and cultured. However, data of less than one percent of the total microorganism in natural environment are obtained through culturing in the growth media (Papudeshi et al., 2017).

History of Microbial Study

The first report of microbes was provided by Leewenhoek in 1676 (Schierbeek, 1959) and later on, Robert Koch cultured microorganisms in solid media in 1888 to isolate, enumerate and visualize them (Blevins and Bronze, 2010). This isolation procedure helped the researcher to most efficiently study the physiology of the microbes. In 1931, Winogradsky revolutionized microbiology by introducing the concept of “microbial ecology” which means the study of microbes and their associated environment (Ackert, 2012). During 1977, Carl Woese suggested the utilization of ribosomal RNA genes as genetic markers for taxonomic classification (Woese and Fox, 1977). These concepts combined with automated DNA sequencing technique of Fred Sanger upgraded the study and categorization of microbes. The Sanger DNA-sequencing technique can only be applicable for individual DNA sequence and therefore data obtained from this method will be insignificant when complex natural samples are to be processed (Sanger et al., 1977). Different methods were used to access the diversity of microbial population due to the constraints associated with culturing. To conquer the difficulties related to culturing, various DNA based molecular techniques were developed. The advancement in molecular technique set the foundation of omics technology called metagenomics, which helped in the study of diversity profile of microorganisms (Alawiye and Babalola, 2009).

Metagenomics

Metagenomics refers to the study of complex genome sequence of microbes without culturing them in the growth media (Wooley and Yuzhen, 2009). Metagenomics is made up of two letters ‘meta’ means ‘vast’ and ‘genomics’ means the study of ‘genome’. The metagenomic term was first defined by Handelsman et al. (1998) as a “microbial genome study”. The other terminology for metagenomics is community genomics, environmental genomics and population genomics (Neelakanta and Sultana, 2013). Metagenomics is the culture-independent methodology used to analyze the genetic material isolated from the microbial sample (Ghosh et al., 2018). This method can be able to overcome the difficulties of culture-based method. In this method, DNA is isolated from the environmental sample without prior culturing in the laboratory and can be used to figure out the heterogeneity of microorganisms (Neelakanta and Sultana, 2013). The major limitation of this approach is the contamination of purified form of DNA with polyphenolic compounds, which are copurified with the DNA. These compounds hinder the enzymatic modifications of the DNA and are very difficult to eliminate (Tsai and Olson, 1992).

 ISBN: 978-81-965655-8-9

Additionally, metagenomic studies not only help in exploring the beneficial genes from nature, but also provides information about the inter-relationships between microbial populations in the biogeochemical cycle in the earth. The word metagenomics brings revolution in the world of microbiological studies, thus allowing researchers to explore new biochemical compounds in nature and utilized in the biotechnological research.

Metagenomic approaches for recovering novel biomolecules from environmental samples are categorized into two main techniques: functional-based and sequence-based methods (Thomas et al., 2012). The integration of both sequence-based and functional metagenomics data enables a more comprehensive examination of microbial community structure and function. The field of metagenomics has expanded rapidly, driven by continuous advancements in DNA sequencing technologies and significant cost reductions. Sequence-based metagenomics has yielded valuable insights into the composition, arrangement, and functional potential of microbial communities. Functional metagenomics has also proven highly effective in identifying novel genes, proteins, and secondary metabolites, including antibiotics, with significant applications in industrial, biotechnological, pharmaceutical, and medical sectors

General procedure of metagenomics

As the significance of metagenomics continues to grow, there is a corresponding increase in methodological knowledge and expertise to steer its future advancements. An outline of the methodological components of metagenomics is provided in Figure 1, encompassing the fundamental steps as follows:

1. Experimental Design and Sampling
2. Extraction of DNA
3. Amplification of DNA
4. Sequencing of DNA
5. Bioinformatics analysis

1. Experimental Design and Sampling

It is strongly advised to engage in thorough preparation and select the right experimental design when conducting metagenomic studies. This is essential to minimize resource westage and save valuable time (Knight et al., 2012; Thomas et al., 2012). Sampling plays a crucial role in metagenomics, as it determines both the quantity and quality of the ultimate results. It encompasses the process of collecting samples, followed by their proper storage and transportation to the laboratory for subsequent analysis. In metagenomic research, samples generally fall into two categories: environmental and non-environmental. Environmental samples can be characterized as having both heterogeneity and homogeneity (Felczykowska et al., 2015). They encompass a wide range of sources such as water bodies, soils, sediments, animal excreta, and industrial effluents, including extreme ecosystems like acidic mines, hot springs, and deserts. Additionally, it is essential to keep the storage duration as brief as feasible and maintain optimal temperatures of either -20°C or -80°C to minimize the loss of microbial communities within the samples.

2. Extraction of DNA

DNA extraction is a critical step in the metagenome analysis process, as it significantly impacts the success of subsequent stages. Felczykowska et al. (2015) emphasize the importance of obtaining DNA fragments within the range of 600 base pairs (bp) to 25 kilobase pairs (kbp) for effective metagenomic analysis. Inadequate results in DNA extraction can render the sample unsuitable for further metagenomic analysis. Characteristics of the optimal DNA extraction techniques:

 ISBN: 978-81-965655-8-9

a) Representative of Extracted DNA:

The DNA obtained from the sample genome should accurately reflect the genetic composition of the entire microbial community.

b) Ease of Replicability:

The method should be straightforward to reproduce, ensuring consistent and accurate results, and should be reasonably fast.

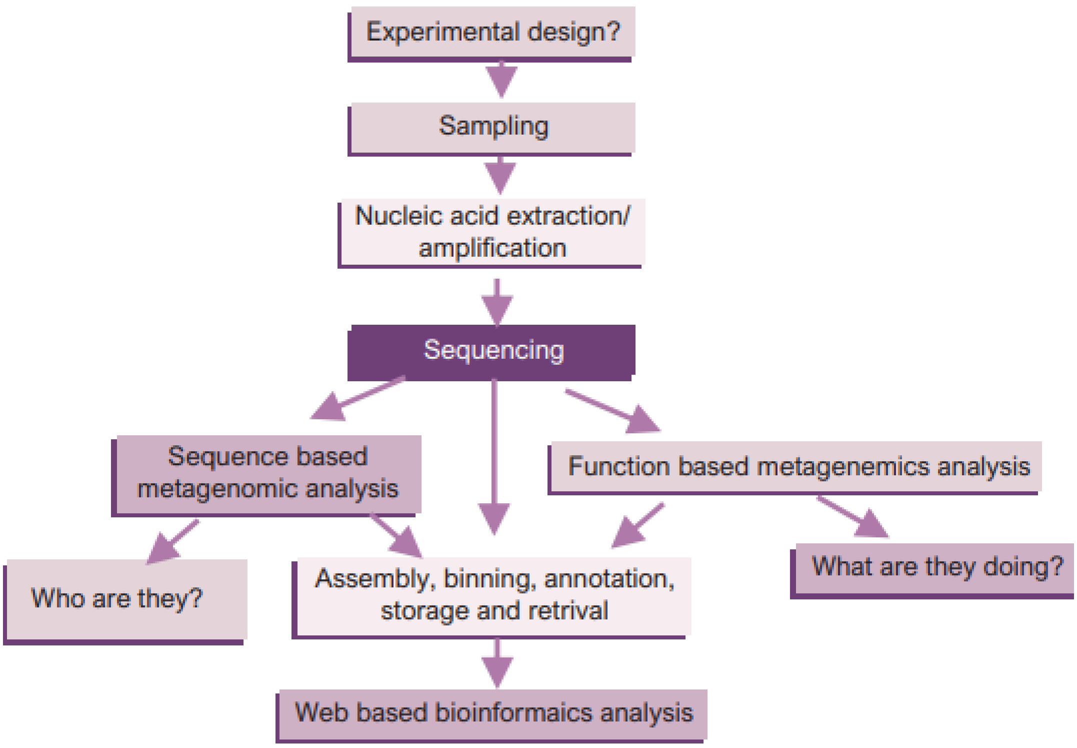


Figure 1: Procedures of metagenomics

Source: Edet et al., 2017

c) Maintaining nucleic acid integrity:

The physical processes used in the extraction should not harm or degrade the nucleic acid, which is crucial to maintain its integrity.

d) High production of nucleic acid:

The method should produce a substantial amount of DNA, ensuring there's enough material for subsequent analyses.

e) Minimization of Exogenous Contaminants:

The method should minimize the presence of external contaminants like clay, humic acid, proteins, and metals, keeping them at low levels (Felczykowska et al., 2015; Macrae, 2000).

f) Prevention of Excessive Fragmentation:

It's important to prevent the genetic material from breaking apart excessively during the extraction process to maintain its usability (Felczykowska et al., 2015).

 ISBN: 978-81-965655-8-9

3. Amplification of DNA

Polymerase Chain Reaction (PCR) is a versatile and robust technique used to exponentially amplify a specified target DNA sequence under controlled laboratory conditions. It is known for its adaptability, reliability, practicality, and speed. The fundamental PCR steps involve denaturation, annealing, and extension (Joshi and Deshpande, 2010).

Ribosomes play a crucial role in protein synthesis and are highly conserved, often serving as a reference point in taxonomical classification. In prokaryotic microorganisms, approximately 65% of their composition is ribosomal RNA (rRNA), while the remaining 35% is made up of proteins. Each prokaryotic ribosome consists of two subunits: a large subunit (LSU) referred to as the 50S, which contains two rRNA molecules (5S and 23S), and a small subunit (SSU) known as the 30S, which contains a single rRNA molecule (16S) (Ramazzotti and Bacci, 2018). The 16S rRNA gene is commonly used as a standard for taxonomy profiling analysis in prokaryotic organisms due to several compelling reasons (Singer et al., 2016). Firstly, this gene is found in all prokaryotic organisms, making it a universal marker for taxonomic classification. Secondly, it is highly resistant to lateral gene transfer, a process where genes are transferred horizontally between different organisms, which can complicate taxonomy. Lastly, the conservative structure of the ribosomal protein associated with the 16S rRNA gene makes its sequence highly stable over evolutionary time. In summary, the 16S rRNA gene is an ideal choice for taxonomy profiling because of its ubiquity, resistance to lateral gene transfer, and sequence stability (Ramazzotti and Bacci, 2018).

4. Sequencing of DNA

Sanger sequencing is widely regarded as the reference standard for DNA sequencing because of various advantages, including its lower error rate, ability to handle large insert sizes, and accuracy. Nevertheless, its primary drawbacks include its relatively high sequencing costs, inability to process multiple samples concurrently, and the requirement for larger initial DNA quantities (Thomas et al., 2012). To overcome these challenges, next-generation sequencing (NGS) has provided a powerful platform for directly obtaining DNA sequence information from environmental samples (Sogin et al., 2006).

5. Bioinformatics Analysis

With the proliferation of data in the field of metagenomics, bioinformatics tools and databases have made significant advancements. The various stages involved in the computational analysis of metagenomic data are outlined below:

a) Assembly

Assembly is the process of regenerating short metagenomic reads to create longer sequences known as contigs (Papudeshi et al., 2017). There are two fundamental approaches to assembly: reference-based and de novo. Reference-based assembly is employed when working with metagenomic datasets that have access to genomes closely related to the target community. Software tools like Newbler or MIRA can be utilized for reference-based assembly (Chevreux et al., 1999). These software packages employ memory-efficient and rapid algorithms, allowing them to run on standard laptops in just a few hours. However, discrepancies between the sample and the genomic sequence, such as the presence of large inserts, deleted regions, or polymorphic sequences, can lead to fragmented assemblies or leave divergent regions uncovered. De novo assembly is initiated without any prior information about the sequence order. This approach is computationally demanding, requiring more powerful hardware compared to reference-based assembly. De novo assembly tools primarily rely on de Bruijn graphs and are capable of handling large datasets effectively. Classic de Bruijn assemblers include Velvet (Zerbino et al., 2008) and SOAP (Li et al., 2008).

 ISBN: 978-81-965655-8-9

b) Binning

Binning is the process of grouping sequences, typically contigs, that have been generated during the assembly process into clusters that represent specific biological taxa (Roumpeka et al., 2017). This step comes after assembling raw sequence reads into contigs (Strous et al., 2012). There are various software tools available for binning analysis, including MetaWatt (Strous et al., 2012) and CONCOCT (Alneberg et al., 2014).

c) Annotation

Annotation in the context of metagenomic sequence data involves the assignment of functions to the genes under investigation. There are two primary approaches for annotation: functional annotation and feature prediction (Thomas et al., 2012). The annotation process typically consists of two stages:

i. Prediction of Features: In this stage, the primary goal is to identify and recognize the features of interest, such as genes, within the metagenomic sequence data.

ii. Functional Annotation: After recognizing these features, the next step is to assign putative functions to the identified genes or elements.

The choice of annotation pathway depends on the objectives of the study and the nature of the data being analyzed:

Reconstructed Genomes and Large Contigs: If the study's objective is to reconstruct genomes or work with large contigs (contigs of 30,000 base pairs or longer), it is advisable to use existing pipelines designed for genome annotation. Examples of such pipelines include IMG (Integrated Microbial Genomes) (Markowitz et al., 2009) and RAST (Rapid Annotation using Subsystem Technology) (Aziz et al., 2008). These tools are optimized for handling longer and more complete sequences.

Entire Community Analysis with Short Contigs or Reads: On the other hand, if the objective is to analyze the entire microbial community using short contigs or unassembled reads, specialized tools developed for metagenomic analyses tend to perform better than traditional genome annotation tools. These metagenomic analysis tools are designed to handle the complexities of mixed microbial populations and often provide more accurate functional annotations for short sequences.

d) Statistical analysis

Initially, metagenomics sequencing was limited due to its high costs. As a result, some early findings were not replicated. Moreover, researchers often focused on specific species or areas of interest within metagenomics. Over time, the costs of metagenomic sequencing have decreased significantly, and the scientific community has come to appreciate the ability of metagenomics to provide insights into microbial ecology. The importance of appropriate experimental designs and statistical analysis in the field of metagenomics, especially considering the reduction in sequencing costs and the growing recognition of metagenomics' potential to address key problems in microbial ecology.

i. Primer-E Package: This package, developed by Clarke in 1993, provides a range of statistical analyses, including the Analysis of Similarities (ANOSIM) and the generation of multidimensional scaling (MDS) plots. ANOSIM helps assess similarities between different samples, while MDS plots visualize these similarities in a multidimensional space.

ii. Metastats: Metastats is a web-based tool, introduced by White and colleagues in 2009, that incorporates multivariate statistics. It can be used to analyze and compare multiple variables or features within metagenomic datasets.

 ISBN: 978-81-965655-8-9

iii. R Statistical Package: The R statistical package is a widely used open-source tool in bioinformatics and metagenomics. The passage mentions "Shotgun Functionalize R," which is an R package that facilitates various statistical methods for evaluating functional differences among samples. This suggests that researchers can use R to perform in-depth statistical analyses of metagenomic data, including assessments of functional diversity.

CONCLUSION

It is anticipated that metagenome technologies will likely uncover a greater number of novel genes compared to traditional methods focused on sequencing individual microbes. However, the current challenge extends beyond simply accumulating these genetic sequences; it revolves around comprehending the functions of these newly discovered genes and proteins within microbial communities and their roles in global ecological cycles. Metagenomics offers the advantage of rapidly identifying new genes, proteins, and even entire genomes from non-culturable organisms with greater accuracy and efficiency than classical microbiology or molecular techniques. Nevertheless, there is no universal tools capable of addressing all the inquiries posed by metagenomics. The absence of standardized methods diminishes reproducibility and hampers comparisons between similar projects, making metagenomics a case study. It is crucial to recognize that each metagenomic project has unique requirements depending on its experimental design. Therefore, the choice of sequencing technology and computational tools must be made thoughtfully. A metagenome typically represents a snapshot of a microbial community at a specific moment when its DNA is collected. To gain a comprehensive understanding of population dynamics, it is advisable to employ a combination of different techniques, including culture methods, DNA and RNA analysis, protein studies, and if feasible, metabolic profiling.

Consequently, the integration of various scientific disciplines into microbiology, such as molecular biology, genetics, bioinformatics, and statistics, is essential for exploring questions related to microbial diversity and ecology in greater depth. While the development of additional bioinformatics tools for metagenomic analysis is necessary, the expertise of scientists in using these tools and interpreting their results is pivotal in reaching meaningful biological conclusions. With sequencing platforms generating vast amounts of data at a minimal cost, the necessity for bioinformatics proficiency has become even more apparent. Ultimately, the imminent challenge will center on managing and analyzing the overwhelming volume of data and devising more integrative approaches to reflect the rich biodiversity present in our world. Metagenomics is a rapidly evolving field with the potential to revolutionize our understanding of the environment and its microbial inhabitants. As it continues to develop and integrate with other technologies, it will play a critical role in unraveling the genetic complexities of diverse microbial communities.

REFERENCE

- Ackert, L. (2012). Sergei Vinogradskii and the Cycle of Life: From the Thermodynamics of Life to Ecological Microbiology, 1850-1950.
- Alawiye, T.T. and Babalola, O.O. (2019). Bacterial diversity and community structure in typical plant rhizosphere. *Diversity*, 11(10):179.
- Alneberg, J., Bjarnason, B.S., De Bruijn, I., Schirmer, M., Quick, J., Ijaz, U.Z., Lahti, L., Loman, N.J., Andersson, A.F. and Quince, C. (2014). Binning metagenomic contigs by coverage and composition. Nat Methods, 11:1144–1146.
- Alves LDF, Westmann CA, Lovate GL, Marcelino G, De Siqueira V, Borelli TC, Guazzaroni M (2018) Metagenomic Approaches for understanding new concepts in microbial science. Int J Genomics 2018:1–15

- Amann, R.I., Ludwig, W. and Schleifer, K.H. (1995). Phylogenetic identification and in situ detection of individual microbial cells without cultivation. *Microbiological reviews.59(1)*:143-69.
- Aziz, R.K., Bartels, D., Best, A.A., DeJongh, M., Disz, T., Edwards, R.A., Formsma, K., Gerdes, S., Glass, E.M., Kubal, M. and Meyer, F. (2008). The RAST Server: rapid annotations using subsystems technology. BMC genomics, 9(1):1- 15.
- Blevins, S. M. and Bronze, M. S. (2010). Robert Koch and the "golden age" of bacteriology. Inter. J. Infect. Diseases. 14:744-751.
- Chevreux, B., Wetter, T. and Suhai, S. (1999). Genome sequence assembly using trace signals and additional sequence information. In German conference on bioinformatics 99 (1): 45-56.
- Edet, U.O., Antai, S.P., Brooks, A.A., Asitok, A.D., Enya, O. and Japhet, F.H. (2017). An overview of cultural, molecular and metagenomic techniques in description of microbial diversity. Journal of Advances in Microbiology:1-19.
- Felczykowska, A., Krajewska, A., Zielińska, S. and Łoś, J.M. 2015. Sampling, metadata and DNA extraction-important steps in metagenomic studies. Acta Biochimica Polonica, 62(1).
- Ghosh A, Mehta A, Khan AM (2018) Metagenomic analysis and its applications. In: Encyclopedia of Bioinformatics and Computational Biology, 1st edn. Elsevier Inc, Amsterdam, pp 1–10 https://doi.org/10.1016/B978-0- 12-809633-8.20178-7.
- Handelsman J, Rondon MR, Brady SF, Clardy J, Goodman RM: Molecular biological access to the chemistry of unknown soil microbes: a new frontier for natural products. Chem Biol 1998, 5(10): 245-249.
- Jansson, J.K. and Hofmockel, K.S. (2018). The soil microbiome-from metagenomics to metaphenomics. Curr Opin Microbiol, 43:162–168.
- Jimenez DJ, Andreote FD, Chaves D, Montan JS, Osorio-Forero C, Junca H, Zambrono MM, Baena S (2012) Structural and functional insights from the metagenome of an acidic hot spring microbial planktonic community in the Colombian Andes. PLoS One 7:1- 15.
- Joshi, M. and Deshpande, J.D. (2010). Polymerase chain reaction: methods, principles and application. International Journal of Biomedical Research, 2(1):81-97.
- Knight, R., Jansson, J., Field, D., Fierer, N., Desai, N., Fuhrman, J.A., Hugenholtz, P., Van Der Lelie, D., Meyer, F., Stevens, R. and Bailey, M.J. 2012. Unlocking the potential of metagenomics through replicated experimental design. Nature biotechnology, 30(6):513-520.
- Li, R., Li, Y., Kristiansen, K. and Wang, J. 2008. SOAP: short oligonucleotide alignment program. Bioinformatics, 24(5):713-714.
- Macrae, A. (2000). The use of 16S rDNA methods in soil microbial ecology. Brazilian Journal of Microbiology, 31(2):77-82.
- Markowitz, V.M., Mavromatis, K., Ivanova, N.N., Chen, I.M.A., Chu, K. and Kyrpides, N.C.2009. IMG ER: a system for microbial genome annotation expert review and curation. Bioinformatics, 25(17):2271-2278.Nazir A (2016) Review on metagenomics and its applications. IJIR 2:277–286.

- Neelakanta, G. and Sultana, H. (2013) The use of metagenomic approaches to analyze changes in microbial communities. Microbiol Insights. 6: 37–48.
- Papudeshi, B., Haggerty, J.M., Doane, M., Morris, M.M., Walsh, K., Beattie, D.T., Pande, D., Zaeri, P., Silva, G.G.Z., Thompson, F., Edwards, R.A. and Dinsdale, E.A. (2017). Optimizing and evaluating the reconstruction of Metagenome-assembled microbial genomes. BMC Genomics, 18:1–13 https://doi.org/10.1186/s12864- 017-4294-1.
- Ramazzotti M, and Bacci G (2018) 16S rRNA-Based taxonomy profiling in the metagenomics era. In Metagenomics (pp. 103–119).
- Roumpeka, D.D., Wallace, R.J., Escalettes, F., Fotheringham, I. and Watson, M. (2017). A review of bioinformatics tools for bio-prospecting from metagenomic sequence data. Front Genet, 8:1–10.
- Sanger, F.; Nicklen, S. and Coulson, A. R. (1977). DNA sequencing with chain-terminating inhibitors. Proc. Natl. Acad. Sci. 74 (12): 5463-5467.
- Schierbeek, A. (1959). Measuring the invisible world: The life and Works of Antoni van Leeuwenhoek. London: Abelard-Schuman. Available online at: https://www.questia.com/library/73684/measuring-the-invisible-world-thelife-and-works.
- Singer E, Bushnell B, Coleman-derr D, Bowman B, Bowers RM, Levy A, Gies EA, Cheng J, Copeland A, Klenk H, Hallam SJ, Hugenholtz P, Tringe SG, Woyke T (2016) High-resolution phylogenetic microbial community profiling. ISME J 10:2020–2032
- Sogin, M. L.; Morrison, H. G.; Huber, J. A.; Welch, D. M.; Huse, S. M.; Neal, P. R. and Herndl, G. J. (2006). Microbial diversity in the deep sea and the underexplored "rare biosphere". Proc. Nat. Acad. Sci. 103 (32): 12115-12120.
- Strous, M., Kraft, B., Bisdorf, R. and Tegetmeyer, H.E. (2012). The binning of metagenomic contigs for microbial physiology of mixed cultures. Front Microbiol, 3:1–11 https://doi.org/10.3389/fmicb.2012.00410 51.
- Thomas, T., Gilbert, J. and Meyer, F. (2012). Metagenomics - a guide from sampling to data analysis. Microbial informatics and experimentation. 2(1):3.
- Tsai YL and Olson BH (1992): Rapid method for separation of bacterial DNA from humic substances in sediments for polymerase chain reaction. Appl Environ Microbiol, 58:2292-2295.
- Woese, C. R. and Fox, G. E. (1977). Phylogenetic structure of the prokaryotic domain: the primary kingdoms. Proc. Natl. Acad. Sci. U.S.A. 74: 5088–5090.
- Wooley, J.C. and Ye, Y. (2009). Metagenomics: Facts and Artifacts, and Computational Challenges. J Comput Sci Technol, 25(1): 71–81. doi:10.1007/s11390-010-9306-4
- Zerbino, D.R. and Birney, E. 2008. Velvet: algorithms for de novo short read assembly using de Bruijn graphs. Genome Resour, 18: 821–829.

ISBN: 978-81-965655-8-9

CHAPTER 8

INSECT AGEING AND ITS EFFECTS ON SUSTAINABLE AGRICULTURE

Sanjay Hazarika[1*] and Rupam Khatua[2], Anto Rashwin A.[3], Anam Khan[4]
[1]PhD Scholar, Department of Entomology, AAU, Jorhat-13
[2]M.Sc (Agri), Department of Entomology, AAU, Jorhat-13
[3]UG Student, Tamil Nadu Agricultural University, Tamil Nadu
[4]AP, Entomology, IAS&T, Sri Ramswaroop Memorial University, Lucknow-Deva Road, Barabanki, UP-225003

ABSTRACT

Insects, the silent architects of our agricultural ecosystems, have long shaped the delicate balance between nature and food production. This book chapter embarks on an illuminating journey into the world of "Insect Ageing and its Effects on Sustainable Agriculture." We delve into the intricate lifecycles of insects, unraveling the mysteries of metamorphosis, growth stages, and the profound physiological changes that accompany the aging process.

