# Agri-Tech Approaches for Nutrients and Irrigation Water Management

Edited by Shivam Gupta,
Sushil Kumar Himanshu and
Pankaj Kumar Gupta

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# Agri-Tech Approaches for Nutrients and Irrigation Water Management

This book includes concepts, methodologies, and techniques used in soil nutrients and irrigation water management with regional and global prospects. This book accommodates up-to-date approaches to agricultural technologies along with future directions and compiles a wide range of chapters ranging from soil moisture flow, nutrient dynamics, crop water estimation techniques, approaches to improve crop water productivity and soil health, crop simulation modeling, and remote sensing/GIS applications. The book also includes chapters on climate-resilient agriculture, advances in big data and machine-learning techniques, IoT, plasma technology, seed priming, and precision farming techniques and their environmental/economic impacts.

Features:

- Discusses applications of sustainable technologies for soil nutrients and irrigation water management at multi-scale.
- Covers the applications of remote sensing/GIS, big data and machine learning, IoT, plasma technology, seed priming, and precision farming techniques for nutrients and water management.
- Reviews concepts, methodologies, and techniques being used in soil nutrients and irrigation water management.
- Provides up-to-date information as well as future directions in the field of nutrients and agricultural water management.

This book is aimed at researchers and graduate students in agriculture, water resources, environment, and irrigation engineering.

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# Contents

# Preface

Irrigation is a major sector of water consumption and requires special attention for the implementation of policies and practices to use water judiciously to optimize its utilization. Similarly, nutrient management is another aspect of agricultural practice, and effective nutrient management is crucial for agricultural sustainability. This book compiles various aspects of nutrients and irrigation water management with regional and global prospects. The state-of-the-art technologies and methods being used for nutrients and irrigation water management are compiled, along with case studies from across the globe. The advanced agro-technologies for nutrients and irrigation water management, such as artificial intelligence, big data analytics, remote sensing, crop modeling, seed priming, and the Internet of Things (IoT) are also key features of this book.

Climate change and its repercussions are severely affecting agriculture, and this is likely to have major implications for global food security, drinking water, and sanitation. Precision agriculture can be a solution to this challenge, which ensures optimized use of water and nutrients for maximizing yield and farm income. This book compiles information regarding the recent key findings on climate change implications on agriculture and related sectors, and strategies to mitigate its impact, along with economic assessments. Advanced remote sensing and GIS-based approaches used for monitoring crop health, managing nutrients, and estimating irrigation water requirements for optimum utilization of water resources are the need of the hour, and these all aspects are well addressed in this book. Simulation-based case studies on crop responses under different irrigation and field practices are also included.

In conclusion, this AI-focused agri-tech book takes the concept of traditional agri-technologies to the next level. By incorporating the IoT, UAVs, artificial intelligence, and machine-learning algorithms, this book can provide more personalized and targeted insights for farmers and others involved in agriculture. This can help farmers make more informed decisions about when to plant, water, nutrients, and harvest their crops, as well as identify potential problems before they become too severe. Overall, this book has the potential to revolutionize the way that farmers approach agriculture, making it more efficient, sustainable, and profitable.

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# Editors

**Shivam Gupta** is Assistant Professor in the Department of Irrigation and Drainage Engineering, Mahamaya College of Agricultural Engineering and Technology, Acharya Narendra Dev University of Agriculture and Technology, Ayodhya, Uttar Pradesh. Previously he worked as Assistant Professor at Central Agricultural University Imphal, Manipur, India. He completed his Ph.D. at the Indian Institute of Technology Guwahati, India, with a specialization in Water Resources Engineering and Management. During his Ph.D., he worked on the impact of climate change on extreme climate events and water resources for the Himalayan River Basin. He has worked as Research Scientist at the National Remote Sensing Center, Indian Space Research Organization, Hyderabad, where he worked on the development of an operational snowmelt model for the Himalayan region. His area of research includes climate change, downscaling of GCM datasets, bias corrections, climatic projections for various climate change scenarios, water resources management, extreme events analysis, snowmelt modeling, and currently he is working on irrigation water management, evapotranspiration estimation, and remote sensing applications in agriculture. He has published seven research articles and four book chapters in prestigious internationally reputed journals. He has reviewed research articles for international journals such as *SERRA*, *TAAC*, *AJGS*, *Acta-Geophysica*, and *CATENA*.

**Sushil Kumar Himanshu** is Assistant Professor in the Department of Food, Agriculture and Bioresources, School of Environment, Resources and Development, Asian Institute of Technology (AIT), Pathum Thani, Thailand. Dr. Himanshu has more than eight years of international experience in research, consultancy, and capacity building in the areas of precision farming, climate-resilient agriculture systems, on-farm irrigation water management, remote sensing and GIS applications in agriculture, applications of unmanned aerial systems (UAS) and wireless sensors in agricultural applications, big data analysis and applications, machine-learning applications in agriculture, and hydrologic/cropping system modeling. He obtained his M.Tech. degree in Hydrology and Ph.D. in Water Resources Development and Management from the Indian Institute of Technology (IIT) Roorkee, India. His Ph.D. research was focused on evaluating satellite-based precipitation estimates for hydrological modeling. Before joining AIT, he was working as Postdoctoral Research Associate at the Texas A&M AgriLife Research Center (Texas A&M University System), US, where his research was focused on developing and evaluating strategies that conserve soil and water, promote water use efficiency, and protect soil and water quality in diverse agro-ecosystems. He also worked as a research scientist at the National Remote Sensing Center of the Indian Space Research Organization (ISRO) in Hyderabad, India, where he worked on the operationalization of a national-level hydrological modeling framework for in-season hydrological water balance components at daily/weekly/fortnightly time steps. Dr. Himanshu has received several awards and honors, including the Distinguished Alumni Award (2022, Indian Institute of Technology Roorkee – India), Outstanding Reviewer Award (2020, Transactions of the ASABE), Best Water Resources Student Award (2018, Indian Water Resources Society), International Travel Award (2017, Science and Engineering Research Board – Government of India), Bergen Summer Research School Award (2016, University of Bergen – Norway), MHRD Scholarship (2010–2012 and 2013–2017, Indian Institute of technology Roorkee-India), and Indian Council of Agricultural Research Fellowship (2006–2010). He has authored/co-authored more than 55 research publications in high-impact journals. He also edited one book, published eight popular press articles, and presented his research to several international conferences/meetings in various countries. He reviewed more than 80 research articles from high-repute journals.

**Pankaj Kumar Gupta** is a Ramanujan fellow, upholding one of the honored scientific positions at the Indian Institute of Technology (IIT) in Delhi, India. As a Ramanujan fellow, he has undertaken an exceptional project "Engineered Microbiome (E-Biome Project)", a unique combination of microbiology, hydrogeology, and chemical sciences for restoration of polluted sites, funded by the SERB, Govt. of India. He is also an adjunct assistant professor at the University of Waterloo, Canada.

Dr. Gupta is a contaminant hydrogeologist, after having completed his Ph.D. at IIT Roorkee, he has been a postdoctoral fellow at the University of Waterloo, Canada. He diversified his expertise in hydrogeology and soil-water quality during his Ph.D./PDF. He is the co-founder of the Society of Young Agriculture and Hydrology Scholars of India (SYAHI) and is also an editorial member of the *Frontiers in Water Journal*, *Biochar*, and *Carbon Research*. etc. He has also edited three books entitled S*oil-Water, Agriculture, and Climate Change: Exploring Linkages*, A*dvances in Remediation Techniques for Polluted Soils and Groundwater* (Elsevier), *Fate and Transport of Subsurface Pollutants*.

Dr. Gupta holds his in-depth experience in incorporating novel technologies (viz. geophysical investigations, groundwater modeling, aquifer mapping, water quality assessment, microbiome, etc.) to map soil-water systems of 30+ sites in India. Dr. Gupta has also worked as a field officer at the Centre for Development Communication, Jaipur, and Salasar temple (Churu, Rajasthan) to improve water and wastewater management practices in the desert villages. Dr. Gupta is passionate about interdisciplinary research and teaching to understand multi-scale interactions between different components of the subsurface environment, especially the soil-groundwater-pollutant-microbes system.

He also teaches and guides Master's and Ph.D. students with diversified knowledge. He has received an AGU Travel Grant (2017), JPGU Travel Grant (2018), and EXCEEDSWINDON and DAAD Germany Grant (2018). He serves as an editorial board member for SN Applied Sciences, Biochar, Carbon Research and Frontiers in Water journals. He has published more than 20 research papers, approximately 30 book chapters, edited two books and two popular science articles. He has reviewed several research articles for reputed journals including *RSC Advances*, *Groundwater for Sustainable Development*, *ASCE JEE*, *ASCE* Irrigation and Drainage, *Env. Sc.*, *Pollution Research*, *Eco-Hydrology*, *Journal of Contaminant Hydrology*, etc. Further, he has led many site restoration and remediation consultancy projects at polluted industrial sites in India. He is a core member of the Society of Young Agriculture and Hydrology Scholars of India (www.syahindia.org), a network of early-career researchers from around the globe.

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# 1 AI for Sustainable Agriculture in the Face of Climate Change

*Poulomi Chakravarty, Sai Gattupalli, Kashyapi Chakravarty, Gulab Chand, and Urjani Chakravarty*

## INTRODUCTION

The population of Earth surpassed 8 billion on November 15, 2022, according to the United Nations report by the Department of Economic and Social Affairs (2022). It took just over a decade for the human population to grow from 7 billion in 2011 to 8 billion (Chakravarty et al., 2017). This overwhelming population rise calls for action in the sector of agriculture to ensure global food security. According to Ben Ayed and Hanana (2021), the elevated population by the year 2050 will require a colossal increase in global food production by 60% to 110%, which is just sufficient to cater to the human population of over 9 billion. Therefore, it is crucial to have sustainable agriculture in modern times to solve food security issues and address hunger as well as poverty worldwide (Rockström et al., 2017). The challenges faced by humanity are not only limited to population and food security but extend to more complex issues such as climate change, water scarcity, lack of land resources, pollution, and infectious diseases. Due to the excruciating burden of anthropogenic forcings on climate, natural resources, ecosystems, and the environment, there is a dire need for swift and strategic action to fortify global agricultural communities.

Now the question arises of how one can achieve this gigantic feat of providing nourishment to billions of people in times of disaster such as the raging COVID-19 pandemic. How to deal with the perpetual human struggles of climate change, water scarcity, resource and energy shortages? The answer to this would be to think and act "smart". The current discussion contends that to act "smart" there is also a need to understand the transdisciplinary aspect of the problem. Even though in the 21st century we are able to effectively use technology in all sectors and we can use smart technology in the field of agriculture as well, the question still remains of understanding the ethical underpinnings related to smart technology. Agriculture is not

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only the provider of nourishment for the global population but also engages a large population in agrarian employment. Now is the time to be proactive and welcome innovative measures to increase yield in agriculture, produce crops that are resistant to diseases and climate change, and produce harvests that are sustainable in nature. Sustainable agricultural practices can be adopted by farmers aided by digital and engineering technologies such as AI, the Internet of Things (IoT), cloud computing, and machine learning (Ben Ayed & Hanana, 2021).

## SMART AGRICULTURE FOR A CHANGING CLIMATE

Agriculture is the practical and scientific method used to cultivate the topsoil layer to grow crops along with practices to raise livestock. Agricultural practices are dependent on various deterministic factors. Climate and topography are among the most important aspects that govern agricultural practices of any region. Climate elements like solar insolation, temperature, rainfall, humidity, and climate extremes (such as droughts, floods, storms, cyclones, tornadoes, and snow) are determinants of the success or failure of agriculture. Water availability for irrigation, water quality and the evapotranspiration process are other major aspects of agriculture. Agriculture requires a medium for the growth of plants and livestock. As we know the topsoil is the key layer for our survival and soil fertility, soil moisture, overall soil health, and the organisms present in the soil determine the yield and productivity of agricultural produce (Mauget et al., 2021). Biotic components such as symbiotic flora and fauna, disease-causing insects, pests, and parasites also have a critical role in the health and yield of agricultural produce. Figure 1.1 portrays the factors that determine agriculture and clearly depicts the role played by the above-mentioned aspects on holistic agricultural practices. Smart agricultural approaches need to maintain these factors for agricultural production in a sustainable fashion.