As we explore the aging pathways of these diminutive organisms, we unveil their multifaceted impact on sustainable agriculture. Insects are both allies and adversaries, influencing crop health, pollination, and the very foundation of our food systems. Understanding how aging transforms their behavior, reproductive strategies, and ecological roles is paramount for the development of effective and sustainable agricultural practices. This chapter scrutinizes the dynamic relationship between aging insects and the crops they interact with, addressing pivotal questions about pest management, pollination, and the broader implications for agricultural sustainability. From the emergence of young nymphs or larvae to the culmination of adulthood, we trace the remarkable journey of insects and their evolving role in the agricultural landscape.

In the context of pest management, we uncover strategies that consider the changing behaviors and vulnerabilities of aging insect populations. We navigate the realm of biological control methods, integrated pest management, and the strategic use of age-specific pesticides to minimize crop damage and environmental impact.

Furthermore, we illuminate the essential role of aging pollinators, such as bees and butterflies, in crop pollination and the significance of preserving their health and longevity. We unravel the intricate connections between aging insects and the ecosystem services they provide, from decomposition to nutrient cycling, highlighting the cascading effects of changing insect populations on biodiversity and sustainability. Lastly, we address the formidable challenge posed by climate change and its profound influence on insect aging patterns. By examining the implications of a shifting climate on insect behavior and lifecycles, we illuminate potential adaptation and mitigation strategies for agriculture in a changing world. This enlightening exploration of "Insect Ageing and its Effects on Sustainable Agriculture," as we uncovers the hidden intricacies of the agricultural ecosystem and chart a course toward resilient and environmentally conscious food production.

Keywords: Silent architects, Insect Ageing, metamorphosis, biodiversity, sustainability

INTRODUCTION

Insects, often regarded as the unsung heroes of agriculture, play a pivotal role in the delicate balance of ecosystems that sustain our food production systems. From the pollination of flowering crops to the regulation of pest populations, their presence and activities are woven into the very fabric of sustainable agriculture. This chapter delves into the fascinating realm of insect aging and its profound implications for the agricultural landscape.

 ISBN: 978-81-965655-8-9

Insects have been instrumental in human agriculture for centuries, with their contributions extending far beyond mere pollination. They act as both allies and adversaries, impacting crop health and yield in complex ways. Understanding how these diminutive organisms age and how this aging process influences their interactions with crops is essential for developing effective and sustainable agricultural practices.

Insect Lifecycles

Insects undergo complex lifecycles, which typically include distinct stages:

1. **Egg:** The insect begins life as an egg, often laid on or near a host plant or suitable habitat.
2. **Larva (or Nymph):** After hatching from the egg, the insect enters the larval stage. Larvae are typically the feeding and growing stage of the insect. In some insects like butterflies and moths, this stage is called a caterpillar.
3. **Pupa:** Many insects undergo a pupal stage, during which they undergo metamorphosis. This stage is marked by significant physiological changes. For example, a caterpillar might transform into a chrysalis in the case of butterflies.
4. **Adult:** The final stage is the adult, which is often the reproductive and dispersal stage of the insect's life. The adult typically has wings (although not always), and its primary purpose is to reproduce and continue the lifecycle.

Importance of Understanding Insect Lifecycles in Aging

1. **Metamorphosis:** Metamorphosis is a key aspect of insect lifecycles. Understanding how insects transform from larvae to adults is crucial for predicting when they might be most vulnerable or active in agricultural systems.
2. **Growth Stages**: Different growth stages are associated with different behaviors and dietary preferences. Knowing these stages can aid in timing pest control measures or optimizing conditions for beneficial insects.
3. **Physiological Changes:** Physiological changes occur throughout an insect's lifecycle, impacting factors like mobility, feeding habits, and reproductive capacity. Recognizing these changes can inform pest management strategies.
4. **Life Expectancy:** The duration of each lifecycle stage varies among insect species. Some insects may have short-lived adults, while others have longer adult lifespans. Understanding these variations is essential for managing populations.

Impact on Crop Health

1. **Increasing Damage:** Some insect species become more damaging to crops as they age. For example, caterpillar larvae of moths and butterflies often consume more plant material as they grow. As they age, their voracious feeding can cause increasing damage to crops, especially during the larval stage.
2. **Changing Feeding Habits:** The feeding habits of insects can change with age. Younger insects may feed on different parts of a plant compared to older ones. Understanding these shifts in feeding behavior is crucial for implementing effective pest management strategies.
3. **Reproductive Impact:** As insects age and reach maturity, their primary focus often shifts to reproduction. This can influence their behavior and interactions with crops. For instance, some insects may lay more eggs or deposit them in specific plant tissues, leading to crop damage or transmission of plant diseases.

4. **Longevity and Persistence:** Insects with longer lifespans may pose a prolonged threat to crops. Pests that live for several generations during a single growing season can continuously damage crops if not managed effectively.

5. **Predatory and Beneficial Insects:** Not all aging insects are detrimental to crops. Beneficial insects, such as certain predatory beetles or parasitic wasps, can become more effective at pest control as they age. Understanding the lifecycles and behaviors of these beneficial insects is essential for promoting natural pest control in agriculture.

6. **Integrated Pest Management (IPM):** Knowledge of how aging insects impact crops is a cornerstone of Integrated Pest Management (IPM). IPM strategies aim to use a combination of methods, including biological control, to manage pests effectively while minimizing the use of chemical pesticides.

   In summary, the impact of aging insects on crop health is multifaceted. Some insects become increasingly damaging to crops as they age, while others may exhibit changing behaviors that can affect crop health in different ways. Understanding these dynamics is crucial for developing targeted and sustainable pest management practices in agriculture.

Pest Management

Managing aging insect populations is crucial for sustainable agriculture. Here's a brief overview of strategies for pest management, including biological control methods, integrated pest management, and age-specific pesticides:

Pest Management Strategies for Aging Insect Populations:

1. **Biological Control Methods:** Biological control involves using natural predators, parasites, or pathogens to manage pest populations. This approach can be highly effective in controlling aging insect pests. For instance, releasing beneficial insects like ladybugs or parasitoid wasps can help keep pest populations in check, regardless of their age.

2. **Integrated Pest Management (IPM):** IPM is a holistic approach that combines multiple strategies for pest management. It considers the lifecycle of pests, including their aging process, and integrates various methods like biological control, cultural practices (e.g., crop rotation), mechanical methods (e.g., traps), and judicious use of pesticides.

3. **Age-Specific Pesticides:** Some pesticides are designed to target specific life stages of insects. For example, insect growth regulators (IGRs) can disrupt the development of immature insects without affecting adults. Using age-specific pesticides can help reduce pest populations without harming beneficial insects or the environment.

4. **Monitoring and Thresholds:** Regular monitoring of pest populations is essential. By tracking the presence and abundance of pests, farmers can make informed decisions about when and how to implement control measures. Thresholds are established levels at which action should be taken to prevent crop damage.

5. **Cultural Practices:** Modifying farming practices can also influence the aging insect populations. Crop diversification, timing of planting, and maintaining healthy soil can impact pest populations and their effects on crops.

6. **Resistant Crop Varieties:** Planting crop varieties that are resistant or less attractive to specific pests can be an effective long-term strategy. This reduces the susceptibility of crops to pest damage, regardless of the age of the insects.

7. **Research and Education:** Staying informed about the biology and behavior of local pests is critical. Research and education programs can provide farmers with up-to-date information on the best practices for managing aging insect populations in their region.

ISBN: 978-81-965655-8-9

In summary, sustainable agriculture requires a multifaceted approach to managing aging insect populations. This includes using biological control methods, implementing integrated pest management strategies, considering age-specific pesticides, and adopting cultural practices that minimize pest damage while safeguarding the environment and beneficial insects.

Pollinators

The aging of pollinating insects can significantly impact crop pollination and, consequently, sustainable agriculture. Here's why understanding the aging processes of pollinators is crucial:

Importance of Pollinators in Sustainable Agriculture

1. Crop Pollination: Pollinators like bees, butterflies, and certain insects play a vital role in transferring pollen from the male parts of flowers to the female parts, facilitating the fertilization of plants. This process is essential for the production of fruits, vegetables, and nuts.
2. Biodiversity: Pollinators contribute to biodiversity by enabling the reproduction of various plant species. Healthy pollinator populations are essential for maintaining diverse ecosystems.
3. Economic Value: Pollinators contribute significantly to the global economy. They enhance the yield and quality of crops, which directly affects agricultural profits and food security.

Impact of Aging Pollinators on Crop Pollination

1. Foraging Efficiency: As pollinators age, their foraging efficiency may change. Older individuals might have reduced mobility or decreased foraging activity, which can affect their ability to visit and pollinate crops effectively.
2. Lifespan and Reproductive Output: The lifespan and reproductive output of pollinators can vary with age. Understanding these variations is crucial for predicting when pollinators are most active and assessing their long-term contributions to crop pollination.
3. Behavioral Changes: Aging pollinators may exhibit different foraging behaviors, such as preferences for specific flower types or altered flight patterns. These behavioral changes can influence which crops receive adequate pollination.
4. Disease Susceptibility: Aging pollinators might become more susceptible to diseases or parasites. This can impact their overall health and longevity, potentially reducing their effectiveness as pollinators.

Sustainable Agriculture and Pollinator Conservation

To promote sustainable agriculture, it's essential to focus on pollinator conservation and management. This includes:

1. Habitat Preservation: Creating and preserving suitable habitats for pollinators, such as wildflower meadows and nesting sites, can support their populations.
2. Reducing Pesticide Use: Minimizing the use of pesticides that harm pollinators is critical. Integrated pest management practices can help strike a balance between pest control and pollinator protection.
3. Educating Farmers: Providing farmers with knowledge and tools for pollinator-friendly farming practices can ensure the health and longevity of pollinator populations.
4. Research: Ongoing research on the biology and behavior of pollinators, including their aging processes, can inform better strategies for their conservation and integration into agricultural systems.

 ISBN: 978-81-965655-8-9

In summary, the aging processes of pollinating insects are intimately linked to crop pollination and, by extension, the sustainability of agriculture. A comprehensive understanding of these processes is crucial for implementing effective strategies to protect and support pollinators in agricultural landscapes.

Ecosystem Services

Insects play various roles in ecosystems, and changes in their populations due to aging can have cascading effects on biodiversity and ecosystem services. Insects play diverse and essential roles in ecosystems, and changes in their populations due to aging can have far-reaching effects on biodiversity and ecosystem services. Let's delve into this further:

Ecosystem Services Provided by Insects

- Pollination: Insects like bees, butterflies, and certain flies are key pollinators of flowering plants. They facilitate the reproduction of numerous plant species, which, in turn, provides food for other wildlife and supports ecosystem stability.
- Decomposition: Insects, such as beetles and flies, are crucial decomposers. They break down dead organic matter, recycling nutrients back into the ecosystem and improving soil health.
- Predation: Predatory insects, like ladybugs and mantises, help control populations of herbivorous insects and maintain a balance in plant-herbivore interactions.
- Seed Dispersal: Insects, particularly ants, play a role in seed dispersal. They move seeds to new locations, aiding in plant regeneration and enhancing plant diversity.
- Nutrient Cycling: Insects contribute to nutrient cycling by transporting organic matter and nutrients through their feeding and waste processes, which benefits the overall health of ecosystems.

Impact of Aging Insects on Ecosystem Services

- **Pollination Services:** Changes in the behavior and efficiency of aging pollinators can affect the pollination of wild plants, potentially impacting the reproductive success of native flora and the animals that depend on them.
- **Decomposition and Nutrient Cycling:** Aging decomposer insects might have altered decomposition rates or feeding preferences. This can influence the pace of nutrient cycling in ecosystems and impact soil quality.
- **Predation and Herbivore Control:** Aging predatory insects may exhibit different hunting patterns or preferences, affecting the control of herbivorous insect populations. This, in turn, can impact the abundance and health of plants in ecosystems.
- **Species Interactions:** Insects often participate in complex ecological interactions. Changes in the behavior or abundance of aging insects can disrupt these interactions and potentially lead to cascading effects throughout the ecosystem.

Conservation and Biodiversity Considerations:

To safeguard ecosystem services and biodiversity, it's crucial to consider the aging processes of insects in conservation efforts:

- Habitat Preservation: Conserving diverse habitats that support insect populations, including their different life stages, is essential for maintaining ecosystem services.
- Reducing Pesticide Use: Minimizing the use of pesticides, especially those harmful to non-target insects, can help protect ecosystem services provided by insects.

 ISBN: 978-81-965655-8-9

- Restoration: Efforts to restore native plant communities and create wildlife-friendly landscapes can support diverse insect populations and their roles in ecosystems.
- Research and Monitoring: Ongoing research on insect ecology, including aging processes, can inform conservation strategies and help detect changes in insect populations.

In conclusion, understanding the aging processes of insects is a critical component of ecosystem management and biodiversity conservation. It allows us to appreciate the intricate web of interactions that insects contribute to and helps us make informed decisions to protect these vital ecosystem services.

Climate Change and Aging Insects

The influence of climate change on insect aging patterns and its implications for sustainable agriculture. Climate change is indeed impacting various aspects of the natural world, including insect populations and their aging patterns. Here's a look at how climate change can influence insect aging patterns and its implications for sustainable agriculture:

Influence of Climate Change on Insect Aging:

- **Altered Lifecycles:** Climate change can affect temperature and seasonal patterns, leading to shifts in the timing of insect lifecycles. Warmer temperatures might accelerate insect development, potentially affecting when they reach adulthood or other key life stages.
- **Extended Lifespan:** Some insects may experience longer adult lifespans under milder winters or extended growing seasons. Extended lifespan can influence their behavior, reproductive rates, and interactions with crops.
- **Range Expansion:** Insects may expand their geographic ranges in response to changing climate conditions. New insect species or populations could emerge in regions where they were previously uncommon or absent.\
- **Altered Behavior:** Changes in temperature and humidity can affect insect behavior. This may include alterations in feeding patterns, mating behaviors, and migration patterns.
- **Pest Outbreaks:** Changes in insect lifecycles and behavior due to climate change can lead to more frequent and severe pest outbreaks. Crops may face increased pressure from pests as warmer conditions create a more favorable environment for their development.
- **Mismatch with Crops:** Altered insect lifecycles can lead to a mismatch between the timing of crop flowering and the presence of pollinators. This can reduce pollination efficiency and crop yields.
- **Invasive Species:** As climate conditions become more favorable for certain insect species, there is a risk of invasive species expanding their ranges and causing damage to crops.
- **Disease Spread:** Climate change can also influence the distribution and prevalence of insect-borne diseases in agriculture. Warmer temperatures may allow disease vectors to thrive in new areas, affecting both crops and livestock.

Adaptation and Mitigation Strategies:

To address the implications of climate change on insect aging and agriculture, one need to focus on following:

- **Resilient Crop Varieties:** Developing and planting crop varieties that are more resilient to pests and changes in climate can be effective.
- **Monitoring and Forecasting:** Continuous monitoring of insect populations and climate conditions can help predict pest outbreaks and implement timely control measures.

ISBN: 978-81-965655-8-9

- **Integrated Pest Management (IPM):** Enhanced IPM strategies that consider changing insect behaviors and lifecycles in response to climate change can be crucial.
- **Conservation of Beneficial Insects:** Protecting and promoting populations of beneficial insects, like pollinators and natural predators, is essential for sustainable pest management.
- **Carbon Emission Reduction:** Addressing the root cause of climate change by reducing carbon emissions is paramount for mitigating its impacts on agriculture, including insect-related challenges.

In summary, climate change can disrupt insect aging patterns and have significant implications for sustainable agriculture. Adaptation and mitigation strategies, along with a focus on resilience and conservation, are essential for addressing these challenges and ensuring food security in a changing climate.

Future Research Directions:

This chapter discuss the gaps in our knowledge and suggest areas for future research in the context of insect aging and sustainable agriculture.

Some potential areas for future research:

- **Climate Change Resilience:** Investigate how different insect species adapt to changing climate conditions, especially in terms of their aging patterns. This can inform strategies for managing pest populations and conserving beneficial insects in a warming world.
- **Aging and Pesticide Tolerance:** Study how aging affects an insect's tolerance to pesticides. Understanding how different life stages respond to chemical treatments can lead to more precise and targeted pest control methods.
- **Behavioral Ecology:** Explore the behavioral changes that occur in aging insects and how these changes influence interactions with crops. This research can help optimize pest management strategies and promote sustainable agriculture.
- **Insect Micro-biomes:** Investigate the role of the insect micro biome in aging and its impact on insect behavior, health, and response to environmental stressors. This area holds promise for novel pest management approaches.
- **Quantifying Ecosystem Services:** Develop better methods for quantifying the contributions of aging insects to ecosystem services such as pollination, decomposition, and nutrient cycling. This can provide more accurate assessments of the benefits insects bring to agriculture.
- **Biotechnology and Genetics:** Explore genetic and biotechnological approaches to manipulate aging processes in insects, potentially offering innovative solutions for pest control and beneficial insect management.
- **Modeling and Predictive Tools:** Develop predictive models that incorporate aging factors, climate data, and crop dynamics to forecast pest outbreaks and optimize the timing of pest control measures.
- **Insect-Plant Interactions:** Investigate the chemical and molecular mechanisms underlying insect-plant interactions, with a focus on how these interactions change with aging. This knowledge can inform strategies for crop protection and improvement.
- **Insect Conservation:** Research on the conservation of beneficial insects, including those involved in pollination and biological pest control, is essential. Identify strategies to protect and enhance these insect populations in agricultural landscapes.

 ISBN: 978-81-965655-8-9

- **Long-Term Studies:** Conduct long-term studies tracking insect populations and their aging patterns in various agricultural systems. This can help identify trends and dynamics that may not be apparent in short-term research.
- **Socioeconomic Impact:** Assess the socioeconomic impact of aging insect populations on agriculture and rural communities. Understand how changes in insect dynamics affect farmer livelihoods and food security.
- **Interdisciplinary Approaches:** Encourage interdisciplinary collaboration between entomologists, ecologists, climatologists, and social scientists to address the complex challenges arising from insect aging and climate change in agriculture.

By focusing research efforts on these areas, we can deepen our understanding of how aging insects influence sustainable agriculture and develop innovative strategies to address the evolving challenges posed by climate change and insect populations.

REFERENCE

- Churchill ER, Dytham C, Thom MDF. 2019. Differing effects of age and starvation on reproductive Performance in Drosophila melanogaster. Sci. Rep. 9:2167
- Daly HV, Doyen JT, Ehrlich PR. 1978. Introduction to Insect Biology and Diversity. New York: McGraw Hill
- Fraser MJ. 2011. Insect transgenesis: current applications and future prospects. Annu. Rev. Entomol. 57:267–89
- Haddadi M, Jahromi SR, Chandrasekhar Sagar BK, Patil RK, Shivanandappa T, Ramesh SR. 2014. Brain aging, memory impairment and oxidative stress: a study in Drosophila melanogaster. Behav. Brain Res. 259:60–69
- Hoffmann AA, Sgro CM. 2011. Climate change and evolutionary adaptation. Nature 470:479–85.

 ISBN: 978-81-965655-8-9

CHAPTER 9

ROLE OF BIOSENSORS IN CLIMATE-SMART AGRICULTURE

Bicky Boro[1], Bhabagiri Malakar[2], Pallabi Dutta[3], and Dimpi Dutta[4]
[1]Tata Institute of Social Sciences
[2]Tezpur University
[3]Gauhati University
[4]Assam Agricultural University, Jorhat

INTRODUCTION

The agriculture sector is grappling with an array of complex challenges, including land fragmentation, the socio-economic vulnerability of farmers, information gaps, inadequate infrastructure, faltering market systems, trade barriers, financial limitations, ill-designed policies, unsustainable agronomic practices, and environmental strain. These issues are further compounded by the ramifications of climate change, as agriculture is intrinsically tied to climatic conditions and variables. Climate change has the potential to extend its impact beyond agriculture, causing disruptions across the economic, social, and political landscapes. The increasing frequency of extreme weather events perpetuates impediments to human progress and development, magnifying their adverse effects on both the environment and its natural equilibrium.

Amidst this intricate backdrop, the concept of climate-smart agriculture emerges as a beacon of hope, serving as a mitigation strategy against the challenges posed by climate change. Climate-smart agriculture holds the potential to not only enhance the resilience of the agricultural sector but also to alleviate the broader repercussions on economies, societies, and governance structures. Innovation stands as a pivotal driver within the realm of agriculture. The dynamic nature of challenges demands innovative solutions that transcend conventional boundaries. Innovation injects adaptability and efficiency into agricultural practices, enabling the sector to effectively navigate through the complexities of contemporary challenges.

Here, biosensors play a transformative role. These advanced analytical devices are capable of providing real-time and accurate data on environmental factors, soil conditions, and crop health. By doing so, biosensors empower farmers with precise insights, allowing them to make informed decisions regarding irrigation, fertilization, pest management, and overall crop health. This real-time data enhances resource allocation, reduces waste, and optimizes productivity. Additionally, biosensors contribute to sustainable agricultural practices by minimizing the usage of resources like water and chemicals, which aligns perfectly with the goals of climate-smart agriculture.

A Smart-system and Biosensors:

“A smart system or product is that which facilitates the interface of a system with persons/users and is able to acclimate the framework of the user without compelling the user to acclimate to it” (Abegunde et al., 2019).

In simple terms, a "smart system or product" is something that can work well with people and adapt to how they use it. It's like a helpful tool that understands how you want to use it and adjusts itself to fit your needs, without making you change the way you want to use it. So, it's about technology that is easy and comfortable for you to use, instead of making you change your habits to use it. Biosensors are one such example.

According to (Karimi et al. (2018) “Smart System” has the following features:

1. Ability to cooperate and communicate effectively with different devices.

2. Flexibility to Improve Compatibility with Surroundings.
3. Self-sufficiency in functioning without needing constant input from the user.
4. Capacity to connect with users using a natural way of communicating.
5. Versatility, i.e., the ability of a single product to perform various tasks effectively.
6. The system should react uniquely to its surroundings, showing a responsive behavior.

Biosensors:

A biosensor serves as an analytical tool, facilitating diagnostics by integrating a biological component with a physicochemical detector, or transducer. This amalgamation aims to gauge the presence or concentration of specific substances like metabolites, drugs, contaminants, microbial levels, and control parameters. Essentially, biosensors are designed to convert a biological reaction into a measurable signal, often an electrical one, resulting from the interaction between a biomolecule and its intended target. This signal is then processed and analyzed to extract valuable information about the target substance (Arora, N., 2013).

In essence, biosensors play a crucial role in rapid and accurate detection across various applications, including medical diagnostics, environmental monitoring, and quality control. Today, a range of biosensors exist, categorized by their transducers. The inaugural instance, dating back to 1956, was the glucose biosensor pioneered by Professor L.C. Clark Jr.

The classification of biosensors is based on two fundamental criteria: the Sensing Component employed and the Transducer Mode used to translate the gathered information.

Sensing Component Classification: Biosensors are categorized according to the biological elements they utilize. These components encompass:

- Enzymes
- Antibodies (Immunosensors)
- Microorganisms (Cell Biosensors)
- Biological Tissues
- Organelles

Transducer Mode Classification: Biosensors are classified based on the techniques they employ to convert biological responses into measurable signals. These modes encompass:

- Piezoelectric: This includes types like acoustic and ultrasonic methods.
- Electrochemical: Types such as amperometric, conductometric, and potentiometric methods fall into this category.
- Optical: Types including absorbance, fluorescence, and chemiluminescence are encompassed within the optical transducer mode.

By categorizing biosensors through these distinct lenses, a comprehensive framework emerges to better understand and describe their various applications and functionalities.

 ISBN: 978-81-965655-8-9

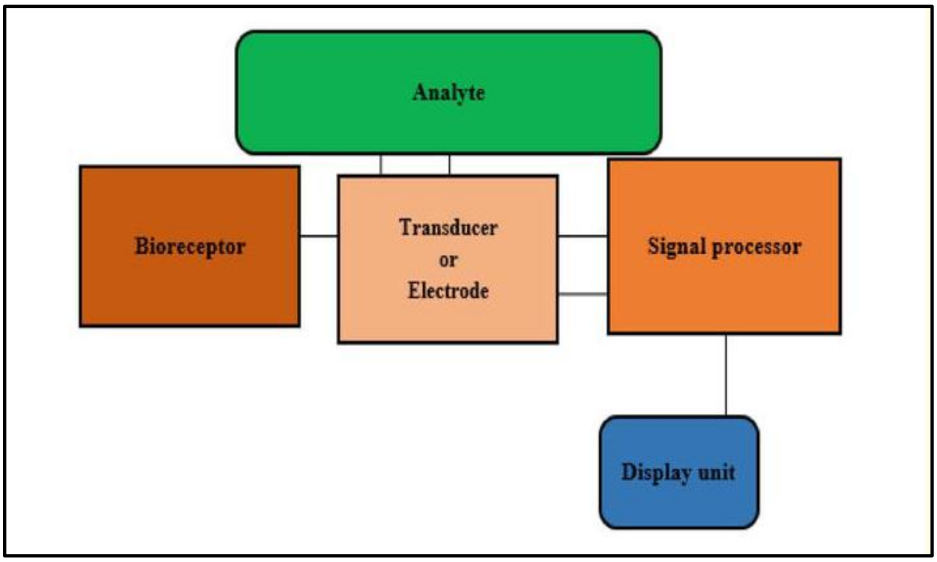


Fig. 1: The major distinctive components of a biosensor are illustrated below as a block prototypical distinctive biosensor (Mehrotra, P. (2016).