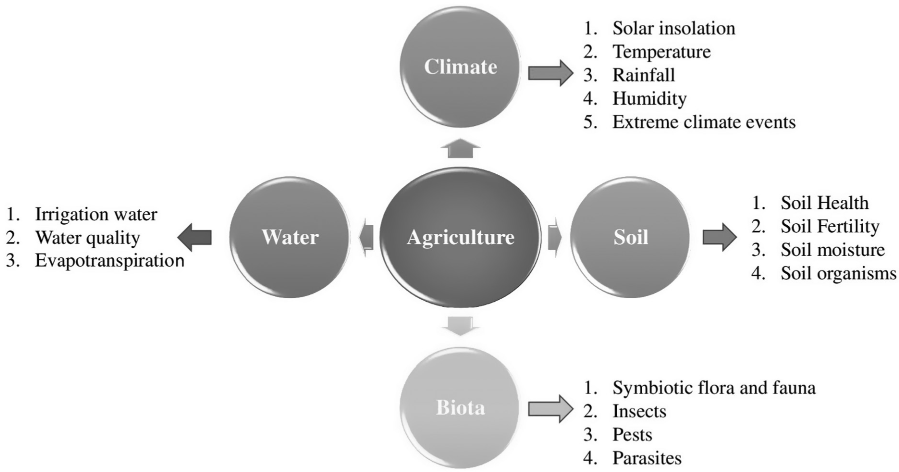


**FIGURE 1.1** Factors critical to sustainable agriculture

## GLOBAL ISSUES ON CLIMATE CHANGE

Climate change is one of the most pressing threats in the 21st century and its negative impacts are observed in all sectors worldwide and the most devastating impact is observed in the agricultural, which directly affects the socio-economic sectors of nations (Jug et al., 2018; Aune, 2012). As the climate change effects are now being felt worldwide there is an urgent need to address issues related to drought, floods, low groundwater table, saltwater intrusion, desertification, and biodiversity loss, among others. In the face of global climate change, worrisome issues have been cropping up all over the planet. One such example is the recent, severe drought in Europe which peaked in the summer of 2022 and has been a multi-year drought initiated from the year 2018. Rakovec et al. (2022) in their paper identify this drought to be a high-intensity, unprecedented benchmark that has remained active for more than two years and covered a shocking 35.6% of area over a period of 12.2 months with the air temperature at the near surface being +2.8° Kelvin. This current persistent drought is worse than any historical droughts in Europe over the past 250 years. As drought periods are identified by below-normal rainfall and high temperatures, it is safe to say that agriculture, which is completely dependent on water for irrigation and optimum temperature and other climate elements, is severely affected in European nations. More intense or equally intense droughts are projected to occur on the continent of Europe by the assessment of soil moisture simulations of the years 2021 to 2099 (Rakovec et al., 2022). African nations like Kenya, which are considered to be within the "Horn of Africa," are also suffering from long drought periods peaking in 2022 that is the worst recorded drought for the nation in 40 years, resulting in drying of 90% of water sources, mass-scale death of livestock, and huge agricultural losses due to parched land bereft of rains as reported by World Meteorological Organization (WMO, 2022). Floods in Pakistan in the year 2022, and wildfires in the United States of America are other examples of climate-related extreme events that have afflicted the socio-economic structures of the affected nations (Buchholz et al., 2022; Devi, 2022; Sharma et al., 2022). The rise in infectious diseases in plants and pests is another major adverse impact of climate change as projected by IPCC reports on food security (2022). Recently, swarms of locusts from African nations have been migrating to Asian nations and destroying agricultural crops, which is just one such example of pest infestation affecting agricultural lands across continents (IPPC Secretariat and FAO, 2021). All these climate-related issues have had a negative influence on the agricultural community around the world therefore it is necessary to understand the link between climate and agriculture and find solutions to end the negative impacts of climate change for the development of the agricultural sector.

## CONNECTING CLIMATE AND AGRICULTURE

Globally agriculture is responsible for 6.4% of the world economy and in nine countries, agriculture is the backbone of the economy (Pathan et al., 2020). In the case of India, agriculture is the contributor to 70% of the country's economy (Chakravarty & Kumar, 2020). India is also the second highest populated country in the world, closely following China, therefore the requirement for resources is extremely high. Larger population density requires food security which should be independent of climatic extremes and resistant to droughts, floods, infectious diseases, and pestilence. Climate change is a global issue that affects us all, but it has an especially profound impact on agriculture. With rising temperatures, low rainfall, and weather patterns becoming more unpredictable, farmers must adapt to new conditions in order to ensure a successful harvest. Connecting climate and agriculture is essential for understanding the effects of climate change and developing strategies to mitigate its impacts on food production. By understanding how climate affects agricultural production, we can develop sustainable farming practices that will help ensure food security in the face of a changing climate. Jug et al. (2018) suggest that "conservation agriculture" has the potential to change the way farmers produce their goods, but it has yet to be adopted on a global scale. The main reasons behind this include lack of knowledge, traditional values and prejudices, and inadequate policies that don't recognize the need for subsidies. Poorly selected machinery, land size not optimally matched to machine cost, minimal profit returns, ineffective training, and guidance programs lead to a need for better planning and execution of any farming operation (Farooq & Siddique, 2014; Jat et al., 2014). Mendelsohn (2009) painted an alarming picture of the higher negative impacts of climate change on developing nations including India in comparison to developed nations like the United States. The study further stated that agriculture in tropical and sub-tropical nations is more sensitive to the changing climate than their temperate counterparts. Even a nominal rise in temperature over Latin American and African regions would result in damaged crop production as the temperature in these latitudes is already on the higher side. Similarly, rain-fed agriculture systems are more vulnerable to climate change impacts than agriculture with developed irrigated systems. The study concluded that all regions across the globe will not face similar impacts on agriculture due to climate change and the scenarios will vary from region to region depending on local climate. Therefore it is highly recommended to study an agricultural sector in each country to study regional climate patterns and devise strategies to overcome climate change impacts on the basis of specific issues. It is also important for sustainable agricultural development to have contingent plans for irrigation, soil health, and overall plant health to succeed in scenarios with warmer temperatures, uncertain weather and rains.

## EXPLORING CHALLENGES OF THE AGRARIAN COMMUNITY

Challenges in the agricultural sector are attributed to climate change, land degradation, water scarcity, and socio-economic constraints. It is important to understand that just as climate change impacts are region-specific, challenges faced by the agricultural sector in each country or region are also case-specific. Mendelsohn (2009) explains that in case of climate change, temperate regions might benefit from a warming climate due to a higher number of days for agriculture in colder countries when global surface temperature rises. Similarly some regions are said to receive more rainfall as an impact of climate change which might be beneficial to agriculture but too much rainfall can cause floods resulting in crop damage. This is where science and technology come to the rescue of the farming community.

Smart agricultural practices have to be adapted by harnessing the available scientific resources to overcome challenges faced by the agricultural community in the face of climate change. Practices such as conservation agriculture, phytoremediation, agroforestry, and irrigation management practices have to be judiciously used with the assimilation of 21st-century tools like AI to have beneficial results.