The major distinctive components of biosensors:

a. **Analyte:** The analyte is the specific substance that the biosensor is designed to detect. It's the target of interest, and the interaction between the analyte and the bioreceptor is what the biosensor is meant to capture and quantify. This could be anything from glucose in a blood sample to a particular chemical pollutant in the environment.

b. **Bioreceptor (Detecting/Sensing Component):** The bioreceptor is a crucial part of the biosensor that interacts with the target analyte. It's typically a biological molecule, such as an enzyme, antibody, or nucleic acid. The bioreceptor binds specifically to the analyte, causing a reaction or change that the biosensor can detect. This interaction forms the basis of the biosensor's selectivity and sensitivity.

c. **The Transducer:** The transducer is responsible for converting the biological interaction between the bioreceptor and the analyte into a measurable signal. It translates this interaction into a form that can be easily detected and quantified. Different types of transducers can be used, such as electrical, optical, or acoustic transducers, depending on the type of biosensor and the desired output.

d. **Signal Processor:** The signal processor takes the raw signal generated by the transducer and processes it to provide meaningful information. It might involve amplification, filtering, and other signal-conditioning techniques. The processed signal is then ready for interpretation and analysis.

e. **Display Unit:** The display unit is the part of the biosensor that presents the final result to the user. It could be a simple visual indicator, a digital readout, or even a computer interface. The display unit presents the information in a way that's easy for the user to understand, allowing them to interpret the presence or concentration of the analyte.

Together, these components form a biosensor system that integrates biological recognition, signal conversion, data processing, and user-friendly output. This enables the biosensor to detect and quantify specific substances in a variety of applications, ranging from medical diagnostics to environmental monitoring.

 ISBN: 978-81-965655-8-9

Jeevula BN. and Sireesha V. (2021) reported various application of Biosensors in Agriculture:

1. **Biosensors can directly help in the detection of Pathogens in plants:**

Example: (i) QCM (Quartz crystalline Micro balancer) biosensor or Accoustic-based biosensor detects plant pathogens like Ralstonia solanacearum, Pseudomonas syringae pv. tomato and Xanthomata's campestris pv. Vesicatoria.

(ii) High-density microelectrode Array biosensors that detect E. coli bacteria in lettuce.

(iii) Bacteriophage-based biosensors help in detecting Pseudomonas cannabina pv. Alisalensis which causes blight in the leaves of various crops.

2. **Biosensors help in the early detection of crop diseases in the field:**

Example: Surface Plasmon Resonance (SPR) based Immunosensor. It helps in detecting and diagnosing the early stages of Soybean Rust and Maize Chlorotic Mosaic Virus.

3. **Biosensors help in understanding the soil chemistry of the crop plot:**

Electrochemical biosensors are the ones that are mostly used to study soil quality, such as pH, nutrients, soil-borne diseases, etc.

Example: Electronic nose (E-nose) biosensor is used for the detection of soil-borne pathogens and insect infestations in soil.

4. **Biosensors can detect increasing concentrations of Organophosphorus in the atmosphere:**

Organophosphorus compounds are a group of chemicals extensively utilized in modern agriculture as insecticides, pesticides, and herbicides to combat a wide array of pests, insects, weeds, and disease-transmitting vectors. Unfortunately, the concentration of these chemicals, along with heavy metals, in agricultural soil and water bodies is steadily on the rise. This proliferation of chemical agents has led to soil, water, and environmental contamination, resulting in significant health risks for living organisms. Consequently, monitoring Organophosphorus compounds has become imperative to ensure the health and sustainability of agricultural lands and aquatic ecosystems.

Example:
(i) Liposome-based nano-biosensors detect the pesticides dichlorvos and paraoxon at very low levels. It is also used for the detection of total toxicity in water samples.

(ii) Novel cyanobacterial Biosensor provides information on the bioavailability of the herbicides in environmental samples.

5. **Biosensors help in detecting pesticides and their residues in bioaccumulation:**

Pesticides are ubiquitously prevalent in our environment, being found in substantial quantities in water, air, soil, plants, and even the food we consume. Public apprehension regarding pesticide residues has surged significantly due to the pronounced toxicity of these chemicals and their potential to accumulate in the environment and biological systems. This growing concern is rooted in the substantial risks that pesticides pose to both the well-being of ecosystems and human health.

Example: Electrochemical acetylcholinesterase (AChE) biosensors detect carbamate pesticides like carbaryl and methomyl in fruits and vegetables.

6. **Biosensors employed to measure the levels of nitrates in plants:**

Example: Bacterial biosensors, Enterobacter cloacae and E. coli, detect the quantity of nitrate present in the soil, it also estimates the microbial niches in complex natural environments such as the rhizosphere.

 ISBN: 978-81-965655-8-9

7. **Biosensors used to identify foodborne pathogens and mycotoxins:**

Biosensors play a crucial role in the food industry by identifying chemical contaminants, food-borne pathogens, and microorganisms, and quantifying food content, including applications in soft drink analysis.

Example:

(i) Optical biosensor, detects the presence of Salmonella and Typhimurium in milk and apple juice.

(ii) Fluorometric biosensor, detects and quantifies aflatoxins.

(iii) Electrochemiluminescent aptamer biosensor, detects the presence of Ochratoxin A in beer and coffee samples.

CONCLUSION

In the pursuit of sustainable and climate-resilient agriculture, the integration of biosensors emerges as a transformative force. Agriculture, fraught with multifaceted challenges and intricately linked to climate dynamics, necessitates innovative solutions. Climate-smart agriculture, with its promise of bolstering agricultural resilience while mitigating broader socio-economic and environmental repercussions, demands the infusion of cutting-edge technologies. And, as we navigate the complex agricultural challenges exacerbated by climate change, biosensors serve as beacons of hope, empowering us to cultivate a more resilient, sustainable, and productive future. These tools, with their capacity to bridge the gap between nature and technology, will continue to revolutionize agriculture, ensuring its vitality in the face of evolving challenges and climatic uncertainties.

REFERENCES

- Abegunde, V. O., Sibanda, M. and Obi, A. (2019). The dynamics of climate change adaptation in Sub-Saharan Africa: A review of climate-smart agriculture among small-scale farmers. Climate. 7: 132.
- Arora, N. (2013). Recent advances in biosensors technology: a review. Octa Journal of Biosciences, 1(2).
- Jeevula. B.N. and Sireesha V. (2021). Role and Use of Biosensors in Agriculture Vol.1
- Karimi, V., Karami, E. and Keshavarz, M. (2018). Climate change and agriculture: Impacts and adaptive responses in Iran. Journal of Integrative Agriculture. 17(1), 1-15.
- Mehrotra, P. (2016). Biosensors and their applications–A review. Journal of oral biology and craniofacial research, 6(2), 153-159.

 ISBN: 978-81-965655-8-9

CHAPTER 10

SERICULTURE: AN APPROACH FOR SUSTAINABLE LIVELIHOOD OF WOMEN

Sanjay Hazarika[1*] and Bidisha Saikia[2], Anadi Ranjan Saikia[3], Khumanthem Babina Devi[4]
[1]Ph D Scholar, Department of Entomology, AAU, Jorhat-13
[2]M.Sc (Agri), Department of Sericulture, AAU, Jorhat-13
[3]Ph D Scholar, Department of Extension Education and Communication Technologies, AAU, Jorhat-13
[4] Ph D Scholar, Department of Environmental Science, Mizoram University, Aizawl-796004, Mizoram

ABSTRACT
Sericulture, the art of silk production, has historically been intertwined with women's participation, making it a significant avenue for gender-inclusive economic development. This book chapter explores the transformative role of sericulture in empowering women and fostering sustainable livelihoods in rural communities. Through case studies, this chapter delves into the economic, social, and environmental dimensions of sericulture as it relates to women. It highlights how sericulture offers women opportunities for income generation, skill development, and community engagement. Moreover, the chapter examines the sustainable practices within sericulture that contribute to environmental conservation and local economic resilience. By shedding light on the multifaceted benefits of sericulture, this chapter advocates for its integration into broader rural development strategies, emphasizing its potential to uplift women and create sustainable livelihoods in diverse cultural and geographical contexts.

Keywords: Sericulture, skill development, community engagement, local economic resilience

INTRODUCTION
Sericulture is the practice of raising silkworms (usually the domesticated silkworm, *Bombyx mori*) for the production of silk, a luxurious and highly prized natural fiber. It is an ancient and intricate process that involves several stages:

Mulberry Cultivation: Sericulture typically begins with the cultivation of mulberry trees, which provide the primary food source for silkworms. These trees are grown to ensure a steady supply of leaves for the silkworms.

Silkworm Rearing: Silkworm eggs are hatched into larvae, and these larvae are then placed on trays or racks where they feed on mulberry leaves. They go through several stages of molting and growth, during which they increase in size.

Cocoon Formation: After a series of molts, the silkworms spin protective cocoon shells around themselves using a fluid that hardens into silk threads. This spinning process takes a few days.

Harvesting: Once the cocoon is complete, it is carefully harvested. At this point, the cocoon is made up of a single continuous silk thread, which can be as long as 900 meters.

Boiling and Reeling: To obtain the silk, the harvested cocoons are boiled to soften the sericin, a protein that holds the silk threads together. After boiling, the softened silk threads are carefully reeled off the cocoon.

Spinning and Weaving: The reeled silk threads are then twisted together to form threads of various thicknesses. These threads can be dyed and woven into different types of fabrics, ranging from delicate silk chiffon to heavier silk satin.

Sericulture is not only an ancient art but also a significant industry in various parts of the world, especially in countries like China, India, and Japan. It has cultural, economic, and historical significance, and the silk produced is highly regarded for its smooth texture, sheen, and durability.

Historical Perspective

The history of sericulture, the cultivation of silkworms to produce silk, is a fascinating journey that spans thousands of years and has its roots in ancient China. Sericulture is believed to have originated in ancient China during the Shang Dynasty. According to legend, Empress Leizu discovered silk when a silkworm cocoon dropped into her tea, unraveling a thread of silk. This discovery marked the beginning of silk production. For centuries, China tightly controlled the knowledge and production of silk. The Chinese guarded their sericulture techniques as valuable state secrets. Exporting silkworm eggs or silk-producing equipment was punishable by death. The knowledge of sericulture gradually spread along the Silk Road, a network of trade routes connecting China with the Mediterranean. This led to the establishment of sericulture in regions like India, Persia (modern-day Iran), and Byzantium (modern-day Turkey), and it became a thriving industry. By the Middle Ages, sericulture had reached Europe, but it remained a luxury reserved for the wealthy due to its high cost and rarity. Efforts to cultivate silkworms and produce silk in Europe were largely unsuccessful until the 15th century. The industrialization of sericulture began in France during the 18th century. The invention of mechanized silk-reeling machines and advances in mulberry cultivation techniques revolutionized the industry. France became a major silk producer, especially in Lyon. Sericulture became a vital industry in Japan during the 19th century. The Japanese introduced improvements in silkworm breeding, leading to high-quality silk production. The industry played a significant role in Japan’s economic development. Traditional sericulture declined in many countries during the 20th century due to factors like competition from synthetic fibers, labor-intensive nature, and disease outbreaks among silkworms. In recent decades, there has been a renewed interest in sustainable sericulture practices. This includes organic sericulture, where silkworms are raised without the use of pesticides, and efforts to preserve traditional sericulture techniques and heritage.

Today, sericulture remains an important industry in countries like China, India, Japan, and Brazil, among others. It has adapted to modern technologies and practices while preserving its historical and cultural significance. Silk, once a luxury for the elite, has become more accessible to people worldwide, thanks to advancements in sericulture and textile manufacturing.

Focus on empowering women through sericulture:

Empowering women through sericulture is a powerful and transformative aspect of the industry. Here are some key points on how sericulture can empower women:

1. **Economic Empowerment:** Women actively participate in various stages of sericulture, from mulberry cultivation to silk rearing and weaving. By engaging in these activities, they contribute to household incomes, gaining financial independence and stability.
2. **Skill Development:** Sericulture offers women opportunities to acquire valuable skills in agriculture, animal husbandry, and silk production. These skills enhance their self-confidence and make them more self-reliant.
3. **Decision-Making:** In regions where sericulture is prevalent, women often have a say in the management of silkworms, mulberry cultivation, and household silk-related businesses. This involvement in decision-making empowers them within their families and communities.
4. **Reduced Gender Disparities:** By participating in sericulture, women challenge traditional gender roles. They gain recognition for their contributions and often play leadership roles in sericulture cooperatives and self-help groups.

 ISBN: 978-81-965655-8-9

5. **Access to Resources:** In many cases, sericulture programs provide women with access to resources like training, credit, and technical support. This access enables them to start and expand their sericulture-related enterprises.
6. **Social Mobility:** The income generated through sericulture can improve the overall quality of life for women and their families. It can fund better education and healthcare, which can lead to improved social mobility.
7. **Community Building:** Women involved in sericulture often form cooperatives and self-help groups. These groups serve as platforms for mutual support, knowledge sharing, and collective decision-making, further enhancing women's empowermentz
8. **Preservation of Tradition:** Sericulture often aligns with traditional practices and craftsmanship. By engaging in sericulture, women can help preserve and pass on cultural heritage to future generations.
9. **Entrepreneurship Opportunities:** Many women entrepreneurs have successfully established small-scale silk-related businesses, such as silk reeling units or handloom weaving. These ventures allow women to become job creators and leaders in their communities.
10. **Role Models:** Successful women sericulturists serve as role models for others in their communities, inspiring more women to join the industry and pursue economic independence.

In conclusion, sericulture not only provides a sustainable livelihood for women but also empowers them economically, socially, and culturally. It fosters gender equality, skill development, and leadership opportunities, making it a powerful tool for women's empowerment in various parts of the world.

Role of women in traditional sericulture practices:

The role of women in traditional sericulture practices has been significant throughout history and remains crucial in many regions where sericulture is practiced. Here are some key aspects of the role of women in traditional sericulture:

- **Mulberry Cultivation:** Women often play a central role in mulberry cultivation, which is the primary food source for silkworms. They are responsible for planting, tending, and harvesting mulberry leaves, ensuring a continuous supply of food for the silkworms.
- **Silkworm Rearing:** Women are actively involved in the care of silkworms. They feed and monitor the silkworms as they go through their growth stages, ensuring optimal conditions for cocoon formation.
- **Cocoon Harvesting:** Women are responsible for harvesting the silk cocoons once they are ready. This delicate task requires precision to avoid damaging the valuable silk threads.
- **Silk Reeling:** After harvesting, women are often engaged in silk reeling, where they carefully unwind the silk filaments from the cocoon. This process is crucial in obtaining long, continuous silk threads.
- **Spinning and Weaving:** In many traditional societies, women are skilled in spinning and weaving silk threads into various textiles. They create beautiful silk fabrics, sarees, scarves, and other products, preserving traditional craftsmanship.
- **Household-Based Production:** In some cultures, sericulture is practiced as a household-based industry, with women managing sericulture-related activities within their homes. This allows them to balance their roles as homemakers and sericulturists.

- **Community-Based Initiatives:** Women often form cooperatives and self-help groups dedicated to sericulture. These groups provide mutual support, access to resources, and opportunities for collective decision-making, strengthening the community's involvement in sericulture.
- **Empowerment and Entrepreneurship:** Women involved in sericulture have opportunities to become entrepreneurs. They can establish small-scale silk-related businesses, such as silk reeling units or handloom weaving units, contributing to their economic empowerment.
- **Cultural Preservation:** Women's involvement in traditional sericulture practices helps preserve cultural heritage and traditional knowledge. It ensures the continuation of sericulture traditions from one generation to the next.
- **Gender Equality:** In some regions, sericulture has played a role in challenging traditional gender roles by providing women with income-generating activities and decision-making power. It contributes to reducing gender disparities in rural communities.

In summary, women have been the backbone of traditional sericulture practices, actively participating in various stages of silk production. Their involvement not only ensures the success of sericulture but also empowers them economically and socially, making sericulture a powerful tool for women's livelihoods and gender equality in many societies.

Challenges faced by women in the industry

Women in the sericulture industry often face various challenges, both traditional and contemporary, that can affect their participation and success in the sector. Some of these challenges include:

- Limited Access to Resources: Women may have limited access to land, credit, and technology required for mulberry cultivation and sericulture activities. This restricts their ability to invest in and expand their sericulture enterprises.
- Unequal Distribution of Labor: Women often bear a significant portion of the labor burden in sericulture, from mulberry cultivation to cocoon harvesting and silk reeling. This unequal distribution of labor can lead to physical and time-related stress.
- Low Income and Wage Disparities: Despite their substantial contributions to sericulture, women frequently earn lower wages than men in the industry. This income disparity can perpetuate gender-based economic inequalities.
- Lack of Training and Education: In some regions, women may have limited access to training and education in modern sericulture techniques. This hinders their ability to adopt more efficient and sustainable practices.
- Limited Decision-Making Power: Women may have limited influence in decision-making processes within sericulture cooperatives or households, especially in traditional, patriarchal societies. This can affect their ability to control resources and investments.
- Lack of Market Access: Women may face challenges in accessing markets for their silk products. Limited marketing skills, information, and networks can hinder their ability to sell silk at competitive prices.
- Seasonal Employment: Sericulture is often seasonal, and women's income may be limited to specific periods of the year. This seasonality can make financial planning and stability challenging.

 ISBN: 978-81-965655-8-9

- Health and Safety Concerns: Women engaged in sericulture activities, such as pesticide application in mulberry cultivation, may face health and safety risks without adequate protective measures.
- Climate Change Vulnerability: Climate-related changes, such as unpredictable weather patterns and temperature fluctuations, can impact mulberry cultivation and silkworm rearing. Women may bear the brunt of these challenges.
- Technological Gaps: The adoption of modern sericulture technologies, like mechanized equipment for silk reeling, may be limited among women due to a lack of access or training.
- Social Norms and Gender-Based Discrimination: Traditional gender roles and discriminatory practices in some societies can limit women's opportunities and hinder their mobility within the industry.

Addressing these challenges requires a multifaceted approach that includes improving access to resources, providing gender-sensitive training, promoting women's participation in decision-making, and raising awareness about the importance of gender equality in the sericulture industry. Empowering women in sericulture can lead to more sustainable and equitable development within the sector.

Economic impact on women and their families:

Sericulture can have a significant and positive economic impact on women and their families. Here are ways in which sericulture can contribute to the economic well-being of women and their households:

1. **Income Generation:** Sericulture provides women with a consistent source of income throughout the year. Women involved in mulberry cultivation, silkworm rearing, cocoon harvesting, and silk production can earn income from various stages of the sericulture process.
2. **Poverty Alleviation:** Income from sericulture can help lift women and their families out of poverty. It provides them with the means to meet basic needs, including food, clothing, and shelter, and access to education and healthcare.
3. **Financial Stability:** Sericulture offers a steady source of income, reducing the vulnerability of households to economic fluctuations and seasonal income variations often associated with other agricultural activities.
4. **Empowerment:** Women's participation in sericulture empowers them economically and socially. They become active contributors to their family's income and decision-making processes within their households.
5. **Education and Healthcare:** The additional income generated through sericulture can be invested in education and healthcare for women and their children. This can lead to improved access to quality education and better overall health outcomes.
6. **Asset Building:** With increased income, women and their families can invest in assets such as land, livestock, or housing, which can further enhance their economic security and future prospects.
7. **Entrepreneurship Opportunities:** Sericulture allows women to explore entrepreneurial ventures, such as establishing their own silk-related businesses or cooperatives. These initiatives can create additional income streams and job opportunities within their communities.

 ISBN: 978-81-965655-8-9

8. **Women's Economic Independence:** Income from sericulture can reduce women's financial dependence on male family members, contributing to greater economic independence and decision-making power.
9. **Community Development:** The economic impact of sericulture extends beyond individual households. It can stimulate local economies, create employment opportunities in rural areas, and contribute to the overall development of communities.
10. **Preservation of Traditions:** In regions where sericulture is a traditional practice, women's involvement helps preserve cultural heritage and traditional knowledge, passing down sericulture traditions to future generations.

In summary, sericulture not only provides women with a source of income but also has broader economic and social benefits for their families and communities. It empowers women, reduces poverty, improves access to education and healthcare, and contributes to the overall economic development of regions where it is practiced.

Success stories of women sericulturists

- There are many inspiring success stories of women sericulturists who have overcome challenges and made significant contributions to the sericulture industry. Here are a few examples:
- **Padmini Bhise (India):** Padmini Bhise, from Maharashtra, India, is a remarkable woman who transformed her life through sericulture. She started with just a small piece of land for mulberry cultivation and a few silkworms. Over the years, she expanded her sericulture activities and became a successful silk producer. Padmini's success story has inspired many other women in her community to take up sericulture as a means of livelihood.
- **Ishikawa Yoshie (Japan):** Ishikawa Yoshie, known as the "Silk Queen" of Japan, is a pioneering woman in the sericulture industry. She introduced innovative methods for rearing silkworms and improved silk production in her region. Her efforts not only boosted the local silk industry but also contributed to Japan's silk export business.
- **Bai Chunli (China):** Bai Chunli is a Chinese scientist who has made significant contributions to sericulture research. Her work focuses on improving silk production through genetic breeding and innovative silkworm rearing techniques. Her research has had a positive impact on the livelihoods of countless women involved in sericulture in China.
- **Nila Madhaba Patra (India):** Nila Madhaba Patra, a resident of Odisha, India, is a successful entrepreneur in the sericulture industry. He and his wife, Binapani Patra, run a silk farm and have trained numerous women in sericulture techniques. Their efforts have helped many women in their community become financially independent through silk production.
- **Mei Zhan (China):** Mei Zhan, a farmer from Zhejiang Province, China, transformed her life through sericulture. She learned modern sericulture techniques and established a thriving silk farm. Mei Zhan's success story is emblematic of how women in rural China are improving their livelihoods and becoming self-reliant through sericulture.

These success stories highlight the resilience, entrepreneurship, and innovation of women sericulturists. They serve as role models for others and demonstrate that sericulture can be a powerful tool for women's empowerment and economic independence. These women have not only improved their own lives but have also made valuable contributions to their communities and the sericulture industry as a whole.

 ISBN: 978-81-965655-8-9

Government Initiatives and Support

Many governments around the world have recognized the economic and social significance of sericulture and have initiated various schemes and programs to promote and support the sericulture industry. These initiatives aim to enhance silk production, improve the livelihoods of sericulturists, and promote sustainable practices. Here are some examples of government schemes and programs promoting sericulture:

1. National Sericulture Mission (NSM), India:

The NSM is a comprehensive program launched by the Government of India to promote sericulture. It focuses on increasing silk production, improving the quality of silk, and enhancing the income of sericulturists. The mission includes components like mulberry cultivation, silkworm rearing, silk weaving, research and development, and technology dissemination.

2. Silk Road Development Program, China:

China has a long history of sericulture and is a leading producer of silk globally. The government supports sericulture through research, technology development, and infrastructure investment. The Silk Road Development Program aims to revitalize the silk industry and strengthen its role in regional economic development.

3. Sericulture Development Program, Japan:

Japan has a rich tradition of sericulture. The government supports sericulture through research institutions, training programs, and financial assistance to sericulturists. These initiatives aim to maintain Japan's leadership in producing high-quality silk.

4. Sericulture Development Programs in various States of India:

Many states in India, such as Karnataka, Andhra Pradesh, and Assam, have their own sericulture development programs. These programs provide subsidies, training, and technical support to sericulturists. State-level initiatives are tailored to the specific needs and conditions of the region.

5. International Sericultural Commission (ISC):

The ISC is an intergovernmental organization that promotes international cooperation in sericulture research, technology transfer, and trade. Member countries collaborate to advance the sericulture industry globally.

6. Support for Value-Added Products:

Some governments provide support for the development of value-added silk products. This includes assistance for sericulturists and weavers in producing and marketing silk-based items like textiles, garments, and accessories.

7. Research and Development:

Governments invest in sericulture research and development to improve breeding techniques, disease control, and cocoon quality. This research benefits sericulturists by increasing productivity and sustainability.

8. Financial Incentives: Incentive programs may include subsidies for mulberry cultivation, sericulture equipment, and cocoon marketing. These financial incentives make sericulture more accessible and profitable for farmers.

9. Training and Skill Development: Governments often organize training programs and skill development workshops for sericulturists and artisans to enhance their knowledge and capabilities in various aspects of sericulture.

ISBN: 978-81-965655-8-9

These government schemes and programs play a crucial role in supporting sericulture as a sustainable and economically viable industry. They aim to empower sericulturists, promote environmentally friendly practices, and ensure the continued growth of the sericulture sector.

Future Prospects

Sericulture is evolving to adapt to changing market demands, sustainability concerns, and technological advancements. Several emerging trends in sericulture offer insight into its future prospects:

1. Sustainable and Organic Sericulture:

Increasing awareness of environmental and health issues has led to a growing demand for sustainably produced and organic silk. Practices like organic mulberry cultivation and chemical-free silk production are gaining popularity.

2. Biotechnology and Genetic Improvement:

Biotechnological advancements are being employed to develop disease-resistant silkworm varieties, leading to higher cocoon yields and silk quality. Genetic improvement through selective breeding is becoming more precise.

3. Digital Agriculture and Precision Farming:

The use of digital tools, such as remote sensing, IoT (Internet of Things), and data analytics, is being integrated into sericulture. Precision farming techniques enable optimized mulberry cultivation and silkworm rearing.

4. Value-Added Silk Products:

The production of value-added silk products, including designer textiles, high-end fashion, and eco-friendly fabrics, is on the rise. These products cater to niche markets and offer higher profit margins.

5. Circular Economy and Waste Reduction:

Efforts to reduce waste in sericulture are increasing. Innovations include using cocoon waste for various purposes, such as cosmetics, pharmaceuticals, and animal feed.