## HARNESSING THE POWER OF AI FOR A GREEN EARTH

The advent of industrialization has escalated the domino effect of problems starting from greenhouse gas emissions (GHGs), over population, global warming leading to climate change, pollution, biodiversity loss, and mass-scale extinction. Anthropogenic impacts on the environment and climate have affected all living beings on the planet. To maintain an equilibrium of ecosystems, it is necessary that we understand that humans are a part of the entire biosphere and try to live in harmony with other species. The United Nations Sustainable Development Goals (SDG) follow the same principle of judicious living to safeguard our planet and its resources for future generations. Scientists have joined hands with policymakers and stakeholders to achieve zero hunger for the globe, which is one of the United Nation's SDGs to be achieved by the year 2030. This can be only attained if drastic measures are employed. As discussed above, the challenges faced are numerous in terms of weather unpredictability, GHG emissions, and water scarcity amidst economic uncertainties (US EPA, 2022). This herculean task can be achieved when we think out of the box and move toward unconventional and sustainable agricultural practices which will ultimately lead to equity and viability in socio-economic structures, positive acceleration in productivity, and negate adverse impacts of changing climate, rising population, and pollution (Lakshmi & Corbett, 2020). It is important now, to understand how we can utilize the power of intelligent technology to help us achieve these goals.

## ROLE OF ARTIFICIAL INTELLIGENCE IN THE 21ST CENTURY

The 21st century has ushered in an era of unprecedented technological advancement, with AI playing an increasingly important role. AI is a field of computer science dedicated to the research of methods and algorithms that have the ability to mimic human intelligence. Pannu (2015) calls AI the intelligence "exhibited by machines or software". We discuss a general understanding of subject technology and cover some of the recent AI-enabled innovations that have transformed the traditional way of practice and being. We see how these innovations have a direct impact on the "end user", in that they allow users to make sense of their agricultural business practices and related ethics, and in implementing new practices that are sustainable in the long run. We summarize with real-world examples how various AI-enabled technologies are shaping our world in new and sustainable ways, and in delaying the critical climate change tipping point. In 2022, Armstrong and colleagues found that Mother Earth has already crossed the tipping point thresholds due to the rise in global warming temperatures. This news brought panic to science communities. News such as this tends to get attention from social media climate activists such as Greta Thunberg, who use their social media powers to bring awareness to the youth populations. We discuss the implications of AI for sustainable agriculture in the face of climate change.

A 2016 White House report highlights the significance of AI and the necessity of a clear roadmap and strategic investment in this area (Intelligence, 2016). With an immense potential to revolutionize the way humans interact with machines and the environment, AI technology's presence is rapidly growing in our daily lives, in businesses we visit online or in person. Especially in the research domain, the field has come a long way since its beginnings in the 1950s, and today it is used in a variety of applications, from self-driving cars to monitoring climate change. For example, AI technology has already saved human lives by identifying hidden or complex patterns in diagnostic data to detect acute diseases earlier and improve treatments (Jamshidi et al., 2020), and helped scientists develop complex computing models and stunned the astronomical community by revealing the first-ever picture of a "black hole" (Event Horizon Telescope Collaboration, 2019). These are only two examples of the several ways in which technology has revolutionized our societies. Researchers thought achievements such as these were impossible to achieve only a few decades ago, but now we are really realizing the hidden potential of advanced technologies such as artificial intelligence. Many businesses have sprung up by harnessing the power of AI to create virtual assistants that many people use daily. Although there is a growing number of concerns relating to AI-ethics and its usage by notorious government agencies, the benefits continue to play an important role in improving our lives now, and in the future. Figure 1.2 represents the application of AI in various sectors such

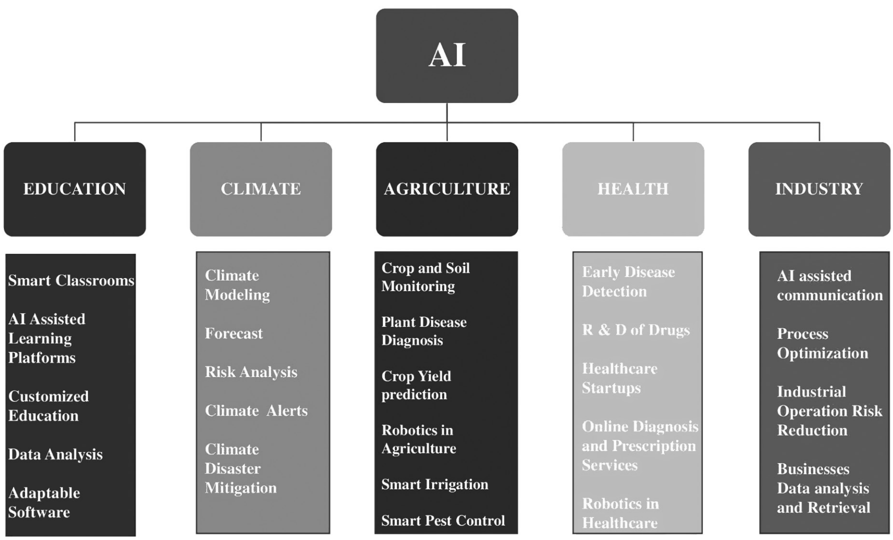


**FIGURE 1.2** Applications of AI in various sectors

as education, climate, agriculture, health, and industry. In this chapter, the authors focus on and expand AI and its applications in agriculture, climate, education, and communication, and briefly summarize the healthcare and industrial aspects of AI.

In industries such as healthcare, researchers are using AI technology for early detection of glaucoma in patients (Al-Aswad et al., 2022), while others such as Liang et al. (2020) use AI to predict the tolerance of chemotherapy drugs for cancer patients and help radiologists map and target tumorous areas accurately. Again, these evolutions in science are directly saving lives; a few decades ago, we thought it would be impossible to achieve anything of this magnitude. In manufacturing, the use of AI and robotics continues to revolutionize the industry. Using AI, engineers automate product assembly processes thereby reducing costs, increasing production speed, and improving overall product quality (see Fahle et al., 2020). The evolution that AI has brought to the manufacturing sector has not only made the industry efficient and productive, but also sustainable (Ghobakhloo, 2020). This next generation of industrial systems is often regarded as “Industry 4.0” (Peres et al., 2020). In the section below, we present more AI-enabled tools in environmentally focused areas such as agriculture and climate. As AI by itself is a software at its core, new businesses have appeared promoting software-as-a-service (SaaS) (Bisong, 2019), to bring new insights into their business decisions and developments.