6. Eco-Friendly Dyeing and Processing:

Sustainable dyeing and processing techniques, like natural dyeing and water-saving methods, are gaining prominence. These practices reduce the environmental impact of silk production.

7. Block chain Technology for Traceability:

Blockchain technology is being explored to enhance the traceability of silk products. Consumers can verify the authenticity and origin of silk, promoting transparency and trust.

8. Female Empowerment and Gender Equality:

Empowering women in sericulture is increasingly recognized as a path to sustainable development. Initiatives to support and uplift women in the industry are gaining momentum.

9. Research on Alternative Silk Sources:

Research into alternative sources of silk, such as spider silk and synthetic silk production using bioengineering, is ongoing. These alternatives have the potential to diversify the silk industry.

10. Global Market Expansion:

Expanding international trade and e-commerce are opening new markets for silk products. Silk-producing countries are exploring opportunities for export and collaboration.

11. Climate-Resilient Sericulture:

As climate change poses challenges, sericulturists are adopting climate-resilient practices and diversifying income sources to mitigate risks associated with unpredictable weather patterns.

 ISBN: 978-81-965655-8-9

12. Sericulture Tourism:
Sericulture tourism is emerging as a niche travel experience, allowing tourists to learn about the silk production process and engage with local sericulture communities.

13. Cocoon Banks and Seed Conservation:
Initiatives to establish cocoon banks and conserve indigenous silkworm varieties and mulberry cultivars are gaining importance to maintain biodiversity.

These emerging trends in sericulture reflect the industry's efforts to meet evolving consumer preferences, address sustainability concerns, and harness technological innovations. As sericulture continues to adapt and innovate, it is likely to remain a significant contributor to livelihoods and the global textile market.

Potential for sericulture in women-led entrepreneurship
Sericulture presents significant potential for women-led entrepreneurship due to its adaptability, sustainability, and economic viability. Here's how sericulture aligns with women-led entrepreneurship and the opportunities it offers:

- **Low Barrier to Entry:** Sericulture requires relatively low initial capital, making it accessible to women entrepreneurs, especially in rural areas. It doesn't demand large-scale infrastructure or heavy machinery, allowing for gradual expansion.
- **Flexible Work Environment:** Sericulture activities can be integrated into a flexible work schedule, allowing women to balance their entrepreneurial pursuits with other responsibilities like caregiving and household duties.
- **Empowerment Through Ownership:** Women-led sericulture businesses empower women by giving them ownership and control over their production processes, income, and decision-making.
- **Sustainability and Market Demand:** The rising demand for sustainable and eco-friendly products aligns with sericulture. Women-led enterprises can cater to the growing market for environmentally responsible silk products.
- **Value Addition:** Women entrepreneurs can explore value addition by producing high-quality silk products, custom textiles, or designer items. These products often command premium prices in the market.
- **Social and Community Impact:** Women-led sericulture enterprises have a positive impact on local communities by creating employment opportunities, improving income levels, and promoting rural development.
- **Training and Skill Development:** Women entrepreneurs can engage in training programs and skill development to enhance their knowledge and expertise in sericulture, silk production, and marketing.
- **Cooperatives and Collaboration:** Collaborative approaches, such as forming sericulture cooperatives or self-help groups, enable women to pool resources, share knowledge, and collectively access markets and resources.
- **Access to Government Support:** Many governments promote women's participation in sericulture through special schemes, subsidies, and financial incentives, making it easier for women-led enterprises to get started.
- **Online Marketing:** Women entrepreneurs can leverage e-commerce and online marketing platforms to reach a broader customer base and explore export opportunities for their silk products.

 ISBN: 978-81-965655-8-9

- **Climate Resilience:** As climate change affects traditional agricultural practices, sericulture's adaptability to changing weather patterns offers women entrepreneurs a more resilient income source.
- **Diversification:** Women-led sericulture businesses can diversify income streams by exploring additional crops or activities alongside silk production, reducing income seasonality.
- **Education and Awareness:** Women entrepreneurs can contribute to educating their communities about sustainable sericulture practices, gender equality, and the importance of environmentally friendly production.
- **Leadership Opportunities:** Women-led sericulture enterprises can foster women's leadership by encouraging them to take on leadership roles in cooperatives and associations, helping shape industry policies and initiatives.

In summary, sericulture provides an ideal platform for women-led entrepreneurship, offering economic opportunities, sustainability, and empowerment. Women can build successful sericulture businesses that not only improve their livelihoods but also contribute to broader community development and promote eco-friendly practices in the textile industry.

CONCLUSION

In conclusion, sericulture holds immense significance for women's livelihoods and empowerment. It is more than just a traditional practice; it represents a pathway to economic independence, sustainable development, and gender equality. Sericulture provides women with a reliable source of income, allowing them to contribute to their households and communities financially. Engaging in sericulture empowers women by giving them control over economic resources, decision-making, and leadership roles within sericulture cooperatives and associations. Sericulture offers opportunities for women to acquire valuable skills in mulberry cultivation, silkworm rearing, and silk production, enhancing their expertise and marketability. Sericulture, when practiced sustainably, promotes eco-friendly farming practices, contributing to environmental conservation and biodiversity. Women's involvement in sericulture enables them to access markets for silk products, from raw silk to value-added items, creating entrepreneurship opportunities. Sericulture generates employment and fosters community development by improving infrastructure, education, and healthcare in rural areas. The adaptability of sericulture to changing weather patterns offers women a more resilient income source in the face of climate change. Sericulture initiatives that promote women's participation and gender-inclusive policies are instrumental in advancing gender equality and women's rights. Sericulture often carries cultural significance in many regions, and women play a crucial role in preserving and passing down these traditions. The changing sericulture landscape presents women with opportunities to engage in sustainable practices, value addition, technology integration, and global market expansion. In essence, sericulture is not just about silkworms and silk production; it represents a means for women to break down economic and societal barriers, improve their quality of life, and contribute to the sustainable development of their communities. Recognizing and supporting women's roles in sericulture is essential for harnessing the full potential of this ancient yet evolving industry. One can create an inclusive and supportive environment for women in sericulture, fostering their empowerment, economic independence, and contribution to sustainable development. Promoting gender equality in sericulture is not only a matter of social justice but also a pathway to a more prosperous and equitable industry and society as a whole.

REFERENCES

- Ahmed, S.A., Deuri, J. And Sarmah, M.C (2013): Ericulture, A Comprehensive Profile, Directorate of Sericulture BTC, Kokrajhar. D. Gangopadhyay: Sericulture Industries in India.
- Amrita, K., Garg, C.P. and Singh, S. (2018), Modelling the critical success factors of women entrepreneurship using fuzzy AHP framework, Journal of Entrepreneurship in Emerging Economies, Vol. 10 No. 1, pp. 81-116.
- Bruni, A., Gherardi, S., &Poggio, B. (2004). Gender and entrepreneurship: An ethno-graphic approach. New York: Routledge.
- Brush, C.G. & Cooper, S.Y. (2012), Female entrepreneurship and economic development: an international perspective, Entrepreneurship and Regional Development, Vol. 24 Nos 1/2, pp. 1-6.
- Buvinic, M., Gwin, C. & Bates, L. (1996). Investing in Women: Progress and Prospects for the World Bank. International Center for Research on Women Policy Essay, No 19, Washington, DC.
- Choudhary, E. (2018). Women Entrepreneurs: Making Green Business a Reality. Jharkhand Journal of Development and Management Studies, Vol-16(4), Pp. 7887-7902.
- Das, M. (2009): Sericulture and Ericulture in Assam, An Economic Analysis, Tushar Publication, Dibrugarh.
- Das. (2013): "Status of Women: North East Region Of India Versus India", International Journal of Science and Research Publication, Vol-3, Issue 1,January 2013
- Devi, M (2008): Muga Silk Industry in Assam: It's forward and Backward Linkages with the Regional Economy. Devi, M (2013): "Women Status In Assam", Journal of Business Management & Social Sciences, Vol-2, No.1, January 2013 Devi, M. (2013): "Women empowerment by way of muga silk industry", Global Methodology Journal, Vol-II,8th issue, Feb-March-April,2013
- Kabeer, N., &Subrahmanian, R. (1996). Institutions, relations and outcomes: Framework and tools for gender-aware planning. IDS Discussion Paper, No. 357, Institute of Development Studies, Brighton.
- Kelley, D. J., Brush, C. G., Greene, P. G., &Litovsky. Y. (2013). Global entrepreneurship monitor, 2012 Women's Report, The Center for Women's Leadership at Babson College and London Business School, Boston.
- M and Tertilt, M. (2010): "Does female empowerment promote economic development", women empowerment in india.com, 2012 Geeth, G.S. and Vindey, G.S. (2012): "Agency and oppurtunitystructure as two bases of women's economic empowerment: The case of silk industry", Central Sericultural Research and Training Institute,
- OECD. (2012). Gender equality in education, employment and entrepreneurship (Final Report to the MCM), May 2012, Paris.
- Panda, S. (2018). Constraints faced by women entrepreneurs in developing countries: review and Ranking. Gender Management. Vol. 33:4. doi: 10.1108/GM-01-2017-0003
- Shrirampur, Mysore, Karnataka, India Kaistha, S., Sahariya, A. and Vibhuti Patel, V. (2001): Gender and Development, The Women Press, Delhi Phukan, R: silk industry of Assam in

 ISBN: 978-81-965655-8-9

Historical Perspectives Statistical Handbook Assam, Directorate of Economics and Statistics Assam.

- Smith, A. (2010). The ecofetish: Green consumerism in women's magazines. WSQ: Women's Studies Quarterly, 38(2), 66-83. doi: 10.1353/wsq.2010.0023
- Sumathi, K., Anuradha, T., & Akash, S. (2014). Green business as a sustainable career for women entrepreneurs in India - An opinion survey. Advances in Management, 7(46).
- The World Bank. (2012). Gender equality and development, world development report 2012. Washington, DC: The World Bank.
- York, J., &Venkataraman, S. (2010). The entrepreneur–environment nexus: Uncertainty innovation, and allocation. Journal of Business Venturing, 25(5), 449-463. doi:10.1016/j.jbusvent.2009.07.007.

CHAPTER 11

ROLE OF REMOTE SENSING IN AGRICULTURAL SURVEY AND MONITORING

Bipasha Borkotoky[1*], Mriganko Kakoti[2], Gariyashi Tamuly and Shreedhar Beese
[1] Department of Soil Science, Assam Agricultural University, Jorhat-785013
[2]Department of Agricultural Meteorology, Assam Agricultural University, Jorhat-785013
[3]SMS, KVK, Baksa, AAU, Assam
[4]Ph.D. Scholar, Department of Floriculture & Landscape Architecture, Dr. Y S Parmar University of Horticulture & Forestry, Nauni Solan (HP)

ABSTRACT

The importance of regular survey and monitoring in India's agriculture sector has never been more critical, given the twin challenges of meeting rising demand and addressing pricing crises. Traditional methods of crop monitoring, such as manual inspections and ground-based sampling, are labour-intensive, time-consuming, and often lack real-time insights.Remote sensing, through both satellite-based and UAV-based methods, has emerged as a gamechanger in agricultural surveying and monitoring. It offers a wealth of advantages, including consistent data acquisition, multi-spectral imaging capabilities, and large-scale mapping through satellites. Meanwhile, drones provide high-resolution, on-demand data collection, making them ideal for localized assessments. The precision and efficiency of remote sensing technologies are paramount in optimizing crop yields, controlling pests and diseases, and enhancing overall agricultural productivity. By harnessing the power of satellite imagery and UAVs, India's agriculture sector can navigate the challenges it faces and move towards more sustainable and data-driven practices. This technological revolution is a significant step towards ensuring food security, economic growth, and environmental sustainability in India's agricultural landscape

Keywords: Remote sensing, Satellite, UAV, Survey, Monitoring

INTRODUCTION

Agriculture holds a central position in India's economy, it faces the dual challenge of meeting surging demand and grappling with a severe pricing crisis. Thus, in this era of rapid growth, the significance of regular survey and monitoring of the agricultural sector has increased than before, because even a solitary issue during crop seasons, be it pests, diseases, or other threats, can significantly disrupt the production. The monitoring of crops extends beyond the prevention of pest outbreaks; it also assures that diseases and weeds, prone to emergence, are effectively controlled, thus controlling major disruptions in terms of yield and end-product quality (Bhandari et al., 2021). Traditional approaches to crop monitoring, such as visual inspections and manual collection of ground samples from random locations (Hafeez et al., 2022), are beset by challenges. The current state of Indian agriculture grapples with a severe shortage of labour to enhance productivity and carry out frequent monitoring. On the other hand, the traditional survey and monitoring system is not only time-consuming but also labour-intensive, and it fails to provide real-time insights into crop and asset status within the fields. The precision and expertise involved in human-led survey and monitoring are also subject to scrutiny. Hence, the need for a smart agricultural system is paramount, one that can efficiently monitor crop yields and pre-empt potential mishaps. Taking into account all these factors, a new era of crop survey and monitoring is emerging, fuelled by the utilization of diverse remote sensing approaches.

Remote sensing involves the intricate process of capturing and observing the physical attributes of a specific area/object by measuring the radiation it emits or reflects from a considerable distance, often accomplished through satellites or aircrafts. Specialized sensors/ cameras are employed to acquire these remote-sensed images, offering researchers a unique window through which they can discern valuable information. This realm of remote sensing comprises two distinctive techniques namely active and passive remote sensing. Active remote sensing devices possess their own emission source or light, which they utilize in the data collection process. In contrast, passive counterparts rely on the reflected radiation from external sources. When activesensors in remote sensing transmit signals toward the target, they meticulously analyze the resulting responses or received quantities. The preference for microwaves in many of these devices is attributed to their resilience against adverse weather conditions. On the other hand, passive sensors in the realm of remote sensing do not emit their own energy towards the subject of scrutiny, unlike their active counterparts. They depend on natural sources of energy, often sunlight, which is reflected by the target of interest. Consequently, the effectiveness of passive remote sensing depends on the presence of adequate sunlight; without it, there would be insufficient radiation for the sensors to capture. For agricultural applications, remote sensing emerges as an all-encompassing technology that harmonizes its power with the computer technology. This fusion is instrumental in advancing agricultural production, agricultural development, and the adequate survey of agricultural land (EOS Data Analytics, 2020).

In the field of agro-ecosystem monitoring, remote sensing primarily relies on two methods: satellite-based remote sensing and unmanned aerial remote sensing. These technologies are utilized for various agricultural objectives, colour display, and other markers for interpretation, to effectively study agricultural resources. They also help in other operations like monitoring crops, estimating their yields, issuing warnings about crop disasters, and assessing the aftermath of such disasters. In-depth analyses of high-quality images, which come from optical and radar sensors over a series of time (known as hyper-temporal analysis), are employed. They are used to observe how things change during different seasons, the life cycle of natural and cultivated plants, and unique land features for identifying different types of crops. Several plant and soil indices, derived from remote sensing data, prove to be valuable in representing the crop (Food and Agricultural Organization).

Principle of Remote Sensing Imaging

The process of remote sensing of ground targets relies on the unique spectral features of the objects being observed. This involves how these objects absorb and reflect light when exposed to it, as well as how they emit radiation after absorbing it.When sunlight reaches the Earth's surface, it first passes through the atmosphere, which has the ability specific absorption of solar radiation. Since sunlight consists of complex range of wavelengths of radiation, the atmosphere interacts differently with each of these wavelengths. As a result, after passing through the atmosphere, some wavelengths get reflected, while others are absorbed by various substances in the atmosphere.

The part of the spectrum that allows certain frequencies of light to pass through the atmosphere most easily is known as the "atmospheric window". This window includes ultraviolet, visible, and near-infrared spectral bands. Remote sensing satellites primarily use data from these bands. When sunlight reaches an object's surface through the atmosphere, it interacts differently with the same spectral band depending on the properties of the objects. As a result, it reflects and emits radiation of different wavelengths back into the atmosphere. Sensors on remote sensing satellites capture these various data signals, which are essentially reflections of the object's spectral characteristics. The combination of these signals forms the remote sensing image of the object.

Characteristics of remote sensing imaging

The key characteristics of remote sensing imaging are as follows:

A. Spectral Sensitivity: Remote sensing imaging systems are designed to capture electromagnetic radiation across different parts of the electromagnetic spectrum, including

 ISBN: 978-81-965655-8-9

visible light, infrared, and microwave wavelengths. Each spectral band provides unique information about the objects or features on the Earth's surface. For example, visible and infrared bands are often used to study vegetation health, while microwave bands are suitable for soil moisture and geological investigations. The ability to sense a range of wavelengths allows for comprehensive analysis and differentiation of various surface properties.

B. **Spatial Resolution:** Spatial resolution refers to the level of detail in an image or dataset. Remote sensing systems can vary in spatial resolution, with some providing high-resolution imagery that allows for the identification of small-scale features (e.g., individual trees or buildings), while others offer coarser resolution suitable for broader land cover analysis. The choice of spatial resolution depends on the specific application and the trade-off between detail and coverage.

C. **Temporal Resolution:** Temporal resolution relates to the frequency at which data is acquired over time. Some remote sensing systems capture images or data at regular intervals, such as daily or weekly, while others have longer revisited periods. Temporal resolution is crucial for monitoring dynamic processes and changes on the Earth's surface, such as crop growth, land use changes, and natural disasters. The availability of frequent and consistent data is essential for tracking and responding to such events effectively (Wang et al., 2022).

Spectral sensitivity, spatial resolution, and temporal resolutiondefines the capabilities and versatility of remote sensing imaging technology, allowing it to serve a wide range of applications in fields such as agriculture, environmental monitoringand disaster management.

Types of remote sensing platforms for surveying and monitoring

Remote sensing platforms play a crucial role in surveying and monitoring various aspects of the Earth's surface. Two prominent categories of these platforms are satellite-based remote sensing and UAV-based (Unmanned Aerial Vehicle) remote sensing which are mainly used in agro-ecosystem surveying and monitoring.

A. Satellite based survey and monitoring

Satellite crop monitoring represents a technology that harnesses the power of high-resolution satellite imagery to provide real-time insights into crop vegetation and development. By analyzing the spectral properties of these images, the growth cycles of the crops can effectively be evaluated.In the realm of remote sensing, the data can be vast and intricate to deal with, especially when it comes to high-resolution imagery. Such images are treasures of information, offering a wealth of insights beyond what the naked eye can perceive. Yet, factors like spectral reflections and interference between objects can create hurdles in the path of precise analysis of the satellite images.The complexity of computer-aided interpretation of remote sensing digital pictures is substantially increased by crops, which have their own growth phases, differ from other areas, differ from other development stages, and differ from other spectrum information and imaging time (Wang et al., 2022).The variations in vegetation indices reveal differences in the growth of individual crops, indicating the need for tailored agricultural interventions in specific field zones. In essence, satellite crop monitoring is the epitome of precision agriculture, enabling to focus on areas where customized attention is required to optimize crop yields.Furthermore, these satellite-based images offer a unique window into assessing the suitability of different crops for specific regions. When combined with critical soil and climatic data, they become invaluable tools for making informed decisions about what to cultivate where, fostering sustainable agriculture practices.In essence, satellite crop monitoring is the bridge between the scientific advancement and the targetedfarmland, bringing the power of

 ISBN: 978-81-965655-8-9

space technology to our agricultural endeavors, all while simplifying the complex process of understanding our crops' needs and optimizing their growth.

The satellite remote sensing system used to observe Earth through satellites includes four key components: the satellite platform system, the satellite operation control system, the data transmission processing system, and the image data application system.

i. The satellite platform system consists of both the space platform system and airborne sensors. It serves as a carrier responsible for providing the means for different observation tools to operate in space. It handles processing and connectivity tasks.The primary function of satellite earth observation equipment is the transmission of image data from the ground to the ground. This equipment acts as the "eyes" of the entire system. It uses various sensors installed on the ground, such as those sensitive to visible light, infrared, and microwaves, to observe and document objects on the Earth's surface.

ii. The satellite control system manages the satellite by combining data from different stations in the system. In order to correct the satellite's operation route, regulate the satellite's operation status, and carry out satellite operation and other activities, the satellite platform is outfitted with detecting equipment, altitude control, and orbit operation through a ground command station.

iii. The satellite data transmission processing system is responsible for a series of critical operations. It involves functions such as receiving and sending data on the ground, making sure the communication data is accurate, compressing the data to save space, converting it into a usable format, and many others. This system essentially serves as the central hub for managing all satellite data-related processes.

iv. The image data application system plays a crucial role in handling remote sensing images from satellites. It takes these images and sends them to the ground processing system. This ground processing system serves various industries by managing tasks like positioning control, creating standard products, advanced image processing, and applications specific to different fields. Ultimately, it offers services that cater to the needs of end-users.

B. Unmanned Aerial Vehicle (UAV) based survey and monitoring

In the era of smart farming and precision agriculture, aerial remote sensing has emerged as a critical technology. Aerial remote sensing, facilitated by drones, involves capturing images utilizing various wavelengths and analyzing vegetation indices to assess the condition of crops (Akram et al., 2017). In the past, obtaining these images for precision agriculture often required costly manned aircraft or satellites. However, using manned aircraft for image capture is expensive, and satellite images may not always provide the level of details needed due to limited spatial resolution, as well as dependence on weather conditions (Hunt and Daughtry, 2018).The advent of Unmanned Aerial Vehicle (UAV) technology and the reduced weight of payload devices have transformed crop monitoring system. UAVs offer a more cost-effective and efficient way to capture high-resolution images without causing harm to crop, making it a preferred choice in modern precision agriculture.

Importantly, there are strong connections between the yield of a crop and the vegetation indices calculated at specific stages of its growth (Xue and Su, 2017). These connections are valuable for monitoring and predicting crop yields.A drone survey involves using an unmanned aerial vehicle (UAV), commonly known as a drone, to collect data from above. These drones are equipped with downward-facing sensors like RGB or multispectral cameras and sometimes LIDAR devices. When conducting a drone survey with a camera, the drone takes pictures of the ground from various angles, and each image is tagged with its location coordinates. These images can be used to create a map that showing spatial distribution of vegetation indices over

 ISBN: 978-81-965655-8-9

an area. These indices are helpful for understanding crop health, identifying issues like diseases, nutrient deficiencies, or water stress (Patel et al., 2013).Vegetation indices are especially useful for distinguishing between healthy plants, unhealthy ones, and unwanted plants like weeds (Swain et al., 2010). These indices are derived from the spectrum of light reflected by the crops in the images, and this spectrum is closely related to the health of the crops.Importantly, there are strong connections between the yield of a crop and the vegetation indices calculated at specific stages of its growth (Xue and Su, 2017). These connections are valuable for monitoring and predicting crop yields.

To ensure successful crop monitoring, selection of right sensors to pair with drones is a critical decision. The selection of sensors primarily depends on their specific applications, such as detecting diseases, assessing nutrient levels, or identifying water status in crops. Over time, researchers have been diligently enhancing drone technology and have crafted specialized drones tailored for crop monitoring purposes.It's worth noting that the real turning point for Unmanned Aerial Vehicle (UAV) systems in agriculture occurred around 2011. This shift was likely fuelled by the affordability and user-friendliness of both drone technology and the accompanying payload devices (Frankelius et al., 2019). This accessibility opened up new possibilities for leveraging drones in the agricultural sector, leading to significant advancements in precision farming and crop management.

Drones have revolutionized topographic surveys, providing data of the same high quality as traditional methods but at a significantly faster pace. This not only cuts down on survey costs but also reduces the workload for specialists. Unlike manned aircraft or satellites, drones can fly much closer to the ground, resulting in rapid generation of high-resolution, highly accurate data. Plus, they are not hindered by atmospheric conditions like cloud cover.Drone-based surveying holds immense potential for GIS professionals too. It's also a boon for farmers, offering aerial views of their crops. This aids in monitoring the water supply, soil types, and identifying pests and fungal infestations. The images captured by drones encompass both infrared and visible spectrums. Extracting various features from these images provides insights into plant health that aren't visible to the naked eye. Moreover, the ability of technology to provide regular crop data updates, even on a weekly or hourly basis, is invaluable. This frequent access to crop information empowers farmers to make timely adjustments for more effective crop management (Garg et al., 2018).

Remote sensing data acquisition and image pre-processing

A. Processing of satellite imageries

Processing of satellite imagery involves a series of steps to enhance, analyze, and extract meaningful information from the raw data collected by satellite sensors.

1. Data Acquisition: The process begins with the collection of satellite imagery by orbiting satellites equipped with sensors. These sensors capture electromagnetic radiation in various spectral bands, such as visible, infrared, and microwave, depending on the mission and satellite.

2. Data Pre-processing:

I. Radiometric Calibration: This step corrects for variations in sensor sensitivity, ensuring that pixel values represent accurate reflectance or radiance values.

II. Geometric Correction: Geometric correction rectifies distortions caused by the satellite's orbit, Earth's curvature, and sensor tilt, ensuring that pixels are accurately georeferenced.

III. Atmospheric Correction: Atmospheric correction removes the effects of the Earth's atmosphere, which can absorb or scatter radiation, to obtain surface reflectance values.

 ISBN: 978-81-965655-8-9

IV. Image Enhancement: Image enhancement techniques are applied to improve the visual quality and interpretability of satellite images. These techniques include contrast stretching, histogram equalization, and filtering to enhance specific features or details.

V. Feature Extraction: After classification, additional features can be extracted from the imagery, such as vegetation indices (e.g., NDVI for assessing vegetation health), texture measures, and object-based information.