## IMPLEMENTATION OF AI IN EDUCATION

As AI offers previously unimaginable possibilities in research and practice in many industries, we take a look at some of the most notable examples. We explore some applications of AI developed for a variety of purposes, ranging from creating awareness of climate change in educational outcomes for children, to detecting diseases early on so they can be cured. In the education pipeline, AI currently provides young math learners with a personalized learning experience tailored to their individual preferences and needs (Arroyo et al., 2014). More recently, scientists have developed learning technologies that use AI to enhance learner engagement in online math learning by observing the facial expressions of the learner (Lee et al., 2022). These examples are instances of AI-enabled technology that focus on the learner. Ironically, AI is far from practical when it comes to climate change education. Climate change education has been a hot topic in educational research for over a decade, and prominent climate change education researchers (see Monroe et al., 2019; Henderson & Drewes, 2020; Shepardson et al., 2012; Feinstein & Kirchgasler, 2015) have all argued the importance of climate change education in our school system. Pogue (2021) in their book *How to Prepare for Climate Change: A Practical Guide to Surviving the Chaos* says that about two-thirds of all US students say that they were never taught about climate change in school. Although there is a lack of proper climate change education in the US school system, there are plenty of open educational resources on the internet. The National Aeronautics and Space Administration (NASA, 2023) lists student and educator resources related to global climate change and includes interactive multimedia. The resources also show how the space research agency is trying to mitigate, and take action on the climate crisis.

Other climate education resources include the United Nations Climate Action online portal (UN Climate Action, 2023), which lists not only the causes and effects of climate change, but also thorough and well-drafted “Initiatives for Action”, and broader goals for participating nations; whereas on the European continent, the centrally funded climate change education initiatives such as the European Climate Change Curriculum (2023) and the Erasmus+ youth educational and training program (2020) provide several climate change learning resources for young children. In Table 1.1, we discuss more AI-enabled tools meant to bring awareness and educate the agricultural community. In developing nations such as India, curricula related to climate education and a sustainable future are practically non-existent within the primary and secondary education systems. The curriculum is restricted to a few theoretical concepts in school textbooks on atmosphere and climate change. However, in higher education, there is scope as institutions offer graduate-level degrees in climate science and sustainable development. The Centre for Environment Education (CEE) has taken initiatives promoting climate change education by joining hands with the UN Framework Convention on Climate Change (UNFCC) after the Paris Agreement in 2016 as reported by the climate change portal of the CEE (2022). This initiative has helped with the creation of a basic framework for research and development of climate action for empowerment in India. It is our argument that in order to accomplish a sustainable future, it is necessary that change begins in our schools, and hence leads to the question of climate change education. In the big picture, we are full of hope that children, in their adulthood, are aware of the environmental and atmospheric changes, sustainable practices, monitor their carbon footprint, and make decisions appropriately and ethically, which is also the aim of the climate change education community and further aids in holistic sustainable practices.

## AI–HUMAN INTERFACE: ANSWERS FROM ENVIRONMENT COMMUNICATION

Agriculture is a human activity. Humans as social animals learn everything through communication. From the time of its inception, AI too has been harnessing the structure of human communication to create the human–machine interface. So, any discussion on the roles of AI in the development of sustainable agriculture would remain incomplete without looking at the overall role of communication in environment management. Over time an exclusive branch of communication deals with issues related to the environment. AI interfacing with environment communication opens up the field to transdisciplinary research (Slovic et al., 2019). This arose in the 1980s and 1990s. As it is a relatively uncharted field, there are various opinions on how to define the term “environment communication”. A change in approach from the 19th-century Romantics that instead of only appreciating nature the focus is on preservation. One prominent scholar in the area, Flor (2004) and later Senecah (2007) explores the scope of “environment communication” for conservation as well as management of the environment. Their thesis on environment communication follows the idea of “mutual understanding” and a “holistic view” of communication at the center of the discipline and not just as part of environment management or even conservation.

One philosophical basis of "environment communication" is "ecological ethics" which studies the relations between human beings and nature. Moreover, it also deals with the ecological crisis, and attempts to find out the cause that leads to the crisis. Donald Worster (1993) points out that the cause of ecological crises faced around the world is not created by ecosystems, but through a lack of proper human ethical systems. He suggests the removal of the crises in possible recognition and reformation of the said ethical system. What is this ethical system? How can we relate this to AI? The area of ecological ethics brings forth the concept of "who has the right?", which was earlier limited to the human world, and expands the same "rights" to the non-human world, i.e., "ecological holism". Going further into this discussion to follow "ecological holism", it is fundamentally about the rights of the natural world, the rights of human beings and their obligations, and in general morality interfacing with the AI systems. As a result, an AI application can be considered conducive when it preserves the human and non-human community's integrity, stability, and beauty leading to no effect on the overall ecology of the Earth. If the extension of the subject of "rights" from humans to the whole of the natural world is cultural and moral progress, the extension of the subject of "rights" from the natural world to the AI world can also be called moral progress. Whereas when it goes to the opposite, it can lead to something wrong.

The above Figure 1.3 shows the implications of ecological ethics for AI applications; further it traces how AI is bridging the gap between environmental communication and ecological practices, i.e., AI–human interface. As technological advancements are tested, Weder et al. (2021) discuss creating a space for "transformative sustainability" and revolutionizing the basic criterion of value present in

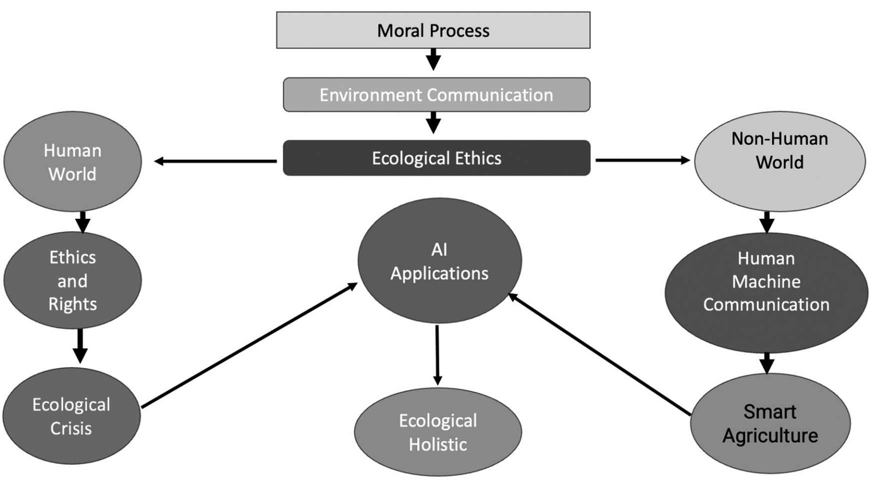


**FIGURE 1.3** Ecological holism for smart agriculture

"holism". Regarding any single part of the ecosystem, be it human beings or AI as a center, does not conform to the law of "ecological holism". Similarly, any role of AI for smart agriculture is not to deny the role of human existence, but to assist humans in judging all things keeping in mind the interests of the ecosystem and keeping themselves within the bounds of ecological law. It is better to see the interface as an "environmental construct" (Chakravarty & Gaur, 2011) where the background knowledge of one can be well executed by the other. We, however, have many specific problems that need to be solved. Wherein the AI system facilitates support and structure to human endeavor. This is definitely possible with the help of what Bartz (2021) calls the "intent–action gap". Human consciousness or lack of it is the main reason for this gap. As the ecosystem is immensely complex, the question of which human conduct follows or does not follow the ecological law is still worth investigating. And how can and should the value of the natural environment be assessed in relation to human needs and goals? The true concern, finally, ought not to be with only general representations, but with humans and whatever it is in the natural world working together interfaced with AI systems.

## PLANTING THE SEEDS OF A SUSTAINABLE FUTURE

Anthropogenic impacts on the environment can be reduced by a comprehensive assessment of cause and effects, then solutions can be achieved via joint efforts of nature, man, and machine. The challenges posed to the Earth and humanity are numerous thus the solutions have to be diverse in nature that address a variety of issues at once.

Hence, AI has become increasingly relevant in the 21st century, as the world is faced with a growing number of complex societal challenges. AI is being used to tackle issues in areas such as healthcare, climate change, and sustainable agriculture. It can also be used to create predictive models for climate change, helping to improve the accuracy of forecasts and reducing the risk of extreme weather events; hence helping us prepare for disasters, making mitigation strategies, and finally rehabilitation after disaster events. AI is also being used to automate various processes, such as those in factories making the requirement of manpower in many sectors obsolete. Automation can help to reduce costs, increase efficiency, and reduce environmental impact. AI can also be used to identify and address problems before they occur, helping to reduce waste and improve the efficiency of operations.

## AI APPLICATIONS IN AGROMETEOROLOGICAL AND CLIMATE SERVICES

The multifaceted applications of AI can be witnessed in the research and development of climate sciences, agrometeorology, and climate education (Chakravarty, 2023). As discussed in the earlier sections, AI can prove to be a successful ally when used judiciously for sustainable agriculture by taking into consideration climate forcings on the land surface. AI has found applications in climate sciences and agrometeorology in many ways and in turn helps agriculture by predicting weather patterns (such as Huntingford et al., 2019). Agrometeorological advisories generated by AI help farmers make decisions about when to irrigate on the basis of water availability information (see Perea et al., 2019), when to harvest (such as Kim et al., 2019), and when to store crops (Kumar et al., 2022). By using AI-powered systems, farmers can gain an understanding of how different farming practices affect the environment. For example, agriculture is a contributor to GHG emissions and causes environmental pollution as agricultural runoff causes eutrophication (Chakravarty & Kumar, 2019). By leveraging data-driven insights, farmers can identify which practices are most sustainable and which are most damaging. In the same way, AI can also help farmers find ways to reduce their water usage, reduce their carbon footprint, and reduce their reliance on chemical fertilizers and pesticides. Mendelsohn (2009) lays emphasis on region-specific climate strategies for successful sustainable agriculture. AI can prove to be an excellent tool in recognizing and predicting specific climate trends a region has and can overlay this information on demographic data, agricultural data, and socio-economic statistics to create a composite analysis of the region that will help policymakers make educated decisions on their agricultural policies.

Implementation of AI as an efficient tool for agrometeorological services is depicted by an innovative mobile application called *Meghdoot* developed in India, which improves access to climate information services. It is essential for farmers to receive timely advice from agronomists in order to make appropriate decisions and reduce the risk of crop failure due to unfavorable weather which helps them maximize their yields and increase their income. The *Meghdoot* application provides essential weather details as well as crop-specific advisories, thus enabling users to make better decisions regarding their crops (Dhulipala et al., 2021). This mobile application was jointly developed by the India Meteorological Department (IMD) along with IMD's District Agrometeorological Advisory Service (DAAS), the Indian Council for Agricultural Research (ICAR), the Indian Institution for Tropical Meteorology (IITM), and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). This application is available in English and 12 other Indian languages (Hindi, Bangla, Tamil, Telugu, Mizo, Assamese, Gujarati, Malayalam, Kannada, Odia, Punjabi, and Marathi) making it accessible to the farmers. This application covers 717 districts of India providing information on real-time weather alerts and crop advisory based on specific point location and has sent out 3,54,312 advisories since its launch in July 2020.

Kumar et al. (2022) carried out a case study on the efficacy of the *Meghdoot* mobile app for the region of Ladakh, which has low accessibility via roads and a very cold and dry climate with minimal precipitation in the form of snowfall in winter. A hundred farmers were sampled randomly, and it was reported that 50% of farmers acknowledged the user-friendly local language on the application and 70% of registered farmers followed the agrometeorological advisory alerts. The application proved superior by giving 16.71% more yield of crops for farmers who used this application over non-users since 2020. As communication is a major barrier in information dissemination, the *Meghdoot* application has bridged that gap and has helped users in a country where there are multitudes of local languages and dialects. Thus, we can safely say that AI strategically correlates climate statistics with current agricultural practices and helps with point-specific solutions to each region.

## IMPLEMENTATIONS OF AI TECHNOLOGY IN AGRICULTURE

In recent years, AI has become an important tool for sustainable agriculture. AI systems are increasingly being used to monitor soil health, predict crop yields, and find ways to reduce greenhouse gas emissions (Bawa et al., 2023). By using data-driven algorithms and machine learning, AI can provide valuable insights into soil composition and crop production. For farmers, identifying the best practices for their fields is crucial, so they rely on AI to make educated decisions and save money. The software enables them to optimize their crop yields and reduce their reliance on chemical fertilizers and pesticides. AI-powered systems can monitor soil health, water usage, and even monitor crop growth and identify areas of the field that need more attention. With this data, farmers can make informed decisions about when to plant, weed, and harvest, as well as which varieties of crops to plant in each field.