VI. Data Integration: Satellite imagery can be integrated with other geospatial data, such as Geographic Information Systems (GIS) layers or ground-based measurements, to enhance analysis and decision-making.

B. Processing of drone survey data

When conducting surveys with drones, multiple images of the ground are captured from various angles and positions. These images are then processed using photogrammetry software, which can create Orth mosaics (geometrically corrected aerial images) and 3D models. The most useful feature of these models is that it can provide precise measurements of distances, surface areas, and volumes of physical objects. This technology enables accurate and detailed assessments of the surveyed area, making it a valuable tool in fields like land surveying, construction, and environmental monitoring.

1. Data outputs from the drone

Images captured by a drone are typically stored on a memory card, similar to a regular camera. Depending on the drone's capabilities, these images may already have location information attached (geo-tagged) orcan import the geo-tags from external software.For a given survey area, there may have anywhere from a few hundred to several thousand drone acquired images. Each of these images contains geographical data, including coordinates (X, Y) and altitude (Z), allowing for precise mapping and analysis of the surveyed site.

2. Importing into a photogrammetry software

Once geo-tagged images are imported or uploaded into photogrammetry software like Propeller, Bentley ContextCapture, or Pix4D, the software stitches these images together to create 2D or 3D models of the surveyed site. The speed of this image processing can vary depending on factors such as the number of images and the computer's performance.Some photogrammetry software is designed for desktop use, requiring a powerful computer with robust hardware for efficient processing. In contrast, there are cloud-based photogrammetry solutions available, which utilize powerful remote servers for data processing. This cloud-based approach can significantly accelerate data processing, particularly for larger datasets. (Link)

Benefits of application of satellite based remote sensing in monitoring and surveying

- **Consistency and Repeatability:** Satellites follow predetermined orbits, resulting in regular and consistent data acquisition. This attribute is crucial for long-term surveys and monitoring projects where trends and changes need to be assessed over extended periods. By capturing data at predefined intervals, surveyors can analyze temporal variations, track seasonal patterns, and detect gradual environmental changes.

- **Multi-Spectral Imaging:** Satellites are equipped with sensors that capture data in various spectral bands of the electromagnetic spectrum. This multi-spectral capability enables surveyors to analyze different aspects of the Earth's surface and atmosphere. For example, optical sensors can capture visible and infrared light, allowing for land cover classification, vegetation health assessments, and geological studies. Microwave sensors, on the other hand, are useful for applications like soil moisture measurement and radar imaging.

ISBN: 978-81-965655-8-9

- **Large-Scale Mapping:** Satellite imagery provides a synoptic or wide-area view of landscapes, making it particularly efficient for large-scale mapping projects. Surveyors can use this data for tasks like land use planning and monitoring changes in vast regions, such as forests or agricultural areas. The ability to cover extensive areas in a single pass minimizes the need for costly and time-consuming ground surveys.

- **Synoptic View:** Satellites provide a synoptic perspective, capturing data simultaneously over entire landscapes. This holistic view allows surveyors to assess the spatial relationships among different features within a region, helping them understand complex patterns and interactions.

Benefits of application of drones in monitoring and surveying

- **Reduction of Field Time and Costs:** The use of drones for capturing topographic data is up to five times faster than traditional land-based methods, requiring fewer personnel. Utilizing geo-tagging eliminates the need for extensive Ground Control Points (GCPs), saving valuable time and resources. This leads to quicker and more cost-effective delivery of survey results.

- **Provision of Accurate and Comprehensive Data:** Drones generate thousands of measurements in a single flight, offering a wide range of data formats such as Orth mosaics, point clouds, Digital Terrain Models (DTMs), Digital Surface Models (DSMs), and contour lines. Each pixel on the resulting map or point in the 3D model contains precise geo-data, enabling highly detailed and accurate measurements.

- **Make Access to Inaccessible Areas:** Aerial surveying drones can access locations that are otherwise difficult or unsafe to reach, including steep slopes and challenging terrains. This eliminates the need to close highways or train tracks for surveys and allows for data capture during ongoing operations without significant organizational disruptions.

- **Precision in Measurements:** High-resolution orthophotos facilitate precise distance and surface measurements, enhancing surveyor accuracy.

- **Stockpile Volumetric Measurement Capability:** 3D mapping software enable efficient and cost-effective volume measurements of drone acquired images, particularly valuable for inventory or monitoring purposes in mining and quarry operations. Drones capture data more comprehensively and safely compared to manual methods, without interrupting site activities. Drones offer surveyors the capability to collect a significantly higher number of topographic data points, resulting in more precise volume measurements. This process is not only more accurate but also considerably safer compared to traditional manual methods, which often involve physically navigating stockpiles.

- **Allowance of Slope Monitoring:** With automated GIS analysis, it is possible to extract slope measurements from DTMs and DSMs generated by drone imageries. Knowing the steepness of the ground surface, the areas can be classified and used for slope monitoring purposes, including landslide mitigation and prevention.With Orth mosaics taken at different times, it is possible to detect changes in earth movement and to measure its velocity. This data can help predict landslides and prevent potential damage to roads, railways and bridges. It is also helpful in crop planning based on precise understanding of the slope patterns of the surveyed field.

CONCLUSION

The combined utilization of satellitebased, and UAVbased remote sensing methods has profoundly transformed the landscape of agricultural surveying and monitoring. These technologies provide timely, accurate, and actionable information to farmers, researchers, and policymakers. Satellite-based remote sensing offers global coverage and consistency, making it ideal for large-scale assessments and trend analysis. UAVs, on the other hand, offer high-resolution, on-demand data collection, enabling precise and localized insights. Together, they enhance crop management, resource optimization, and resilience in the face of evolving agricultural challenges, contributing to global food security and sustainable farming practices.

REFERENCES

- Akram, T., Naqvi, S. R., Haider, S. A., and Kamran, M. (2017). Towards real-time crops surveillance for disease classification: exploiting parallelism in computer vision. Computers & Electrical Engineering, 59: 15-26.
- Bhandari,Y., Ingale M., Jagtap, M., Raghuvanshi, A., and Dhade, P.(2021). A Survey on Precision Agriculture: Crop Health Monitoring and Protection.International Journal of Engineering Research & Technology, 10(12).
- EOS Data Analytics (2020). Types of remote sensing: technology changing the world. https://eos.com/blog/types-of-remote-sensing/
- Food and Agricultural Organization. Geospatial information for sustainable food systems: Agricultural monitoring. https://www.fao.org/geospatial/our-work/what-we-do/agricultural-monitoring/en/
- Frankelius, P., Norrman, C., and Johansen, K. (2019). Agricultural innovation and the role of institutions: lessons from the game of drones. Journal of Agricultural and Environmental Ethics, 32: 681-707.
- Garg, B., Aggarwal, S., and Sokhal, J. (2018). Crop yield forecasting using fuzzy logic and regression model. Computers & Electrical Engineering, 67: 383-403.
- Hafeez, A., Husain, M. A., Singh, S. P., Chauhan, A., Khan, M. T., Kumar, N., Chauhan, A. and Soni, S. K. (2022). Implementation of drone technology for farm monitoring & pesticide spraying: A review. Information processing in Agriculture, 10(2): 192-203.
- Hunt Jr, E. R., and Daughtry, C. S. (2018). What good are unmanned aircraft systems for agricultural remote sensing and precision agriculture. International journal of remote sensing, 39(15-16): 5345-5376.
- Patel, P. N., Patel, M. A., Faldu, R. M., and Dave, Y. R. (2013). Quadcopter for agricultural surveillance. Advance in Electronic and Electric Engineering, 3(4): 427-432.
- Swain, K. C., Thomson, S. J., & Jayasuriya, H. P. (2010). Adoption of an unmanned helicopter for low-altitude remote sensing to estimate yield and total biomass of a rice crop. Transactions of the ASABE, 53(1): 21-27.
- Wang, M., Wander, M., Mueller, S., Martin, N., & Dunn, J. B. (2022). Evaluation of survey and remote sensing data products used to estimate land use change in the United States: Evolving issues and emerging opportunities. Environmental Science & Policy, 129, 68-78.
- Wang, N., Liu, T., Tang, X., and Yuan, Q. (2022). Remote Sensing Satellite Image-Based Monitoring of Agricultural Ecosystem. Wireless Communications and Mobile Computing, 2022.
- Xue, J. and Su, B. (2017). Significant remote sensing vegetation indices: A review of developments and applications. Journal of sensors.

ISBN: 978-81-965655-8-9

CHAPTER 12

PHYTOREMEDIATION OF HEAVY METALS

[1*]Kishor Jyoti Bhuyan, [2]Manish Kumar Maurya, [3]Dimpi Dutta, [4]Debasmita Nath
[1,2,4]MSc. Scholar, Assam Agricultural University
[3]Ph.D Scholar, Assam Agricultural University

INTRODUCTION

The accumulation of heavy metals in the environment has emerged as a significant problem, leading to increased pollution and causing irreversible harm to the ecosystem. Heavy metal pollution has evolved into a global concern, driven by their release into the environment through processes like mining and various industrial activities. With industrialization and disruptions in natural biogeochemical cycles, heavy metal contamination has escalated in severity and impact. Unlike organic compounds, heavy metals are largely resistant to biodegradation, which results in their persistent buildup in the environment. This accumulation of heavy metals in soils and groundwater poses threats to both the environment and human health. These elements tend to accumulate in the tissues of living organisms through a process called bioaccumulation, and their concentrations increase as they move up the food chain in a phenomenon known as biomagnification. In soil, the buildup of heavy metals can adversely affect beneficial microorganisms by interfering with their metabolic processes (Khan et al., 2010).

In biological systems, heavy metals are categorized as either essential or non-essential based on their biological roles. Essential heavy metals are required in trace amounts for vital physiological and biochemical functions in living organisms. Examples of such essential heavy metals include manganese (Mn), iron (Fe), copper (Cu), zinc (Zn), and nickel (Ni) (Cempel and Nikel, 2006). Non-essential heavy metals, on the other hand, are not needed by living organisms for any physiological or metabolic processes. Non-essential heavy metals encompass cadmium (Cd), lead (Pb), arsenic (As), mercury (Hg), and chromium (Cr) (Dabonne et al., 2010). Elevated concentrations of heavy metals exceeding certain threshold levels can have detrimental health effects as they disrupt the normal functioning of biological systems.

Heavy metals find their way into the environment through both natural processes and human activities. Natural sources include mineral weathering, erosion, and volcanic activity, while anthropogenic sources involve activities like mining, electroplating, pesticide and phosphate fertilizer use, the application of biosolids in agriculture, industrial discharges, atmospheric deposition, and more.

Negative impacts of heavy metals in human health

Heavy metal pollution poses a significant threat to human health, necessitating special attention due to its potentially severe consequences, including the risk of cancer. Even trace amounts of heavy metals can lead to serious health issues (Memon and Schröder, 2009). The presence of heavy metals triggers the generation of free radicals, leading to the onset of oxidative stress (Mudipalli, 2008). Oxidative stress is characterized by an increased production of reactive oxygen species (ROS), which can overwhelm the cell's natural antioxidant defenses, resulting in cell damage or death (Das et al., 2008). Heavy metals known for their toxicity include mercury (Hg), lead (Pb), cadmium (Cd), copper (Cu), arsenic (As), zinc (Zn), tin (Sn), and chromium (Cr). These toxic heavy metals can cause a wide range of health issues, depending on the specific metal, its concentration, and its oxidation state. The following table provides a list of adverse effects associated with certain heavy metals on human health.

 ISBN: 978-81-965655-8-9

Heavy metal	Harmful effects
As	Since As (as arsenate) is a phosphate analogue, it hinders the critical cellular functions such as oxidative phosphorylation and ATP generation
Cd	Carcinogenic, mutagenic, teratogenic; endocrine disruptor; interferes with calcium control; causes chronic anaemia and renal failure
Cr	Causes hair loss
Cu	Higher levels have been linked to brain and kidney malfunction, chronic anaemia, cirrhosis of liver as well as inflammation of stomach and intestine
Hg	Anxiety, sleepiness, autoimmune disorders, depression, exhaustion, hair loss, insomnia, irritability, memory loss, infections, restlessness, temper outbursts, ulcers, and damage to the brain, kidneys, and lungs are all symptoms of a faulty immune system
Ni	Itching due to nickel is an allergic dermatitis; it's inhalation can cause cancer of the nose, lungs and sinuses; malignancies of the stomach and throat have also been related to its inhalation; Causes hair loss and is hematotoxic, immunotoxic, neurotoxic, genotoxic, reproductive toxic and hepatotoxic
Pb	Its higher doses can cause delay in development, lower IQ, short-term memory loss, and coordination issues in children; may lead to renal failure and increase the chances of developing cardiovascular disease
Zn	Over dosage may lead to fatigue and dizziness

Phytoremediation—A Sustainable Solution to Heavy Metal Pollution

Phytoremediation primarily involves using plants and their associated soil microorganisms to reduce pollutant concentrations in the environment. This approach can effectively target heavy metals, radionuclides, and organic contaminants like polynuclear aromatic hydrocarbons and pesticides. It is an environmentally friendly and cost-effective in-situ remediation method known for its innovative nature. Phytoremediation allows plants to manage environmental toxins without negatively impacting topsoil, preserving its fertility. In fact, it can even enhance soil fertility by introducing organic materials (Mench et al., 2009). The term "phytoremediation" is derived from the Greek words "phyto" (meaning plant) and "remedium" (meaning to repair). Green plants possess a unique ability to detoxify contaminants in various ways.

Phytoremediation technology is relatively recent, with the majority of research conducted in the past two decades (1990s). The concept of phytoremediation, initially proposed by Chaney in 1983 (as phytoextraction), has gained widespread support due to its appealing nature. It is particularly suitable for large agricultural areas where other cleanup methods may be less effective. Compared to alternative remediation approaches, phytoremediation stands out for its lower installation and maintenance costs. In terms of expenses, it can be as low as 5% of the cost of alternative cleanup methods (Prasad, 2003). Planting vegetation on polluted soils also serves to prevent erosion and leaching (Chaudhry et al., 1998). Economically, phytoremediation can serve three purposes when restoring damaged areas: (1) risk reduction through phytostabilization, (2) phytoextraction of valuable metals like gold, nickel, and thallium, and (3) long-term land management in which phytoextraction gradually improves soil quality for future cultivation of high-value crops. Additionally, rapidly growing plants that produce ample biomass, such as willow, jatropha, and poplar, can be used for both phytoremediation and energy production

 ISBN: 978-81-965655-8-9

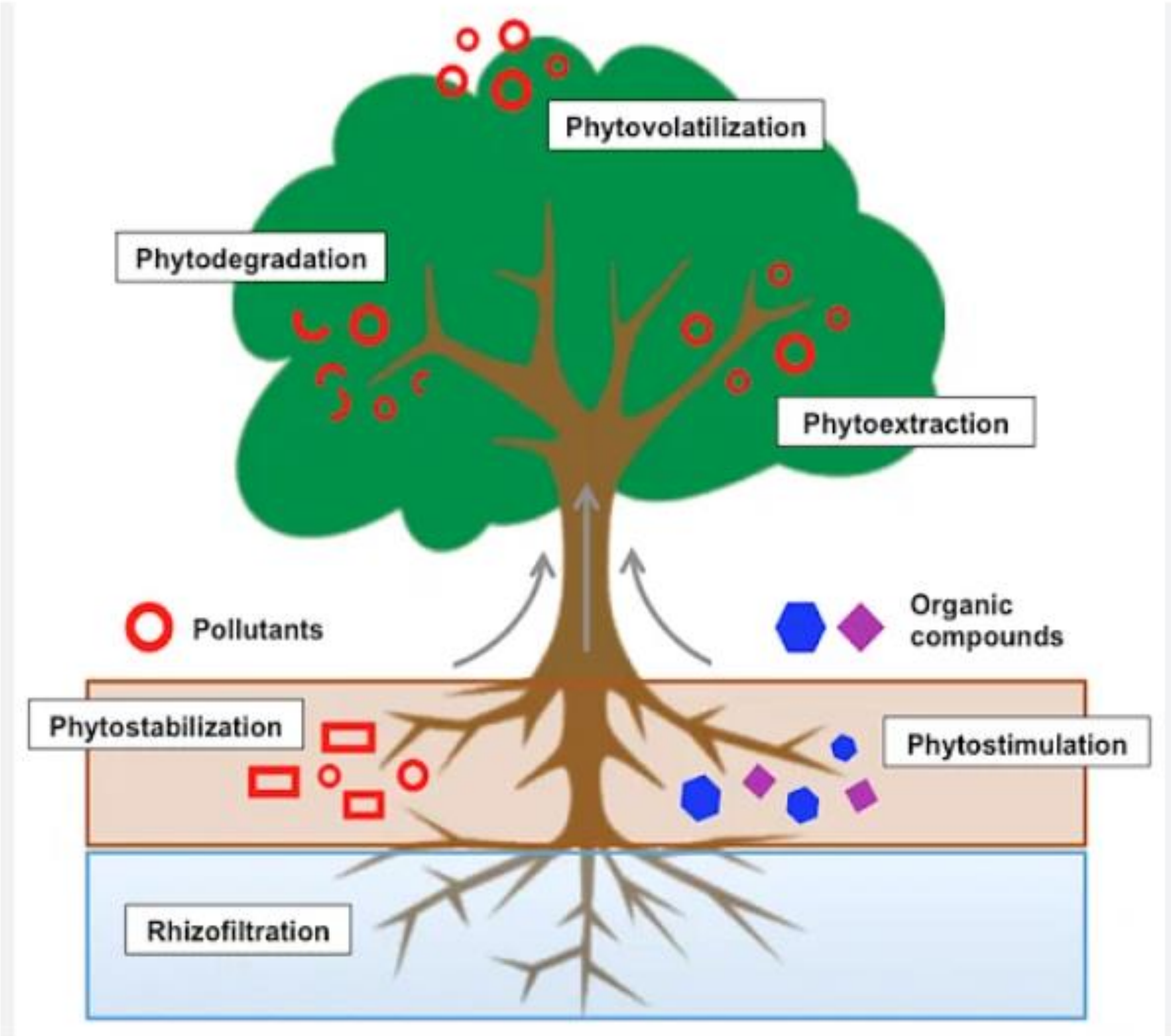


Fig: Illustration of different strategies of phytoremediation

Strategies of phytoremediation

Various techniques within the realm of phytoremediation encompass phytoextraction (also known as phytoaccumulation), phytofiltration, phytovolatilization, phytostabilization, and photodegradation.

Phytoextraction

Phytoextraction, also referred to as phytoaccumulation, phytosequestration, or phytoabsorption, involves the uptake of pollutants by plant roots and their subsequent transport and accumulation in the aboveground biomass, particularly in the shoots (Rafati et al., 2011). The crucial biochemical process of metal translocation to the shoots is essential for the effectiveness of phytoextraction, as harvesting root biomass is often impractical.

Phytofiltration

Phytofiltration, as described by Mukhopadhyay and Maiti (2010), is a method in which plants remove contaminants from the surface of polluted water. Phytofiltration can be implemented in various ways, including rhizofiltration (utilizing plant roots), blastofiltration (employing

 ISBN: 978-81-965655-8-9

seedlings), and caulofiltration (using excised plant shoots). During this process, contaminants are either absorbed or adsorbed, effectively diminishing their movement into subsurface waters.

Phytostabilization

Phytostabilization is a strategy involving the use of specific plant species to secure and immobilize pollutants within contaminated soils (Singh, 2012). This approach has been employed to contain the spread of contaminants in the environment, preventing their entry into groundwater sources or the food chain (Erakhrumen, 2007). Plants achieve the immobilization of heavy metals in the soil through processes like root sorption, precipitation, complexation, and reduction of metal valence in the plant's rhizosphere. It's important to note that the toxicity of metals with varying valences can differ significantly. Plants effectively convert hazardous metals into less harmful forms and alleviate metal-induced stress and damage by releasing specific redox enzymes. For instance, extensive research has focused on the transformation of Cr(VI) into Cr(III), as the latter is less mobile and less dangerous. While phytostabilization curtails the accumulation of heavy metals in organisms and their subsequent release into groundwater, it's not a permanent solution since the heavy metals remain in the soil with restricted movement. In essence, phytostabilization serves as a management technique for the containment (inactivation) of potentially harmful pollutants.

Phytovolatilization

Phytovolatilization is the process by which plants extract pollutants from the soil, convert them into a volatile form, and then release them into the atmosphere. This method can be employed to eliminate various types of pollutants, including organic contaminants and heavy metals like mercury (Hg) and selenium (Se). However, its application has limitations since it doesn't completely eliminate the pollutants; instead, it transfers them from one location (the soil) to another (the atmosphere), where they have the potential to be re-deposited. Among phytoremediation technologies, phytovolatilization is the most debated and contentious. Phytodegradation

Plants have the ability to break down organic pollutants using enzymes like dehalogenase and oxygenase, and this process doesn't rely on rhizospheric bacteria (Vishnoi and Srivastava, 2008). In contaminated environments, plants can absorb organic xenobiotics and detoxify them through metabolic processes. This concept suggests that green plants could be seen as nature's "Green Liver" within the biosphere. It's important to note that phytodegradation is effective only for eliminating organic pollutants since heavy metals cannot undergo biodegradation.

Rhizodegradation

Rhizodegradation is described as the process in which organic pollutants in the soil are broken down by rhizosphere bacteria, as outlined by Mukhopadhyay and Maiti (2010). The rhizosphere is the area extending approximately 1 mm around the plant's roots and is influenced by the plant itself. The primary reason for the enhanced degradation of pollutants in the rhizosphere is likely the increased presence of bacteria and their heightened metabolic activity. Plant exudates, which include substances like carbohydrates, amino acids, and flavonoids, can stimulate microbial activity within the rhizosphere. It's worth noting that this process is effective only for eliminating organic contaminants, as heavy metals are not biodegradable.

Phytodesalination

Phytodesalination is the utilization of salt-tolerant halophytic plants to extract salts from salt-affected soils, enabling these soils to support normal plant growth. There is a proposition that halophytic plants are inherently better equipped to handle heavy metals when compared to glycophytic plants. In a separate study, it was observed that the aboveground biomass of the obligate halophyte S. portulacastrum, when grown on salinized soil, accumulated approximately 1 ton per hectare of Na^+ ions. The reduction in salinity and sodicity in the soil subjected to

 ISBN: 978-81-965655-8-9

phytodesalination significantly mitigated the adverse impacts on the growth of the glycophytic crop Hordeum vulgare in the test culture.

Phytoextraction of Heavy Metals

Phytoextraction stands out as the most significant and effective phytoremediation method for extracting heavy metals and metalloids from contaminated soils, sediments, or water, and it has proven to be the most economically feasible (Sun et al., 2011). The success of phytoextraction is influenced by numerous factors, including the availability of heavy metals in the soil, soil characteristics, the chemical form of the heavy metals, and the choice of plant species. To be well-suited for phytoextraction, plants should possess the following characteristics:

(i) Rapid growth rate.

(ii) Extensive and highly branched root system.

(iii) High production of above-ground biomass.

(iv) Efficient accumulation of the target heavy metals from the soil.

(v) Tolerance to the toxic effects of the target heavy metals.

(vi) Ability to transport accumulated heavy metals from roots to aerial parts.

(vii) Resistance to diseases and pests.

(viii) Adaptability to prevailing environmental and climatic conditions.

(ix) Natural deterrents to herbivores to prevent contamination of the food chain.

(x) Easy cultivation and harvest.

Two key factors primarily determine a plant species' ability for phytoextraction: the metal content in its aboveground parts and its aboveground biomass (Li et al., 2010). In the context of heavy metal phytoextraction, two approaches have been explored:

(i) Using hyperaccumulators: These plants produce less aboveground biomass but are highly efficient at accumulating specific heavy metals.

(ii) Utilizing alternative plants like Brassica juncea (Indian mustard): These plants accumulate target heavy metals to a lesser extent but generate more aboveground biomass, leading to comparable overall metal accumulation as hyperaccumulators due to biomass production.

According to Chaney et al. (1997), the capacity for hyperaccumulation and hypertolerance is more critical than having a high biomass in phytoremediation. Employing hyperaccumulators results in a metal-rich, compact biomass that is cost-effective and easy to manage for metal recovery and safe disposal. Conversely, non-accumulating plants yield a metal-poor, voluminous biomass that is economically impractical for metal recovery and involves higher costs for secure disposal.

Plant species that can yield multiple harvests within a single growing season, such as Trifolium spp., show a promising potential for heavy metal phytoextraction (Ali et al., 2012). When it comes to phytoextraction, grasses are preferred over shrubs or trees due to their quicker growth rate, higher stress tolerance, and greater biomass production (Malik et al., 2010). Some researchers have explored the use of agricultural crops like maize and barley for heavy metal phytoextraction. However, in such cases, multiple crop cycles are necessary to reduce heavy metal contamination to acceptable levels. Nonetheless, the use of crops for heavy metal phytoextraction has the drawback of potentially introducing contaminants into the food chain. As suggested by Vamerali et al. (2010), when employing field crops for phytoremediation, it's

 ISBN: 978-81-965655-8-9

important to consider not using the harvested products for animal feed or direct human consumption.

Limitations of phytoremediation

While phytoremediation holds promise as an approach for addressing heavy metal contamination, it is subject to several limitations:

(i) The remediation process is time-consuming.

(ii) It can be challenging to mobilize a significant portion of tightly bound metal ions in the soil, resulting in limited bioavailability of contaminants.