AI has had a major impact on the field of sustainable agriculture, with many potential benefits to the industry, research communities and governments. AI has the potential to increase crop yields, identify pests, optimize irrigation and fertilizer use, and reduce food waste. Additionally, AI is able to minimize human error, increase efficiency, and even predict the weather (Xu et al., 2021). Researchers and farmers alike may also benefit from AI-powered autonomous vehicles and monitoring systems, which reduce the need for manual labor. As such, researchers should consider the implications of AI-driven systems and regulations must be in place to govern its use. Some examples of AI-powered tools that have a direct impact on sustainable agriculture include *Masa*, which is a mobile app for newcomers to the agricultural sector to get a first-hand walk-through guide containing all the information they need to get started and be successful and sustainable farming (Ogubuike et al., 2021). DroneDeploy is used by farmers for surveying their agricultural land area seeks to better predict the impact of weather systems (Giri et al., 2020). Table 1.1 summarizes some of the AI-driven tools and technologies in the field of agriculture.

The potential of AI to benefit the agricultural community has long been evident. With the ability to increase yields for farmers, optimize pest management, and reduce food waste, AI offers opportunities for more efficient and cost-effective agricultural practices. While some members of the agricultural community argue that AI offers more benefits than risks, others are more cautious. Despite the potential benefits of AI, there are also potential drawbacks. AI-driven decisions can have serious implications and if autonomous robotics are not properly regulated, they could lead to negative environmental consequences. A major drawback of AI robotics in agriculture would be unemployment to humans as a major number of repetitive tasks would be assigned to AI-driven machinery and human involvement would shrink to only supervision purposes (Ben Ayed & Hanana, 2021).

**TABLE 1.1**
**Application of Artificial Intelligence and Related Tools in the Agriculture Sector**

| AI Tools | Applications | Methods | Benefits | Country | Source |
|---|---|---|---|---|---|
| *Meghdoot* Mobile Application | Weather alerts<br>agro-advisory<br>forecasts | Satellite imagery<br>Automated<br>weather stations<br>District-wise advisory offices | Information to farmers<br>Higher yields<br>Beneficial alerts for storms, heatwaves,<br>coldwaves,<br>cyclones, hail, snow, rain, lightning | India | Dhulipala et al. (2021)Kumar et al. (2022) |
| *Agrilyst* | Precision agriculture<br>prediction | Harvest period projection<br>Sowing cycles regulation | Good yield by prediction and guidance system | US | Prescott (2016) |
| *MDFC–ResNet* | Crop disease recognition systems | Fine-grained Disease Recognition<br>on three levels<br>Residual neural networks with multi-dimensional feature compensation applied | Species recognition<br>Disease recognition<br>Disease level<br>recognition | Mongolia | Hu et al. (2020) |
| Fast Image Processing, (FIP)<br>Robust<br>Crop Row Detection, (RCRD) | Weed management | Weed detection in maize fields through cameras<br>for herbicide dosage | 95% weed detection<br>80% crop row detection | Spain | Burgos-Artizzu et al. (2011) |

(*Continued*)

**TABLE 1.1 (CONTINUED)**
**Application of Artificial Intelligence and Related Tools in the Agriculture Sector**

| AI Tools | Applications | Methods | Benefits | Country | Source |
|---|---|---|---|---|---|
| *Alesca Life* | Precision farming modular food production | System driven environmental controlled crop growth containers | Production of specific edible plants in the controlled environment of the consumer | China | Kakani et al. (2020) |
| John Deere | AI-powered tractors, farm equipment, machinery, and tools | Utilizes computer-vision sensors on machinery | Autonomous weed identification and eradication<br>Hands-free farm tractor driving | 30 countries including the US and Canada | Chattopadhyay et al. (2022) |
| Trace Genomics | Analysis of agricultural data | Machine learning application to gather metadata | Soil metadata provides information on the overall health and condition of soil | US | Kakani et al. (2020) |
| TEAPEST | Identification of pests in tea plant | Neural networks and objective-based pest management system | Pest management in tea plantations | India | Ghosh and Samanta (2003) |
| Drone Deploy | Survey of agricultural land | Aerial map creation through drones | Information provided to stakeholders regarding agricultural land | Available worldwide | Giri et al. (2020) |
| *Masa* mobile App | Sustainable agriculture guidance system | Walk-through guidance for novices in agriculture | Promotes sustainable agriculture for beginners in farming | Available online | Ogubuike et. al (2021) |

While research continues, it is important for agricultural decision-makers to strike a balance between these two perspectives. In many cases, existing agricultural practices can be augmented with the use of AI, while ensuring that any potential risks are minimized.

## ROLE OF AI IN CONTROL OF AGRICULTURAL DISEASES AND PESTS

A major challenge faced by farmers in agricultural practices is damage to crops due to plant diseases and pests. Two significant aspects of agriculture are pest management and disease management (Sharma, 2021). There are three main components to the pest and disease management process namely prevention, detection, and control. Conventional methods have been applied in the past to deal with these aspects of agricultural practices. However, there are certain limitations to human interventions that are now being curtailed using AI in order to achieve maximum protection from pests and diseases and in turn reduce agricultural losses.

### Pest Management

The most troubling issue in farming leading to heavy economic loss is pest infestation of crops. For the longest time, scientists have tried to devise various methods through computational processes in order to classify different pests and ways to identify and manage their infestations. Mostly these methods are confusing and do not provide a proper solution (Pasqual & Mansfield, 1988). Therefore many logic-based systems of expertise were devised to solve these issues (Saini et al., 2002; Siraj & Arbaiy, 2006). A method based on an objective-oriented technique was employed to create an expert system based on a rule by Ghosh and Samanta (2003) for pest management in tea called TEAPEST. Categorical identification and implementation of the consultation process was carried out along with the restructuring of the system by applying multifaceted back proliferation neural networks (Samkanta & Ghosh, 2012). Later on, this was modified by utilizing a functional prototype based on the radial technique in order to achieve higher rates of sorting (Banerjee et al., 2017). Characteristics ranging from the route of pest infestation to future pest attacks are now being predicted by utilizing advanced programming AI by companies and the government for pest control in agriculture. Drone footage of crops can now be used to constantly monitor the presence of diseases, pests, poor soil, and unusual degradation in plants, which will help farmers get better pest management results. Data on any particular pest-infested area can be obtained through this and this information can be used to control the further spread of any pest or disease at the earliest stage possible.

### Disease Management

Plant diseases in their countless forms pose a significant threat to the agricultural economy, environment, and in turn to global consumers' health. A massive loss of crops of approximately 35% occurs in India alone due to destruction caused by plant diseases and pests. Uncontrolled application of pesticides is also hazardous to human health as they could be biomagnified and spread toxicity. All these issues can be dealt with through proper surveillance of agricultural crop plants in order to look for potential plant diseases and the application of customized treatments at the earliest. A significant level of expertise is essential to detect diseased plants and decide a course of action for recovery. Figure 1.4 broadly illustrates the steps involved in the detection of diseases in crop plants by application of AI and laboratory analysis (Sharma, 2021). For this, a computerized systematic approach is used globally for disease analysis and suitable crop recovery.