(iii) The effectiveness of phytoremediation using metal hyperaccumulators is often constrained by their slow growth rates and low biomass production.

(iv) Poor management and a lack of oversight create a potential risk to the food chain.

(v) Phytoremediation is not suitable for highly polluted soils as plant growth cannot be sustained, making it most appropriate for areas with low to moderate levels of metal contamination.

Future trends in phytoremediation

Phytoremediation is a relatively recent field of research and application. Presently, the majority of studies are conducted on a small scale in laboratories and greenhouses, with only a limited number of investigations carried out to evaluate its effectiveness in real-world field conditions. Various factors such as temperature, nutrient levels, precipitation, moisture, plant diseases, herbivore activity, uneven distribution of contaminants, soil type, pH levels, and soil structure can all influence the success of phytoremediation in field applications (Vangronsveld et al., 2009). It's important to note that outcomes observed in the field may differ from those obtained in controlled laboratory settings. To ascertain the feasibility of commercializing this approach, it is imperative to conduct field studies assessing the effectiveness of various plant species in phytoremediating specific target heavy metals.

CONCLUSION

Addressing the serious environmental issue of hazardous heavy metal contamination in soils and waterways necessitates efficient remediation methods. Traditional physical and chemical approaches to clean up heavy metal-contaminated soils have significant drawbacks, including high costs, irreversible alterations to soil properties, disruption of natural soil microorganisms, and the potential for secondary contamination. In contrast, phytoremediation emerges as a superior solution. Phytoremediation is an environmentally friendly and ecologically ethical solar-powered technique that enjoys broad public support. It is a relatively new technology, primarily in the research phase, requiring interdisciplinary expertise in soil chemistry, plant biology, ecology, soil microbiology, and environmental engineering. Fortunately, multidisciplinary research is highly valued in scientific communities. Current research efforts involve screening native plants for their ability to phytoremediate specific heavy metals, evaluating the impact of various factors on phytoremediation effectiveness, genetically modifying selected plants for enhanced heavy metal remediation, and identifying and characterizing proteins involved in heavy metal transport and sequestration within plant cells.

Progress and achievements in molecular studies are expected to significantly enhance our understanding of the phytoremediation process and improve its effectiveness. A better grasp of how plants uptake heavy metals from soil could also promote phytomining, an eco-friendly approach to metal extraction from even low-grade ores using plants. The future holds promise for the commercial viability of phytoextraction as a solution for heavy metal phytoremediation and phytomining.

REFERENCES

- Ali, H., Naseer, M., Sajad, M.A., 2012. Phytoremediation of heavy metals by Trifolium alexandrinum. Int. J. Environ. Sci. 2, 1459–1469.
- Cempel, M., Nikel, G., 2006. Nickel: a review of its sources and environmental toxicology. Pol. J. Environ. Stud. 15, 375–382
- Chaney, R.L., 1983. Plant uptake of inorganic waste constituents. In: Parr, J.F.E.A. (Ed.), Land Treatment of Hazardous Wastes. Noyes Data Corp., Park Ridge, NJ, pp. 50–76
- Chaney, R.L., Malik, M., Li, Y.M., Brown, S.L., Brewer, E.P., Angle, J.S., Baker, A.J.M., 1997. Phytoremediation of soil metals. Curr. Opin. Biotechnol. 8, 279–284
- Chaudhry, T.M., Hayes, W.J., Khan, A.G., Khoo, C.S., 1998. Phytoremediation-focusing on accumulator plants that remediate metal-contaminated soils. Aust. J. Ecotoxicol. 4, 37–51.
- Dabonne, S., Koffi, B., Kouadio, E., Koffi, A., Due, E., Kouame, L., 2010. Traditional utensils: Potential sources of poisoning by heavy metals. Br. J. Pharm. Toxicol. 1, 90–92.
- Das, K., Das, S., Dhundasi, S., 2008. Nickel, its adverse health effects and oxidative stress. Indian J. Med. Res. 128, 412–425.
- Erakhrumen, A.A., 2007. Phytoremediation: an environmentally sound technology for pollution prevention, control and remediation in developing countries. Edu. Res. Rev. 2, 151–156
- Khan, S., Hesham, A.E.-L., Qiao, M., Rehman, S., He, J.-Z., 2010. Effects of Cd and Pb on soil microbial community structure and activities. Environ. Sci. Pollut. Res. 17, 288–296.
- Li, J.T., Liao, B., Lan, C.Y., Ye, Z.H., Baker, A.J.M., Shu, W.S., 2010. Cadmium tolerance and accumulation in cultivars of a high-biomass tropical tree (Averrhoa carambola) and its potential for phytoextraction. J. Environ. Qual. 39, 1262– 1268
- Memon, A.R., Schröder, P., 2009. Implications of metal accumulation mechanisms to phytoremediation. Environ. Sci. Pollut. Res. 16, 162–175.
- Mench, M., Schwitzguebel, J.-P., Schroeder, P., Bert, V., Gawronski, S., Gupta, S., 2009. Assessment of successful experiments and limitations of phytotechnologies: contaminant uptake, detoxification and sequestration, and consequences for food safety. Environ. Sci. Pollut. Res. 16, 876–900
- Mudipalli, A., 2008. Metals (micro nutrients or toxicants) and global health. Indian J. Med. Res. 128, 331–334.
- Mukhopadhyay, S., Maiti, S.K., 2010. Phytoremediation of metal enriched mine waste: a review. Global J. Environ. Res. 4, 135–150.
- Rafati, M., Khorasani, N., Moattar, F., Shirvany, A., Moraghebi, F., Hosseinzadeh, S., 2011. Phytoremediation potential of Populus alba and Morus alba for cadmium, chromuim and nickel absorption from polluted soil. Int. J. Environ. Res. 5, 961– 970.
- Singh, S., 2012. Phytoremediation: a sustainable alternative for environmental challenges. Int. J. Gr. Herb. Chem. 1, 133–139.
- Sun, Y., Zhou, Q., Xu, Y., Wang, L., Liang, X., 2011. The role of EDTA on cadmium phytoextraction in a cadmium-hyperaccumulator Rorippa globosa. J. Environ. Chem. Ecotoxicol. 3, 45–51.

 ISBN: 978-81-965655-8-9

- Vamerali, T., Bandiera, M., Mosca, G., 2010. Field crops for phytoremediation of metal-contaminated land. A review. Environ. Chem. Lett. 8, 1–17.
- Vishnoi, S.R., Srivastava, P.N., 2008. Phytoremediation-green for environmental clean. In: The 12th World Lake Conference, pp. 1016–1021.

ISBN: 978-81-965655-8-9

CHAPTER 13

SECRETS OF THE SOIL

Krisanu Golui[1]*, Rupsikha Baruah[2], Okram Ricky Devi[3] and Khumanthem Babina Devi[4]
[1,2]M.Sc. scholar, Department of Soil Science, Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana-125004
[3]Ph. D Scholar, Department of Agronomy, AAU, Jorhat-785013
[4]Ph. D Scholar, Department of Environmental Science, Mizoram University, Aizawl-796004, Mizoram

ABSTRACT

Soil is the most wonderful gift of nature to the human society. It is the three dimensional dynamic natural body that supports life on earth. It will be a major mistake if we consider soil as a mixture of sand, silt and clay. Mineral or inorganic matter, organic matter, water and air together forms such an intricate network that sustain lives. In botany point of view, soil should be considered as a medium for plant growth. Soil performs various ecosystem services including nutrient cycling, plant growth support, water filtration and purification, carbon sequestration and climate regulation, biodiversity habitat, waste decomposition, erosion prevention, habitat for microorganisms, cultural and historical significance, agricultural productivity, source of genetic and medicinal resources, water regulation, provision of human infrastructure, understanding educational and research value etc. But the main mystery lies in the fact that how does the soil do it. The secrets of the soil can be understood when we start considering soil as a living body and focus more on its organic constituents. It sustains millions of microorganisms and soil organic matter serves as their food. By the activity of these microorganisms, supported by continuous supply of food, water, air and habitat from soil, it gets its hidden power of sustaining lives. The delicate balance of resilience of its own in the face of disturbances, and its essential role in mitigating climate change, always reminds us that beneath the surface lies a vibrant world that holds the key to a sustainable future.

Keywords– Natural body, lives, soil organic matter, microorganisms, resilience, sustainable, habitat

INTRODUCTION

Earth is the only known planet that sustains life on it, making it a unique haven in the vast expense of the universe. Soil is one of the major natural resources, alongside water and air, which supports diverse ecosystems and life forms. The present quality and calibre of the soil determines the nature of ecosystems alongside the capacity of land to support life and society to a great extent.

The word soil is derived from a Latin word ‘solum’ which means floor. Soil can be understood from various perspectives and viewpoints. To engineers, it is a foundation or support structure for their buildings, roads, bridges etc. To the clay modellers, it is a basic, inanimate raw material for crafting pottery and ceramics. To the economists, soil represents a vital resource with economic value that contributes to ecosystem services. Agriculturists consider soil as a living body which is a medium for plant growth. Unfortunately, one of the stark reality of 21st century

 ISBN: 978-81-965655-8-9

is that, the soil resource is rapidly shrinking due to soil degradation, as most of the human beings consider soil as a natural dustbin to dump all kinds of wastes and polluting materials.

What Soil Actually Is and How It Is Different From Land?

Providing a definition of soil is not a mere task due to its complexity and heterogeneity. Over time, the concept of soil has evolved as we have gathered and analysed more information and knowledge ever since it was accepted as a scientific entity. Soil was described as a nutrient bin by Whitney (1892). Dokuchaev (1900), the father of soil science, defined soil as a natural body which is made up of mineral and organic constituents, having a definite genesis and distinct nature of its own. Jenny (1941) considered soil as a naturally occurring body, evolved due to mutual action of climate and organisms, acting on parent materials as conditioned by relief over time.

Considering several definitions of soil as well as their limitations into account, a generalized definition can be put forward: ‘Soil is a dynamic three dimensional natural body, developed from weathering of rocks via various pedogenic processes, consisting of mineral as well as organic constituents, having a definite physical, chemical and biological properties, covering the surface of the earth at variable depth and providing a medium for growing terrestrial plants’.

Confusion often arises between the terms 'land' and 'soil,' as they are sometimes used interchangeably. Practically, land encompasses broader geographical context which, in addition to soil, considers factors such as climate, vegetation, water bodies, and topographical features. Along with the productivity of soil, the value of land relies on its location, size, accessibility etc.

Approaches of Soil Study

There are two basic approaches for scientific study of the soil, i.e.

A) Pedological Approach: in this approach soil is treated as a natural body and its origin, classification and description are examined.

B) Edaphological Approach: the term ‘Edaphology’ is derived from the Greek word edaphos, means soil or ground. This approach considers soil a habitat or medium for living things like plants and micro-organism and focuses on studying various soil properties that influences plant growth, nutrient cycling and overall ecosystem health. It helps researchers and agriculturists to optimize soil management practices for higher productivity, sustainable agriculture and environmental conservation. Edaphological approach is most suited for botanists.

 ISBN: 978-81-965655-8-9

Important Ecosystem Services That Soil Performs

Soil performs various ecosystem services (Figure 25.1) which can be broadly classified as,

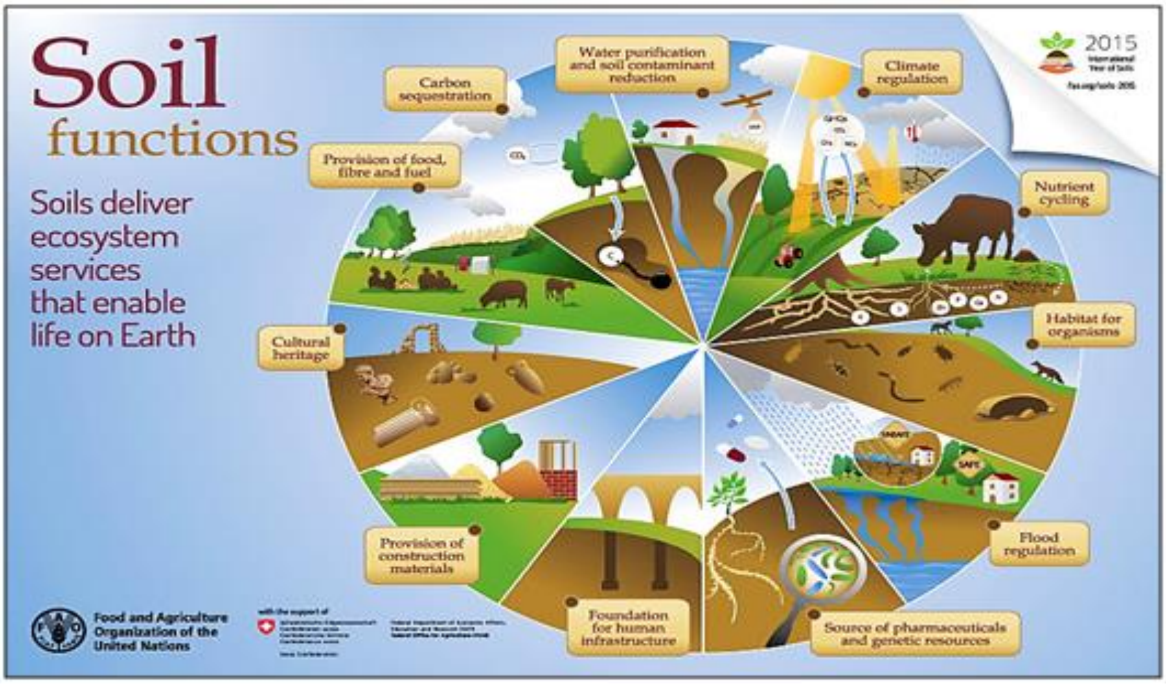


Figure 25.1 Ecosystem services that soil performs

Provisioning: Provisioning function of soil refers to the ways in which soil provides essential resources and services that support human well-being. These include water, food, medicine, lumber etc.

Regulating: Regulating function of soil refers to the ways in which soil helps regulate different environmental processes and functions. These includes water regulation and purification, nutrient retention and release, soil micro climate regulation, erosion control, waste decomposition, pest control, noise reduction etc.

Supportive: Supportive function pertains to the ways in which soil provides a foundation for various activities and processes. These includes assisting nutrient cycling, seed dispersal, primary biomass production, medium for growing plants allowing them to anchor securely, foundation for building, roads and infrastructures ensuring their stability and safety.

Cultural: Cultural function of soil refers to the significance of soil in shaping human culture, traditions and identity. These includes providing spiritual uplift, scenic views, and recreation opportunities, contributing to the understanding of cultural heritage and traditional practices etc.

 ISBN: 978-81-965655-8-9

Soil as Environmental Interface

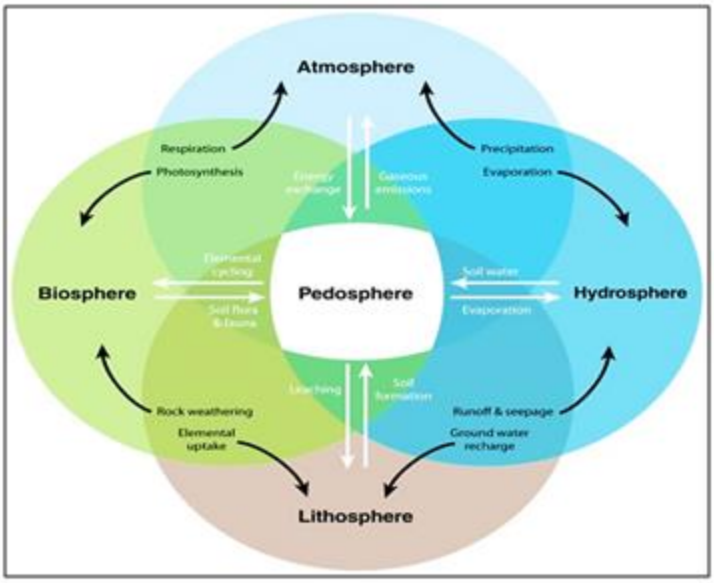


Figure 25.2 The pedosphere in association with all 4 spheres

COMPOSITION OF SOIL

The soil or pedosphere is a peculiar example of such an environment that connects the variety of rocks and minerals (the lithosphere), air (the atmosphere), water (the hydrosphere) and living organisms (the biosphere) (Figure 25.2). Indeed, environments where multiple distinct elements or ‘worlds’ or ‘spheres’ interact can lead to the intricate and complex dynamics owing to the interplay and dependencies between them. Such complexities in this productive part on earth arises from the need to consider the relationships and influences among all four worlds which can lead to fascinating and often challenging scenarios.

Soil is a three phase system: solid, liquid and gaseous phase. But in completely dry or frozen condition, it becomes a two phase system, i.e. solid and gaseous phase.

Solid phase: Solid phase is composed of mineral or inorganic component (sand, silt and clay) and organic component.

Liquid phase: Water occupies the spaces between the solid particles creating a liquid phase in the soil. This water carries dissolved nutrients that plants can absorb and it provides a medium for chemical reactions and microbial activity.

Gaseous phase: Air fills the pore space that are not occupied by water. This gaseous phase is essential for root respiration and it provides oxygen to self-dwelling organisms.

Although a handful of soil may appear to be a solid thing, but in an ideal scenario its 50% volume should be occupied by pore space filled with water and/or air. Rest 50% is solid material, mineral matters contribute 45% and remaining 5% by organic matter in ideal soil.

The gaps or voids between soil particles, i.e. pore space allows the water and air movement, root penetration, growth of microorganisms. Under optimum condition of plant growth, 50% of the pore space (25% of total soil volume) should be occupied by air and rest 50%by water (Figure

25.3). This proportion may vary but proper soil management is necessary to maintain an optimal balance of pore spaces for healthy soil functioning.

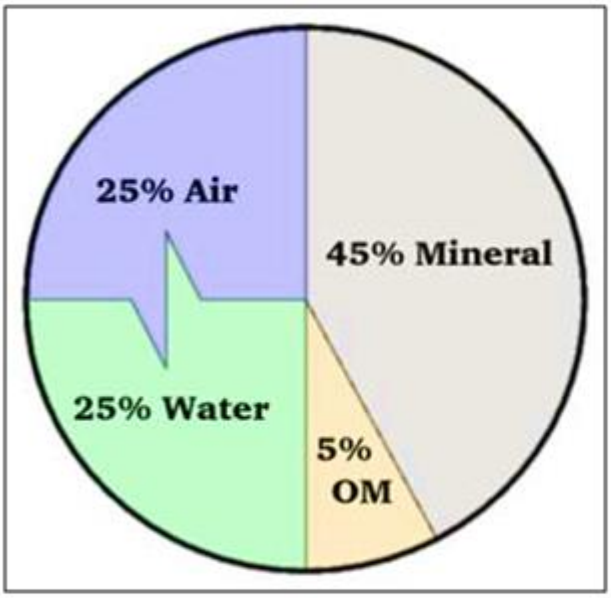


Figure 25.2 The pedosphere in association with all 4 spheres

COMPOSITION OF SOIL

Mineral or Inorganic Constituent of Soil

Except in organic soils like peats and mucks, most of the solid framework of soil consists of mineral particles. The large soil particles also known as aggregates like stones, gravel and coarse sands, are generally rock fragments consisting of various kinds of minerals. However, smaller size particles are composed of a single mineral. Minerals largely vary in size. Primary minerals that are formed during formation of rock with no or very little change in composition from the original rocks, are mostly found in sand (2 to 0.05 or 0.02 mm diameter) and silt (0.05 or 0.02 to 0.002 mm diameter) fractions. Secondary minerals that are formed by breakdown and weathering of primary minerals, are predominant in clay fractions (<0.002mm diameter). The secret of mineral constituents is that they are the original source of most elements that are essential for plant growth and provide a surface for chemical reactions occurring in the soil.

Soil Organic Matter- The Real Secret of Soil

As discussed earlier, soil organic matter constitute only 5% of the total soil volume in ideal condition. It makes up only about 2% of the soil on the basis of weight because it is less dense than the mineral matter (density of mineral matter 2.6 to 2.75 g/cm^3 whereas density of organic matter is 0.9 to 1.3 g/cm^3). However, its impact on soil properties are substantially greater than its contribution as soil constituent. Soil organic matter consists of various decomposed (partially or completely) plant and animal materials including carbonaceous compounds, microorganisms, cell components or metabolic by-products of soil organisms. It serves as food, acting as a carbon and energy source for all soil organisms. That is why continuous replenishment is essential to maintain a healthy soil. If we consider

 ISBN: 978-81-965655-8-9

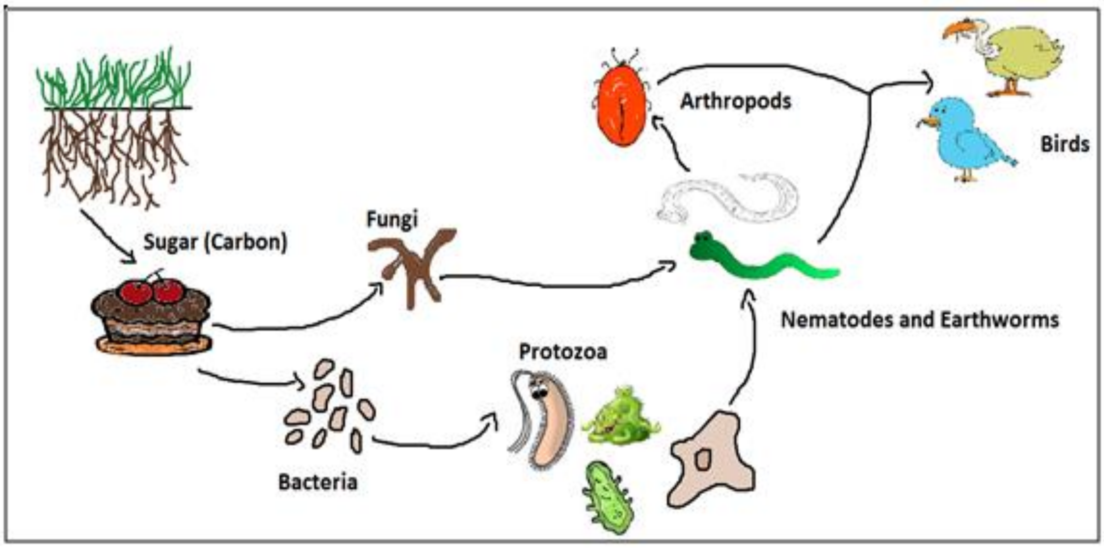


Figure 25.4 Organisms living in soils to link food we

soil as nothing more than mere dust particles, it will be a huge mistake by us as a handful of soil may contain a several times more microbes than the total human population on the earth. These microbes are the reason why soil is considered as a living body. They play a crucial role in various transformation processes occurring in the soil ecosystem. They are responsible for the conversion organic forms of nutrients locked in organic residues to the form available to plants. We can certainly consider them as chefs for the plants for plants and as integral components of the food web for the entire living community (Figure 25.4). If the activity of this living entity comes to a halt, the soil-plant-animal ecosystem will break down.

Soil water

Water is essential for survival and growth of plants and soil organisms. Moreover, soil water is essential for different processes of soil formation like weathering, humus formation, mobilization and transportation within the soil. Thus, it is important that soil meets the water needs in a balanced way. Water balance in soil refers to the equilibrium between inflow and outflow of water within a soil system that depends on precipitation, evaporation, surface runoff, infiltration, drainage, transpiration by plants. Water received through precipitation, infiltrates into the soil or may lost by surface runoff. The water that infiltrates, partly penetrates down through soil profile to replenish ground water and partly held within soil pores with varying degrees of tenacity as bound water. Later, ground water may rise through capillarity to replenish stock of bound water which plants can absorb as and when required (Figure 25.5).

Bound water is attached to surfaces of soil particles by adsorption against gravity and by capillary forces in small pores. Thus free movement of water is greatly restricted. When soil contains moisture at optimum level, initially, plants are able to absorb water from larger (macro) pores. The water in smaller (micro) pores are so close to the soil particles that it is tenaciously held and plant roots cannot pull it away. Therefore, not all the water present in the soil is available for plants.

Soil water does not exist in pure form rather it contains number of dissolved organic and inorganic substances. So, it is called soil solution. The dissolved salts in soil solution are the actual source of various mineral nutrients for plant growth. These plant nutrients are taken up by plant roots by exchange mechanism under the influence of concentration gradient. The concentration of H^+ and OH^- ions in soil solution which is expressed by pH, plays a vital role as

 ISBN: 978-81-965655-8-9

it controls the solubility and availability of nutrients by governing several chemical and biological reactions.

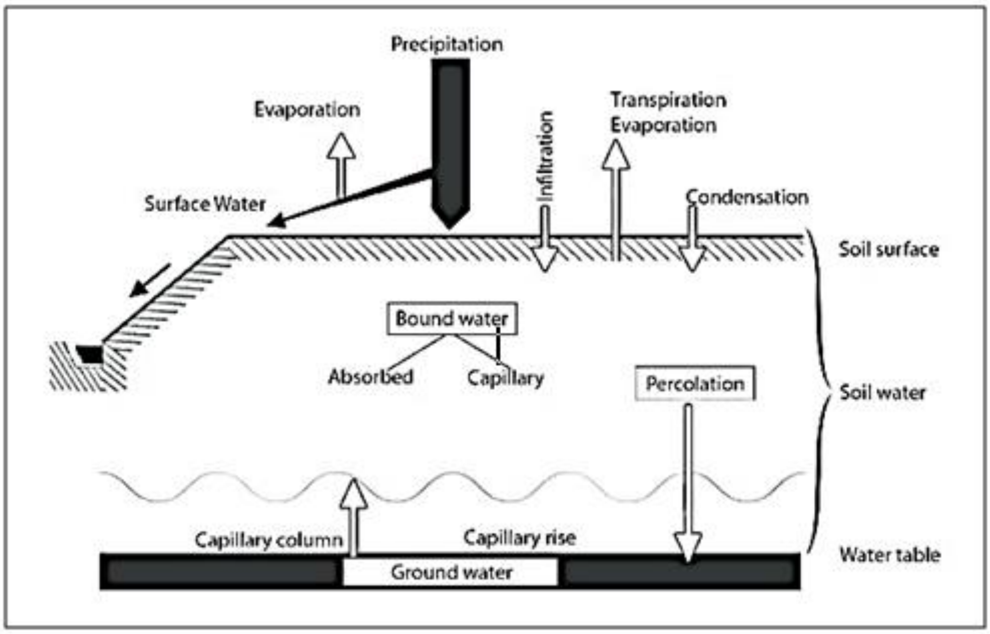


Figure 25.5 Distribution of water after it reaches soil environment

Soil Air

At any instant, air occupies those pores which are free from water. As soil water drains after rainfall or irrigation owing to gravity, evaporation and plant uptake, air starts to fill the large pores first, then medium and finally small pore. It acts as a ventilation system for soil environment connecting airspace to atmosphere. When soil pores are filled with water the pores get clogged. The oxygen entrapped inside, rapidly gets used by plant roots and soil organisms for respiration and carbon dioxide is produced. Neither O_2 can get in nor can CO_2 come out.

The composition of soil air differs from atmospheric air because of varied diffusion rate of gases in soil system. Diffusion of oxygen from atmosphere to soil is crucial for respiration of plant roots and soil organisms. Usually soil air contains higher percentage of CO_2 (8-10 times higher) and moisture (except in very dry soil) and lesser percentage of O_2than atmospheric air (Table 25.1).

Components	Soil air (%)	Atmosphere (%)
N_2	79.2	79.0
O_2	20.6	20.9
CO_2	0.25	0.03

Table 25.1 Comparison between soil air and atmospheric air

How Do The Soil Support Lives?

We typically see the shoots- the foliage, flowers, stems and limbs - when we imagine of the forests, grasslands, landscapes and farmlands around us, forgetting that the roots constitute the lower half of the plant world. We know a lot fewer facts about plant-environment interconnections belowground than aboveground because plant roots are typically concealed from our view and challenging to research, but we need to recognise both to properly comprehend either. Same goes for soil organisms. Although we can envision the macro organisms but they are much lesser in number as well as diversity when compared to microorganisms. Let's enlist and briefly discuss what these living bodies obtain from to proliferate gradually.

Physical habitat: The soil offers a porous, three-dimensional matrix with tremendous tortuous pathway and a lot of surface for soil-inhabiting species. From the biological perspective, the most crucial component of soil structure in which life exists is the pores that exist within the soil. The root system is physically held in place by the soil mass, preventing the plant from collapsing or blowing over.

Air for respiration: Likewise human or animal, in plants and soil organisms, respiration is an essential metabolic process to convert food into energy. In this process O_2 is consumed and CO_2 is evolved. That is why continuous supply of O_2 is pre-requisite. So, ventilation of soil is necessary which is accomplished by the intrinsic network of pore spaces.

Water for metabolism: Water is essential for metabolic activities in living bodies. Since, plants are exposed to sunlight, they need continuous water supply for cooling, photosynthesis, nutrient transportation, turgor maintenance. Soil pores absorb and hold water to make it accessible to plants and microbes when required. Deep soils having a higher water retention capacity holds lives for extended period of time.

Temperature regulation: All plants and microorganisms requires optimum temperature for their efficient growth. Temperature below minimum and above maximum can have deleterious effect on their metabolism eventually causing death. Soil plays a crucial role in regulating energy balance of the soil and its surrounding micro environment by altering radiation exchange and thermal properties. The insulating nature of soil safeguards the deeper section of the soil system from temperature fluctuations that often occurs near the surface.

Nutrient supply: An adequate supply of mineral nutrients in proper quantity and proportion will always be available from a fertile and productive soil. Plant roots take up these nutrients from soil solution by exchange mechanism and majority of them are incorporated by plants in their tissue as organic compounds. Soil microorganisms uptake nutrients through a process called mineralization where the break organic matter, releasing nutrients from that. Then they absorb nutrients through their cell membranes.

Protection from toxins: Human activities like pesticide application, waste disposal may produce phytotoxic substances in soil. They can also be secreted by plant roots and soil microorganisms themselves. Many soil managers believe that a healthy soil should be able to protect plants from such pollutants by releasing gases, destroying or adsorbing organic poisons, or restricting organisms that produce toxins. It is also true that some soil microbes create organic chemicals that promote development. These chemicals may increase plant vigour when absorbed by plants in small amounts.

How Do Soils Control Water Supply and Its Purification?

Concerns have been raised regarding the quality and amount of water in our rivers, lakes, reservoirs and underground aquifers. In order to preserve or enhance water quality, we must acknowledge that nearly every drop of water in our lakes, rivers, waterways, and aquifers has either travelled through the soil or flowed over its surface (with the exception of the relatively minor amount of rain that falls directly into bodies of fresh surface water).If the soil permits rain to penetrate and soak in, some of the water will be held in the soil, some will be consumed by the trees, and some will slowly seep down through the different layers of soil to the groundwater, eventually ending up in the river as base flow over the time. The contaminated water is filtered as it soaks through the upper layers of soil by soil processes that eliminate

 ISBN: 978-81-965655-8-9

numerous pollutants and kill possible disease causing organisms. Consider what would happen if the soil was so thin or impervious that the vast majority of the rainwater could not enter the soil and instead raced off the land surface, sweeping surface dirt and debris as it hurried towards the river. This comparison demonstrates how the nature and management of soils affect the purity and amount of water reaching aquatic systems.

Soil plays a crucial role in purifying water through a natural process called "soil filtration" or "soil absorption." This process involves various physical, chemical, and biological mechanisms that work together to remove impurities and pollutants from water as it percolates through the soil layers. Purification can be done by physical filtration (trapping larger particles, such as sediment, debris, and suspended solids), chemical adsorption (heavy metals and organic compounds, carry positive charges and can be adsorbed onto negatively charged colloidal soil particles), ion exchange (undesirable ions in the water can be replaced by less harmful ions from the soil), chemical reactions(contaminants can undergo chemical reactions with components of the soil, transforming them into less harmful substances), biological activity (microorganisms present in the soil can break down organic matter and biodegradable pollutants, converting them into simpler substances).

How Do Soils Recycle Raw Materials?

What would the earth look like if soil stops its recycling operation? Plants and animals would have ran out of food long ago if nutrients were not reused. The globe would be coated with a layer of plant and animal excrement and cadavers, maybe hundreds of metres thick. Recycling is obviously critical to ecosystems, whether they are woods, farms or cities. Soils play a critical role in recycling raw materials within ecosystems through various natural processes. These processes involve the transformation and cycling of nutrients, organic matter, and minerals that are essential for the growth of plants, animals, and microorganisms. Soils have the ability to absorb large amounts of organic waste, converting it into beneficial soil organic matter, turning the mineral nutrients in the waste into forms that plants, animals, and microbes can use, and returning the carbon to the atmosphere as carbon dioxide, where it will again become a part of living organisms through plant photosynthesis. Some soils can store huge amounts of carbon as soil organic matter, lowering the concentration of carbon dioxide in the atmosphere and potentially moderating global climate change. Erosion can transport soil particles and organic matter to other areas, where they may contribute to the formation of new soil layers. Sedimentation in water bodies can lead to the accumulation of nutrient-rich sediment that can be used by aquatic and riparian ecosystems.

Overall, the recycling of raw materials in soils is a dynamic and interconnected process that sustains the health of ecosystems. It ensures that nutrients and essential elements are continually available for plant growth, which in turn supports the entire food web and maintains the balance of natural systems.

How Do Soil Modify Atmosphere- Its Own and The Earth's?

Since the soil "breathes" through its pores, it interacts with the earth's blanket of air in a variety of ways. Soil-atmospheric gaseous exchanges have a profound impact on atmospheric makeup and global climate change. Soil moisture evaporation is a key source of water vapour in the atmosphere, influencing air temperature, composition, and weather conditions. Soil is a major reservoir of carbon, with soil organic matter containing substantial amounts of carbon compounds. Certain types of soil, like peatlands and forests, can sequester large amounts of carbon dioxide by storing organic matter in the soil. This helps to mitigate the increasing CO_2 in the atmosphere and contributes to climate regulation. During photosynthesis, plants absorb CO_2 from the atmosphere and release O_2. This exchange of gases between plants and the atmosphere significantly affects the concentrations of these gases locally. Soil microorganisms facilitate processes like nitrogen fixation, nitrification, denitrification, and ammonification. These

 ISBN: 978-81-965655-8-9

processes affect the concentrations of nitrogen-containing gases such as nitrous oxide (N_2O), a potent greenhouse gas, and nitric oxide (NO).Some types of soil, particularly wetlands and rice paddies, are sources of methane (CH_4), another potent greenhouse gas. Soil microorganisms, plants, and organic matter collectively emit a range of volatile gases, including sulfur compounds, isoprenoids, and terpenes. These biogenic emissions can interact with atmospheric chemistry, influencing air quality and contributing to the formation of secondary organic aerosols. The interactions between soil and the atmosphere are just one aspect of the intricate relationships that shape our planet's environmental systems.

How Do Soil Components Interact to Feed Its Inhabitants?

Plants and organisms require various essential nutrients to grow and thrive, that are obtained from the soil. All the four soil components work together to determine the nutrient supplying capacity of a soil. Soil moisture, which directly serves the water needs of plants, also regulates a large portion of the air and nutrient delivery to the plant roots. Mineral particles, particularly the finest ones, attract soil water, influencing its flow and availability to plants. Similarly, organic matter changes the arrangement of mineral particles into clusters and, as a result, increases the number of macro pores, so altering the water and air interactions.

The provision of essential nutrient elements to plants is perhaps the most crucial interacting mechanism involving the four soil components. Plants immediately absorb necessary nutrients and water from one of these components: the soil solution. The amount of critical nutrients in the soil solution at any given time, however, is only enough to meet the needs of developing vegetation for a few hours or days. As a result, nutrients must be regularly supplied from inorganic or organic soil components, as well as fertilisers or manures that are added to agricultural soils.

Nutrients are released from these solid forms through a variety of chemical and biological processes to replenish them in the soil solution. The smallest colloidal particles, for example, both clay and humus, have negative and positive charges. These charges attract or adsorb oppositely charged ions from soil solutions, retaining them as exchangeable ions. Ion exchange allows elements such as Ca^{2+} and K^+ to escape from electrostatic adsorption on colloidal surfaces and enter the soil solution, where they can be conveniently absorbed by plant roots. Some scientists believe that the ion exchange process is one of nature's most essential chemical reactions after photosynthesis.

As soil microbes breakdown organic tissues, nutrient ions are released into the soil solution. Plant roots can easily take all of these nutrients from the soil solution if there is sufficient O_2 in the soil air to support root metabolism.

The majority of nutrients in a soil are generally not easily available for plant usage because components in the coarser soil structure of the soil are only slowly released into the soil solution over extended periods of time. Colloid particles have a structure that makes nutrients more easily available to plants since they degrade more quickly due to their larger surface area. As a result, in many soils, the structural framework serves as a large source and main repository for important components.

Soil Health, Quality and Resilience

Health is always related to living beings. The term "health" is related to soil because soil health refers to the overall well-being and functionality of soil as a living ecosystem that supports plant growth, sustains biodiversity, and contributes to various ecosystem services. Just as human health refers to the well-being of individuals, soil health refers to the well-being of the soil ecosystem. In contrast to unhealthy, degraded soils, healthy soils perform more effectively and require minimal expensive human inputs and treatments. Soil quality refers to the overall

 ISBN: 978-81-965655-8-9

condition and suitability of soil for supporting various ecosystem functions. Soil quality is essential for maintaining productive and sustainable land use practices.

Although preserving soil quality should come first, it is also important to make an effort to improve the quality of soils that are already damaged. If given the chance to regenerate on their own, some soils have enough resilience to rebound from slight damage. In other situations, more work is needed to rehabilitate degraded soils. The field of restoration ecology has quickly developed to help managers bring back plant and animal populations to their previous levels of diversity and production as societies throughout the world assess the harm already done to their natural and agricultural ecosystems. In-depth knowledge of every component of the soil system is necessary for the task of soil restoration, a crucial component of these efforts.

Soil and Human Health

Soil indirectly affects human health through its influence on the quality and safety of the food we consume and the environment we live in. Healthy soil with adequate nutrient levels leads to nutrient-rich crops that contribute to a balanced and nutritious diet. Plants grown in contaminated soil can absorb pollutants and contaminants, such as heavy metals, pesticides, and industrial chemicals, which may then be ingested by humans during consumption of crops. Contaminants present in the soil can leach into groundwater, potentially affecting drinking water quality. Certain soil types and conditions can provide breeding grounds for disease-carrying vectors such as mosquitoes and ticks. Agricultural and construction workers who come into direct contact with soil may be exposed to hazardous substances present in the soil, such as chemicals or toxins. People who engage in gardening, landscaping, and other activities involving soil should be aware of potential risks and practice proper hygiene to minimize exposure to contaminants.

To safeguard human health, it's important to implement proper soil management practices, especially in agriculture and urban planning. This includes monitoring soil quality, minimizing soil contamination, using appropriate fertilizers and pesticides, managing water runoff, and promoting sustainable land use practices.

CONCLUSION

Soil is not just a medium for plant growth but a living, dynamic and most complex element of the environment with profound implications for life on Earth. It establishes a crucial connection between the abiotic, biotic and anthropogenic elements. Beneath the surface lies a vibrant world that holds the key to a sustainable future. Starting from the interconnectedness of soil, water, air, and life; the microscopic realm of soil microorganisms to the grandeur of nutrient cycling and ecosystem services; the delicate balance of nutrient availability, the resilience of soil in the face of disturbances, and its essential role in mitigating climate change through carbon sequestration to how soil acts as a silent partner in the symphony of nature, all these are the mysteries of the soil. By acknowledging the secrets of the soil, we are empowered to become stewards of the Earth, working harmoniously with nature to preserve the delicate balance that sustains life.

This chapter inspires us to engage with soil in a more profound way and encourages to rethink our relationship with the land and adopt sustainable practices that nurture soil health for current and future generations.

REFERENCES

- Allison, F. E. (1973). Soil organic matter and its role in crop production. Elsevier.
- Berrueta, P. C., Luna, M. L., Giudice, G. E., & Ponce, M. M. (2021). Secrets beneath the soil: recovery of fern spores as a strategy of biodiversity conservation in Punta Lara Nature Reserve (PLNR), Argentina. Rodriguésia, 72.

ISBN: 978-81-965655-8-9

- Bhattacharyya, T. & Pal, D. K. (2015). The Soil: A natural resource. Soil Science: An Introduction; Rattan, RK, Katyal, JC, Dwivedi, BS, Sarkar, AK, Tapas Bhattacharyya, JC, Tarafdar, SK, Eds, 1-19.
- Brady, N. C., Weil, R. R., & Weil, R. R. (2008). The nature and properties of soils (Vol. 13, pp. 662-710). Upper Saddle River, NJ: Prentice Hall.
- Caldwell, B. A. (2005). Enzyme activities as a component of soil biodiversity: a review. Pedobiologia, 49(6), 637-644.
- Das, D. K., & Das, D. K. (2004). Introductory soil science. Kalyani publishers.
- Doran, J. W., & Zeiss, M. R. (2000). Soil health and sustainability: managing the biotic component of soil quality. Applied soil ecology, 15(1), 3-11.
- Epstein, E., & Bloom, A. J. (2005). Mineral nutrition of plants: principles and perspectives, 2nd edn. Sinauer Assoc. Inc., Sunderland, UK, 2005.
- Fox, G. A., &Metla, R. (2005). Soil property analysis using principal components analysis, soil line, and regression models. Soil Science Society of America Journal, 69(6), 1782-1788.
- Giri, B., Kapoor, R., Wu, Q. S., &Varma, A. (Eds.). (2022). Structure and Functions of Pedosphere. Springer.
- Pal, S. K. (2016). Textbook of soil science. Oxford & IBH Publisheing Company, Pvt., Limited.
- Seybold, C. A., Mausbach, M. J., Karlen, D. L., & Rogers, H. H. (1998). Quantification of soil quality. In ‘Soil processes and the carbon cycle’.(Eds R Lal, JM Kimble, RF Follett, BA Stewart) pp. 387–404.
- Subba, R. (2017). Soil microbiology. Oxford and IBH Publishing.
- Tompkins, P., & Bird, C. (1992). Secrets of the soil: new age solutions for restoring our planet. Penguin Books.
- von Haden, A. C., Yang, W. H., &DeLucia, E. H. (2020). Soils' dirty little secret: Depth-based comparisons can be inadequate for quantifying changes in soil organic carbon and other mineral soil properties. Global Change Biology, 26(7), 3759-3770.

CHAPTER 14

FUTURE PERSPECTIVES ON NON-CHEMICAL WEED CONTROL

Dr. C. M. Bhaliya[1*] and H. A. Shekhada[2], Dr. Raj Bahadur[3], Dr. Anuradha Singh
[1,2]Department of Plant Pathology, College of Agriculture, Junagadh Agricultural University, Junagadh- 362001
[3]Associate Professor, Department of Agronomy, Acharya Narendra Deva University of Agriculture & Technology, Kumarganj, Ayodhya-224229, UP
[4]Assoc. Prof., Dept. of Botany, Meerut College, Meerut-250001

ABSTRACT

Biological control is the use of other naturally occurring living entities, such as insects and fish that devour plants, other animals, disease organisms and competitive plants, to restrict an organism's growth. Although biological management cannot totally eradicate weeds, it can reduce their population. This method of weed control does not work well against all types of weeds. The biological controls that are most effective are those against invasive weeds. The least harmful to the environment, leaving no lasting impacts, relatively affordable to apply, having a reasonably long-lasting effect, being safe for non-targeted plants, and being particularly effective at controlling weeds in uncultivated areas, is biological control. Furthermore, certain fish, snails, and other creatures eat weed plants and turn them into food.

Keywords: Biological control, Bio-agent, Bioherbicides, Weed

INTRODUCTION

In agronomic cropping systems, several plant species are regarded as weeds. In most parts of the earth, weeds have a significant impact on human affairs. Some of the adverse characteristics of weeds include lowering crop yields due to competition for resources like sunlight, water, nutrients, and space. Additionally, it might serve as a refuge for insects and a host for specific plant infections. Weeds' unwanted appearance, unattractive features, and capacity to adapt to an imbalanced environment are their main characteristics. Weeds are expected to reduce the global food supply by 11.5% yearly. (Combellack, 1992). Many of the troublesome weeds we have are of foreign origin and accidentally arrived here. They thrive in the new habitat because they have evaded the natural rivals that would have otherwise stifled their vigour and aggression in their native nations. The ultimate goal of weed control is to eliminate or minimise the detrimental impact that weeds have on agricultural and horticultural crops. (Sushil Kumar, 2015).

There are numerous ways to get rid of weeds. However, the chemical industry has imposed the necessity for weed management on a global scale (Mukherjee and Singh, 2004). After the Second World War, farmers started to become more interested in having better herbicides for the efficient control of various weeds as they learned more about chemicals like 2, 4-D. Since then, other chemicals have been developed and are now used extensively in agriculture. After the 1962 publication of Rachel Carson's "Silent Spring" and several related reports on the harmful effects of chemical pesticides on people, animals, and the environment, the public's perception of their use gradually changed, and interest shifted towards biological control. Since the beginning of the evolutionary process of crop plants, diverse agricultural and horticultural crops have been subject to natural biological control by predators, parasites, and pathogens of weeds. The promise of biological control for long-term, inexpensive, and environmentally responsible weed management is enormous (Singh, 2004).

Weeds cannot be completely eliminated with the biological control method, although their population can be decreased. Not all weed varieties can be controlled with this strategy. The best targets for biological control are introduced weeds. Two notable events of early-period biological control of weeds are the use of specific insect bioagents for controlling lantana in Hawaii and Opuntia spp. (prickly pear) in Australia (Evans, 2002).

Biological weed control

"Biological control" a term first used by H.S. Smith (DeBach, 1964), it means using one living organism to control another. Biological weed control includes using living organisms such as; insects, nematodes, bacteria and fungi to suppress weed population and to keep it at or below needed levels without knowingly affecting economically important plants.

According to Alberta (AESA), Manitoba and Saskatchewan Agriculture and Food factsheet (2000), Herbivore management, inundative methods, and traditional (inoculative) methods are all examples of biological control. Major biotic weed control agents include mammals, fish, birds, insects, mites, nematodes, plant infections, and toxic products of these organisms.

1. Classical (Inoculation) release of a relatively small amount of control agents is part of the strategy for biocontrol of weeds. These agents devour the weed, reproduce and progressively minimise it as their numbers increase. Arthropods are typically used as control agents in this strategy. According to conventional approaches, a rare biocontrol agent is introduced in a small patch of the contaminated zone. This method's regulation is gradual and also reliant on favourable ecological conditions. The following different steps in the classical biological control program

- Initiation of a biological control program- Review relevant literature and assemble information on the target weed's natural enemies.
- Approval to work on the weed- Seek approval and funds to work.
- Foreign exploration- Find the target weed's natural habitat and look for its natural enemies.
- Survey the exotic range of the weed- Survey fauna attacking the weed and determine their origin.
- Ecology of the weed and its natural enemies- Investigate the weed and its hosts, as well as its natural opponents.
- Host specificity studies- Prepare lists of test plants and conduct host testing trials.
- Approval to import biological control agents- To get permission to release, submit a report of the host testing to the relevant authorities.
- Importation- Prior to discharge, obtain certified clean material or get rid of any parasites and pathogens.
- Rearing and Release- Mass rear and make field releases.
- Evaluation- Determine the establishment, spread, and impact on the target weed through field investigations.
- Distribution- Spread out the agents and work with other institutions.

The introduction of the rust fungus Puccinia chondrillina to Australia to control rush skeleton weed (Chondrilla juncea) is one of the best examples of classical biological control of weeds. It is a Mediterranean-born plant that severely damages Australian cereal crops. The fungus, which is also from the Mediterranean, was introduced as a conventional biocontrol agent together with three insects. The fungus spread quickly and widely after being introduced and established, controlling the most prevalent biotype of the weed. According to estimates, this very effective biocontrol initiative in Australia had a cost-to-benefit ratio of 1: 100 (Cullen, 1985).

 ISBN: 978-81-965655-8-9

One of the three kinds of the plant that is most common is attacked by the rust fungus. The two other forms first expanded more widely when the population density of this susceptible type was decreased by biocontrol. As a result, more rust strains from the Mediterranean were introduced and became virulent on these more resilient forms, controlling the resistant forms to some extent. (Hasan, 1985). This instance highlights a potential drawback of biological management, namely the emergence of more resilient weed biotypes in the weed population. It also demonstrates the feasibility of using novel pathogen strains to combat the presence of natural resistance in weed populations.

To eradicate rush skeleton weed, puccinia chondrillina was also introduced into the western US. However, it hasn't been as successful as it was in Australia. Therefore, in actual practice, an integrated weed management programme uses the rust fungus, two insect biocontrol agents, and chemical herbicides. The rust fungus has been the most successful biocontrol agent of the weed, just like in Australia. (Supkoff et al., 1988).

2. Inundative (Bio herbicides) A large-scale application of a control agent typically a pathogen (a microbe or fungus that infects weeds and causes disease) is used to biocontrol weeds in a manner similar to applying herbicides. In this method, a control agent that is mass-reared and released for weed control is often native to the application country. (Julien and White, 1997).

As stated by Singh (2004), Aquatic weed biological control (55.5%) and terrestrial weed biological control (23.8%) saw the greatest effectiveness using traditional biological control agents. McFadyen (2000) also discovered 44 weeds that were effectively eradicated globally employing a variety of insects and viruses.

Characteristics of successful bio-agent

1. Host-specific

Bioagents must be host-specific and must not harm other species of economically important plant life. If they would rather starve to death than feed on anything other than host weeds, they should pass the starving test. The insect bio-agent Teleonemia scrupulosa managed to control lantana. However, it is likely to harm sesame (Sesamum indicum) and teak (Tectona grandis) in India. An efficient leaf-eating bio-agent against Parthenium (carrot grass) is Zygogramma bicolarata. But in India, it has been discovered to harm sunflowers. Because some biologists and bureaucrats worry that plant diseases could "host shift" and attack non-target plant species, they have been utilised less frequently than insects in weed biological control, despite the fact that plant pathogens are typically fairly host-specific (Harris 1973).

2. Ease of multiplication

The natural reproduction rate and ease of a bio-agent should be high. For diseases, snails, insects, and aggressive plants, it is crucial. However, because of the expanded population's competition with wild fish, it is undesirable for carp.

3. Feeding habit

In comparison to root and leaf feeders, bio-agents are more effective in controlling weeds when they target the weed's flowers or seeds or pierce its stems. Perennial weeds can be more successfully managed by insects that feed on their roots. Harley and Forno (1992) suggest a biological control agent must either i) attack vital tissues, like photosynthetic, meristematic, or cambium tissues, ii) create an energy imbalance, like by inducing gall production, or iii) have a physiological effect, like causing plants to become water stressed, in order to cause "critical damage."

4. Bioagent hardiness

The biological agent must be free of its own parasites and predators. When the target weed population is reduced to a low level, the bio-agent should be able to endure famine for either

ISBN: 978-81-965655-8-9

brief or extended periods of time. Carp, however, cannot endure even a brief period of famine. Theoretically, the better adapted a biological control agent is to its new environment the more abundant it will become. Insects from similar climates and the same variety or subspecies of plant are thus given a higher priority because they are more likely to be preadapted to conditions in the new environment

Biocontrol Agents of Weed

1. Insects

The utilization of insects as a biocontrol agent for weed was begun in 1902 against the brush weed, Lantana camara, in Hawaii. Entomologists team visited the native land of this weed in Central America and Mexico and succeeded in finding Crocidosema lantana (Moth), as the most promising bioagent for this perennial weed (Gupta, 2013).

The insect Dactylopius ceylonicus accidentally provided India with the first effective biocontrol of weed. It was brought from Brazil in 1795 in order to create premium commercial dye. In North and Central India, it was established on Opuntia vulgaris, causing suppression. Eventually, prickly pears made previously uncultivated areas acceptable for farming. (Sushil Kumar, 2015). Following its success in South India, where it had a significant area under control of O. vulgaris, D. ceylonicus was introduced there in 1865. This was the first instance of a natural enemy being intentionally transferred for weed biological control. (Sushil Kumar, 1993).

The most effective instance for biological control of weeds in India is that of Parthenium hysterophorus (congress grass or carrot grass) which has occupied several thousands of land throughout the country. Efforts were started in India in 1983 by Dr. K.P. Jayanth at the Indian Institute of Horticulutral Research (IIHR), Bangalore, based on the well-documented success by Z. bicolorata from the native home of Parthenium and other nations where they were imported. The beetle, Z. bicolorata, is commonly known as the Mexican beetle, but is also called as Parthenium beetle (CABI 2020). In a very conservative estimate, it is calculated that the beetle has already spread in about 7 million hectares of amounts to about 20% area of the land with an estimated 35 million hectares of land infested with the Parthenium. Since the beetle was first released in the field in 1984 at Bangalore, it has been well established in most of south India and many parts of central and north India. Parthenium becomes skeletonized, defoliated, and produces fewer flowers and seeds as a result of larval and adult eating. Z. bicolorata has the ability to completely defoliate Parthenium, which will diminish the amount of weeds, plant height, biomass, flower output, and soil seed bank.

Likewise, water fern (Salvinia molesta) affects large water bodies and rice fields in Kerala. It has been controlled by weevil (Cyrtobagous salviniae). The insect is native of South America. This weevil takes about 4-6 months for the completely destruction of S. molesta. The terminal buds, rhizomes, and petioles of the floating weed are harmed by the juvenile larvae of this insects. (Gupta, 2013).

In India, water hyacinth is regarded as the aquatic weed that causes the greatest harm. All fresh water ponds, tanks, lakes, reservoirs, streams, rivers, and irrigation canals now experience it. Exotic natural enemies, such as galumnid mites (Orthogalumna terebrantis) and hydrophilic weevils (Neochetina bruchi and N. eichhorniae), are used to biologically control water hyacinth. With the help of the hyacinth moth (Sameodes albigultalis), which eats hyacinth's young leaves and buds, it has been successfully controlled in Florida (USA) (Sushil kumar, 2011 and Gupta, 2013).

 ISBN: 978-81-965655-8-9

Sr. No.	Natural enemies/ Bio-agent for weed	Weed plant affected	Reference
1	Chrysolina quadrigemina	St. Johnswort weed	Singh, 2004
2	Microlarinus lypriformis	Puncturevine	Gupta, 2013
3	Lantanophaga pusillidactyla	Brush weed (Lantana)	Sushil kumar 2001; Singh, 2004
4	Mescinia parvula	Siam weed	Singh 2004
5	Phytomyza orobanchia	Broomrape	Singh 2004
6	Osphronemus goramy	Aquatic weeds	Singh, 2004
7	Procecidochares utilis	Crofton weed	Sushil kumar, 2015
8	Rhinocyllus conicus	Musk Thistle	Zimdahl, 2013
9	Orthogalumna terebrantis	Water hyacinth	Singh, 2004; Sushil kumar 2011
10	Teleonemia scrupulosa	Brush weed (Lantana)	Sushil kumar, 2015
11	Agasicles hygrophyla	Alligator weed	Gupta, 2013
12	Paulinia acuminata	Salvinia	Gupta, 2013

2. Fish

Several herbivorous fish (Grasscarp) also called white amur or Chinese carp (Ctenopharyngodon idella), is a greedy feeder of several submerged and emerged aquatic vegetation. The daily aquatic weed consumption of this grass carp is equal to its own body weight, which is about 1 kg when it is one year old. Its body weight reaches up to 32 kg at its full length of 1 meter (Gupta, 2013). In the same way, sea manatee (Trichechus manatus) feeds on water hyacinth and other aquatic vegetation (Zimdahl, 2013).

3. Fungi

By using an inoculative application of microorganisms, weeds in a particular region can be controlled. This strategy is also known as the mycoherbicide strategy. (Charudattan, 1993). The target weed is sprayed with specialised fungal spores or their fermentation products, which later release their phytotoxins to eradicate the threat. Mycoherbicide is another name for these fungus-based medications. For the control of weeds, plant pathologists and weed scientists have discovered over 200 plant diseases. The following examples of fungal bioagents used to control weeds are provided.

Hemp sesbania (Sesbania exaltata) most troublesome weed in soybean which can easily be controlled by Colletotrichum truncatum (Boyette, 1991). Fusarium oxysporum applied a potential mycoherbicide for controlling three species of Striga spp. like as; S. asiatica, S. gesneroides and S. hermonthica (Marley et al., 2005).

The same goes for the management of Chenopodium amaranticolor, Senna obtusifulia, Sesbania exaltata, Datura stramonium, Carduus acanthoides and Euphorbia esula with Myrothecium verrucaria (Walker, et al., 1997; Yang and Jong, 1995). The toxin trichothecenes produced by M. verrucaria inhibit seed germination of the parasitic plant Orobanche ramose (Andolfi, et al., 2005).

ISBN: 978-81-965655-8-9

Sr. No.	Fungal bioagent	Weed plant affected	Reference
1	Phomopsis amaranthicola Aposphaeria amaranthi Microsphaeropsis amaranthi	Amaranthus species	Rosskopf, 1997 Heiny et al., 1992 Ortiz-Ribbing et al., 2006.
2	Drechslera avenacea	Avena fatua	Hetherington et al., 2002.
3	Pyricularia setariae	Setaria viridis	Peng et al., 2004
4	Phoma macrostoma	Taraxacum officinale Cirsium arvense	Bailey et al., 2003 Zhou et al., 2004.
5	Dactylaria higginsii	Cyperus rotundus	Kadir et al., 2000.
6	Plectosporium tabacinum	Galium spp	Zhang, 1999

Among the numerous fungal pathogens for weed control Phytophthora palmivora was first used commercially as DeVine in 1981 to control Milkweed vine (Kenny, 1986). Later, Colletotrichum gloeosporioides f.sp. aeschynomene was developed in the United States in 1982 for the control of northern joint vetch. By the same token, spores of C. gloeosporioides (Penz.) Sacco f. sp. malvae was used for the control of round leaved mallow in wheat (Mukherjee and Singh, 2004). At present thirteen different bioherbicide products have been launched, out of them only nine bioherbicides are available for sale/purchase in the market globally.

Professor Charudattan has employed a different strategy in an effort to control the aquatic weed water hyacinth (Eichhornia crassipes) in Florida, USA. This strategy combines an insect biocontrol agent with a fungus. To produce "hot spots" of infection, the spores of the fungus Cercospora rodmanii are sprayed in restricted spaces. The fungus spores are distributed when two previously imported weevils migrate from plant to plant, attacking the swollen petioles of water hyacinth.

As classic weed-control agents, fungi bioagents were introduced to many nations (based partly on Julien 1992)			
Pathogen	Target weed	Target country	Year of introduction
Colletotricum gloeosposoides	Clidemia hirta	Hawaii	1986
Diabole cubensis	Mimosa pigra	Australia	1995
Entyloma compositarum	Ageratina riparia	South Africa	1989
Maravalia cryptostegiae	Cryptostegia grandiflora	Australia	1993
Phaeoramularia sp.	Ageratina adenophora	South Africa	1988
Phragmidium violacaum	Rubus procerus	Chile Australia	1973 1991
Puccinia abrupta var. partheniicola	Parthenium hysterophorus	Australia	1991
Puccinia carduorum	Carduus tenuiflorus	USA	1987
Puccinia chondrillina	Chondrilla juncea	Australia	1991
Puccinia evadens	Baccharis halimifolia	Australia	1996
Sphaerulina mimosa-pigrae	Mimosa pigra	Australia	1994
Uromyces galegae	Galega officinalis	Chile	1973
Uromyces heliotropii	Heliotropium europaeum	Australia	1992
Uromycladium tepperanium	Acacia saligna	South Africa	1987

 ISBN: 978-81-965655-8-9

4. Bacteria

The bacteria also have the potential for controlling the weed by causing diseases in weeds. Weed control by using bacteria have several advantages due to their rapid growth. Xanthomonas campestris, a bacterial pathogen, was created as a bioherbicide to eradicate weeds of the Asteraceae family and annual bluegrass (Poa annua) (Johnson et al., 1996). Likewise; The growth of weeds in cranberries is controlled by a phytotoxin made from a crude extract of Pseudomonas syringae (Norman et al., 1994).

Some Commercial and Experimental Available Bioherbicides
[Boyette (2000); Upadhyaya and Blackshaw (2007)]

Sr. No.	Weed host	Pathogen
1.	Spurred anoda (Anoda cristata)	Fusarium lateritium
2.	Spurred anoda (Anoda cristata)	Colletotrichum coccodes
3.	Round-leaved mallow (Malva pusilla)	Colletotrichum gloeosporioides f. sp. malvae (BioMal)*
4.	Annual bluegrass (Poa annua)	Xanthomonas campestris (Camperico)*
5.	Spurred anoda (Anoda cristata)	Alternaria macrospora
6.	Giant rag weed (Ambrosia trifida)	Protomyces gravidus
7.	Field bind weed (Convolvulus arvensis)	Phomopsis convolvulus
8.	Jimson weed (Datura stramonium)	Alternaria crassa
9.	Florida beggarweed (Desmonium tortuosum)	Colletotrichum truncatum
10.	Sickle pod (Cassia obtusifolia)	Alternaria cassiae
11.	Common purslane (Portulaca oleraceai)	Dichotomophthora portulacaceae
12.	Horse purslane (Trianthema portulacastrum)	Gibbago trianthemae
13.	Hemp sesbania (Sesbania exaltata)	Colletotrichum truncatum
14.	Eastern black nightshade (Solanum ptycanthum)	Colletotrichum coccodes
15.	Strangler vine (Morrenia odorata)	Phytophthora palmivora (DeVine)*
16.	Velvet leaf (Abutilon theophrasti)	Fusarium lateritium
17.	Northern jointvetch (Aeschynomene virginica)	Colletotrichum gloeosporioides f. sp. aeschynomene (Collego)*
18.	Spurred anoda (Anoda cristata)	Alternana macrospora
19.	Texas gourd (Cucurbita texana)	Fusarium solani f. sp. cucurbitae
20.	Marijuana (Cannabis sativa)	Fusarium oxysporum var. cannabis
21.	Hemp sesbania (Sesbanla exaltata)	Colletotrichum truncatum
22.	Sicklepod (Cassia obtusifolia)	Fusarium oxysporum
23.	Sicklepod (Cassia obtusifolia) and others	Alternaria cassiae (Casst)*

*Bold name in the bracket are commercially available formulation

Commercially Available Bio-herbicides

1. DeVine

DeVine is a fungal product that was registered in 1981 and contains chlamydospores from the fungus Phytophthora palmivora MWV pathotype. Abbott Laboratories and the Florida Department of Agriculture and Consumer Services collaborated to produce DeVine. (Ridings

 ISBN: 978-81-965655-8-9

1986). It is used to manage milkweed vine, strangler and Morrenia odorata in citrus plantations. Depending on the size and age of the vine, this fungus will cause a root infection in milkweed vine plants that will cause the vine to die two to ten weeks after treatment.

2. Collego

The US Department of Agriculture, the Upjohn Company, and a team at the University of Arkansas under the direction of Professor George Templeton collaborated to create Collego. The fungus Colletotrichum gloeosporioides f. sp. aeschynomene produces Collego, which are live spores. Collego has two different compounds. Component B is a wettable powder formulation containing living C. gloeosporioides f. sp. aeschynomene fungal spores, while Component A is a water soluble spore dehydrating agent. For the control of northern joint vetch (Aeschynomene virginica) in rice and soybean, it is a selective post-emergent mycoherbicide. It was registered for commercial use in 1982. Collego should be applied to emerge joint vetch plants that are from 20 to 30 ern tall and have not reached the bloom stage. Rice fields should be flooded before application. Soybean fields should be irrigated just prior to application. C. gloeosporioides f. sp. aeschynomene cause anthracnose disease in joint vetch and produces lesions on the above ground parts of it.

3. BioMal

It is yet another Canadian-developed mycoherbicide based on Colletotrichum. Colletotrichum gloeosporioides (Penz) Sacco f. sp. malvae spores are present in biomal. Malva pusilla (rounded-leaved mallow) is controlled with it as a post-emergence method. 3×10^2 L/ha at a rate of 2×10^9 spores/L. Field tests have shown that round-leaved mallow can be controlled (Makowski and Mortensen 1989).

Biomal infested round-leaved mallow plants show typical anthracnose disease symptoms. Lesions produce on the leaves, petioles and stems of infested plants within 2-4 hrs after application. As the disease progresses, the stems are girdled by lesions resulting in plant mortality.

Limitations

Even if similar weeds are not frequently found in the same locations or crops, it might be advantageous economically to create a bioherbicide that can control a number of closely related weed species. Commercial interest in this technology may increase if a bioherbicide can be used on a variety of crops and weeds. In light of this, efforts are being made to eradicate closely related weeds including pigweeds (Amaranthus spp.), nutsedges (Cyperus spp.) and grasses using fungal diseases that have wide and overlapping host ranges. (i.e., restricted to several species of a genus) (Rosskopf et al., 1999).

Furthermore, efforts are being undertaken to combine a number of host-specific diseases into a single application in an effort to increase the efficacy and acceptance of bioherbicide agents. This "multiple-pathogen strategy" involves mixing three or more pathogens at the ideal inoculum levels and applying the mixture to the weeds post- or pre-emergently. Exserohilum longirostratum, Exserohilum rostratum and Drechslera gigantea were treated in an emulsion to manage seven weedy grasses in greenhouse and field trials, proving the viability of this strategy. (Chandramohan et al.,2000).

There are various significant flaws in mass production, formulation, shelf life, and application systems that have been addressed with novel approaches and technologies. More cutting-edge methods and tools are being created, many of which may be quickly customised for specific weed-pathogen systems. Lack of proper support is one of the main obstacles to employing plant diseases for traditional biocontrol of weeds. This results from the mistaken belief held by some institutions and funding bodies that the

 ISBN: 978-81-965655-8-9

outcome of traditional biocontrol is frequently too delayed, the process of discovery and deployment takes too long, and the probable non-target threat is politically difficult to contemplate. However, one simply needs to consider the quantity of effective cases and their cost-benefit ratios to draw the conclusion that classical biocontrol is among the best options, particularly for weeds that negatively impact sizable regions of undeveloped land and water.

CONCLUSION

Future expansion will only be conceivable if the problems created by increasing agricultural output are dealt with efficiently and swiftly. The increase in crop output brought on by modern agricultural methods has plateaued in many nations, including India, and environmental issues brought on by the excessive use of chemical fertilisers and pesticides are of concern. Biological control can thus be a viable alternative strategy to meet agriculture's goals.

LITERATURE CITED

- Alberta (AESA), Manitoba Agriculture, Saskatchewan Agriculture and Food factsheet. 2000. Biological control of weed. Factsheet.
- Andolfi, A., Boari, A., Evidente, A., Vurro, M. (2005). Metabolites inhibiting germination of Orobanche ramosa seeds produced by Myrothecium verrucaria and Fusarium compactum. Journal of Agricultural and Food Chemistry, 53(5):1598-1603.
- Bailey, K.L.; Derby, J and Falk, S. (2003). Evaluation of Phoma macrostoma for control of broadleaf weeds in Turgrass. VI international bioherbicide Group Workshop, Canberra, Australia.
- Boyette, C. D. (1991). Host range and virulence of Colletotrichum truncatum, a potential mycoherbicide for hemp sesbania (Sesbania exaltata). Plant Disease, 75(1):62-64.
- Boyette, C. D. (2000). The bioherbicide approach: using phytopathogen to control weed. In Cobb, A.H. and Kirkwood, R.C. (eds) Herbicides and their Mechanism of action. Sheffield Academic Press, Sheffield, UK. pp: 134-152.
- Chandramohan, S., Charudattan, R., Singh Megh, Sonoda, R. M. (2000). Biological herbicide to control grasses in citrus. Citrus Vegetable Mag., 64(7): 6-8.
- Charudattan, R. (1993). In: pesticides interactions in crop production, CRC Press, Ann Arbor, MI. pp. 421-432.
- Combellack J. H. (1992). The importance of weeds and ways of reducing concerns about methods for their control. Proceedings of the First International Weed Control Congress, Melbourne. 43-63.
- Cullen, J. M. (1985). Bringing the cost benefit analysis of biological control of Chondrilla juncea up to date. E. S. Delfosse (Ed.), Proceedings of the VI International Symposium on Biological Control of Weeds, Agriculture Canada, Ottawa, pp. 145-152.
- DeBach, P. (1964) Biological Control of Insect Pests and Weeds. Cambridge University Press, Cambridge, UK, 844 p.
- Evans, H. C. (2002). Biological control of weeds. In: agricultural applications, springer, Berlin Heidelberg, Gemany, 135-152.
- Gupta, V., Singh, M., Kumar, A., Sharma, B. C., and Kher, D. (2013). Influence of weed management practices on weed dynamics and yield of urdbean (Vigna mungo) under rainfed conditions of Jammu. Indian Journal of Agronomy, 58(2): 220-225.

ISBN: 978-81-965655-8-9

- Harley, K. L. S. and Forno, I. W. (1992). Biological control of weeds. A handbook for practitioners and students. Inkata Press, Sydney. 74 pp.
- Harris, P. (1973). The selection of effective agents for the biological control of weeds. Canadian Entomologist. 105: 1495-1503.
- Hasan, S. (1985). Search in Greece and Turkey for Puccinia chondrillina strains suitable to Australian forms of skeleton weed. E. S. Delfosse (Ed.), Proceedings of the VI International Symposium on Biological Control of Weeds, Agriculture Canada, Ottawa, pp. 625-632.
- Heiny, D. K., Mintz, S., Weidemann, G. J. (1992). Redisposition of Aposphaeria amaranthi in Microsphaeropsis. Mycotaxon., 44(1): 137-154.
- Hetherington, S. D., Smith, H. E., Scanes, M. G and Auld, B. A. (2002). Effects of some environmental conditions on the effectiveness of Drechslera avenacea: a potential bioherbicidal organism for Avena fatua. Biological Control, 24(2): 103-109.
- Jayanth, K. P. (1987). Introduction and establishment of Zygogramma bicolorata on Parthenium hysterophorus at Bangalore, India. Currant Science, 56: 310-311.
- Johnson, D. R., Wyse, D. L and Jones, K. L. (1996). Controlling weeds with phytopathogenic bacteria. Weed Technology, 10: 621–624.
- Julien, M. and White, G. (1997). Biological control of weeds: theory and practical application. ACIAR Monograph No. 49. pp:35-36.
- Julien, M. H. (1992). Biological control of weeds. 3rd Edition. CAB International, Wallingford. 186 pp.
- Kadir, J., Charudattan, R., Stall, W.M. and Brecke, B. J. (2000). Field efficacy of Dactylaria higginsii as a bioherbicide for the control of purple nutsedge (Cyperus rotundus). Weed Technology, 14(1): 1-6.
- Kenny, D. S. (1986). De vine the way it was developed: an industrialist view, weed science, 34(1): 15-16.
- Makowski, R. M. D. and Mortensen, K. (1989). Colletotrichum gloeosporioides Esp. malvae a bioherbicide for round-leaved mallow (Malva pusilla): conditions for successful control in the field. In: Delfosse, E.S. ed. Proceedings VII International Symposium on the Biological Control of Weeds, Rome, 1988. Instituto Sperimentale per la Patologia Vegetale, Rome. 5: 13-522.
- Marley, P. S., Kroschel, J., Elzien, A. (2005). Host specificity of Fusarium oxysporum Schlect, a potential mycoherbicide for controlling Striga spp. in West Africa. Weed Research, 45(6): 407-412.
- Mcfadyen Cruttwell R. E. (2000). Successes in biological control of weeds. In: Proceedings of the X International Symposium on Biological Control of Weeds. 4-14th July, 1999, Montana State University, Montana, USA. pp. 3-14.
- Mukherjee Dhiman and Singh, R. P. (2004). The biological control of weeds - a review. Agric. Rev., 25(4): 279 – 288.
- Norman, M., Patten, K. and Gurusiddaiah, S. (1994). Evaluation of a phytotoxin from Pseudomonas syringae for weed control in cranberries. Hort. Science, 29: 1475–1477.

 ISBN: 978-81-965655-8-9

- Ortiz-Ribbing, L., Williams, M. M. (2006). Potential of Phomopsis amaranthicola and Microsphaeropsis amaranthi, as bioherbicides for several weedy Amaranthus species. Crop Protection, 25(1): 39-46.
- Peng, G., Byer, K. N and Bailey, K. L. (2004). Pyricularia setariae: a potential bioherbicide agent for control of green foxtail (Setaria viridis). Weed Science, 52(1): 105-114.
- Ridings, W. H. (1986). Biological control of strangler vine in citrus-a researcher's view. Weed Science, 34 (Suppl. I): 31-32.
- Rosskopf, E. N. (1997). Evaluation of Phomopsis amaranthicola sp. nov. as a Biological Control agent for Amaranthus spp. Ph.D. Dissertation, University of Florida, Gainesville, FL, USA.
- Rosskopf, E. N., Charudattan, R., Kadir, J. B. (1999). Use of plant pathogens in weed control. T. W. Fisher, T. S. Bellows, L. E. Caltagirone, D. L. Dahlsten, C. Huffaker, G. Gordh (Eds.), Handbook of Biological Control, Academic Press, San Diego, CA, pp. 891-918.
- Singh, S. P. (2004). Some success stories in classical biological control of Agricultural pests in India. Success Stories, Asia-Pacific Association of Agricultural Research Institutions (APAARI), Bangkok, Thailand.
- Supkoff, D. M., Joley, D. B., Marois, J. J. (1988). Effect of introduced biological control organisms on the density of Chondrilla juncea in California, J. Appl. Ecol., 25: 1089-1095.
- Sushil Kumar. (1993). Biological control of forests and waste land weeds in India. Annals of Entomology, 11(2): 131-153.
- Sushil kumar. (2011). Aquatic weeds problems and management in India. Indian Journal of Weed Science, 43(3&4): 118-138.
- Sushil Kumar. (2015). History, progress and prospects of classical biological control in India. Indian Journal of Weed Science, 47(3): 306–320.
- Upadhyaya, M. K. and Blackshaw, R. E. (2007). Non- chemical weed management (Principles, Concepts and Technology), CAB International, UK. pp: 93-110.
- Walker, H. L., Tilley, M. (1997). Evaluation of an isolate of Myrothecium Verucaria from sickle- pod (Senna obtusifolia) as a potential mycoherbicide agent. Biological Control, 10(2): 104-112.
- Yang, S., Jong, S.C. (1995). Host range determination of Myrothecium verrucaria isolated from leafy spurge. Plant Disease, 79(10): 994-997.
- Zhang, W. (1999). Development of bioherbicides for biological control of cleavers. Alberta Research Council, Canadian Seed Growers, Association Research and Development Funding, Alberta, CA.
- Zhou, L., Bailey, K. L and Derby, J. (2004). Plant colonization and environmental fate of the bio-control fungus Phoma macrostoma. Biological Control, 30(3:634-644.
- Zimdahl, L. R. (2013). Fundamentals of weed sciences, 4th Edition, Academic Press, USA. Pp. 323-346.

ABOUT THE EDITORS

Dr. Mudasir Ali
Assistant Professor & Head at Division of Renewable Energy Engineering
COAE&T, SKUAST-Kashmir

Ms. Khumanthem Babina Devi
Ph.D Research Scholar in Environmental Science
Mizoram University

Miss Kshetrimayum Manishwari Devi
Ph.D Research Scholar at Department of Agronomy
College of Agriculture, Central Agricultural University, Imphal

Er. Bilal Ahmad Langoo
Assistant Professor,
College of Agricultural Engineering, SKUAST-Kashmir, Shalimar Srinagar

Mr. Dibyajyoti Nath
Ph.D Research Scholar in Soil Science
Dr. Rajendra Prasad Central Agricultural University (RPCAU), Pusa, Bihar

EMPYREAL
PUBLISHING HOUSE

ISBN 978-81-965655-8-9

India | UAE | Nigeria | Uzbekistan | Montenegro | Iraq | Egypt | Thailand | Uganda | Philippines | Indonesia

Empyreal Publishing House || www.empyrealpublishinghouse.com || info@empyrealpublishinghouse.com