In order to detect the disease, sensing and analysis of images are carried out to categorize them into external disease-free regions, background imagery, and the diseased portion of the leaf. Samples of infected regions are then retrieved and analyzed further in the laboratory. This process greatly aids in the detection of pests and the presence of nutrient deficiency. Earlier, the rule-based systems were designed by Byod and Sun (1994) for disease management in agricultural crop plants. Francl and Panigrahi (1997) established an artificial neural network model for plant disease eradication in a variety of harvested crop plants. Along with these certain hybrid control systems were also applied. A neural network model in conjunction with an image dispensation prototype was developed to map out and detect the phalaenopsis sapling disease (Huang, 2007).

The margin for human error in disease and pest detection in agricultural crop plants is greatly reduced by the application of digital image processing techniques of AI. Therefore, AI greatly enhances the identification and categorization of diseases and pests in plants and aids in the application of early methods of treatment and in turn reduces agricultural crop damages and economic losses. Implementation of AI systems in pest and disease management in agriculture is a newer domain and still has a vast untapped territory of advanced applications. At present a combination of

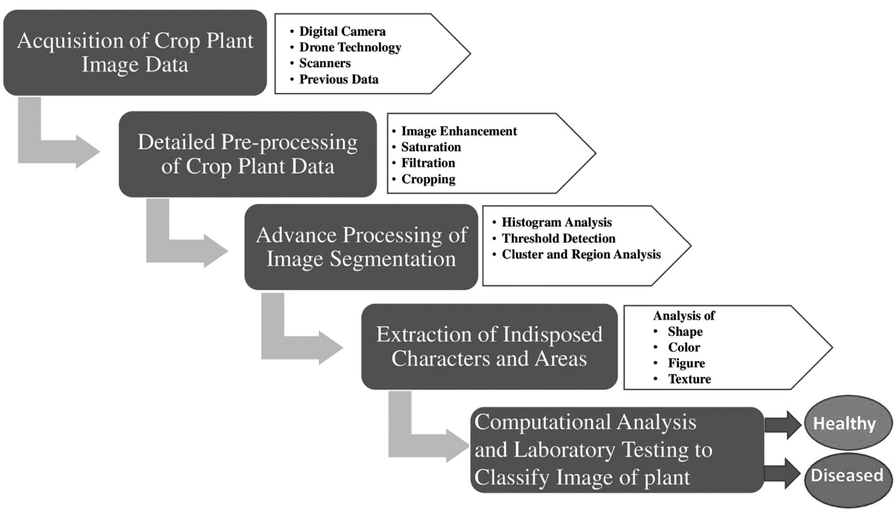


**FIGURE 1.4** Crop plant disease detection process

AI and laboratory testing of samples provides suitable pest and disease monitoring and control. For future analyses completely based on AI, much more research and development are necessary to overcome the limitations of current methods of detection and management.

## RECOMMENDATIONS FOR AI IN AGRICULTURE

As climate change continues to be a global concern, the agricultural sector is quickly undergoing significant changes in ways that it is making the industry sustainable and ethical. Advances in AI technologies are furthering the sector to meet its sustainability goals in the face of climate change. Using AI as a vehicle, farmers are able to make better sense of their farming data, detect patterns, and respond to changes in the environment in sustainable ways. The following are our recommendations for making the most out of the technology.

Start with education. AI has already brought many benefits to the education field, especially in computing and math literacy programs. However, there is rarely any mention of AI being used in literacy programs aligned with addressing climate change and sustainable agriculture. This can be addressed by creating learning modules that provide real-life climate change events, including the causes and effects. Such modules are worthless if they are not taught in our school curricula. Again, this recommendation is aimed at stakeholders from climate change education communities along with members of AI education to address. Next, we recommend changes in agricultural practices that have traditionally been carried out since the Industrial Revolution. We are currently living in the information age, where even farming tractors come equipped with sensors that provide real-time digital dashboards for farmers. Intelligent decisions are made based on AI-powered algorithms that allow personnel to make educated decisions that are not only cost-effective, efficient, and productive, but also address sustainability and ethical concerns. Lately, many researchers have been researching the use of modular sensory equipment that plugs into existing farming machinery (Thomasson et al., 2019) for the benefit of the equipment operator. Companies such as Toradex are developing modular attachments that enable equipment operators to make educated decisions for saving costs and for a sustainable future. Our next recommendation is aimed at our collective realization that it is our ethical responsibility to be more conscious of our impact on the environment and to do what we could to reduce it. We believe that in order to be aware of the ecological implications of smart agriculture, we need to first be aware ethically. Here, we recommend that AI-enabled technologies in environmental communication take the lead in facilitating support and structure to human endeavor. One way to achieve this is by proactively taking steps to harness the benefits of AI, such as in remote areas as they most commonly tend to be out of the applicable communication channels and may need the use of local vernacular versions to reach all corners of the society. Although the recommendations mentioned here are for climate change communities, we encourage anyone who is directly involved in farming activities to find use in them. The AI-powered tools discussed in this chapter are currently being used by many farmers across the world, and we hope you do too.

## CONCLUSION

The chapter is an attempt at a transdisciplinary approach to not only AI applications but also to sustainable agriculture. The investigations deal with multifaceted fields ranging from climate change to ethics to capture the relevance and solutions being implemented. Nonetheless, the benefits and implications AI technology brings to agriculture are phenomenal, which allow us to make ethical decisions focused on sustainable agriculture and in the face of climate change. AI continues to revolutionize the way we conduct farming, and at the same time influences how we treat the environment, for the betterment of human civilization.

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Conflict of Interest: The authors declare no competing interests.

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# 2 Development of a Modeling Approach for Agriculture Crop Type Classification Aiming at Large-Scale Precision Agriculture by Synergistic Utilization of Fused Sentinel-1 and Sentinel-2 Datasets with UAV Datasets

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## INTRODUCTION

Most developing countries like India are agriculture-based economies. Presently, the agriculture sector plays an essential role in India by providing livelihoods to more than 60% of the population (Sharma et al. 2010). It provides food to the people and ensures food security for the country. This sector delivers raw materials for many industries and contributes to the country's food exports (Palanisami et al. 2019). India's food security depends on producing cereal crops. The agriculture sector has been showing decent growth in the past few decades, which has led to increased productivity and exports (Seelan et al. 2003). Despite this high growth rate, the agricultural sector is still facing various challenges and issues (Jain & Pandey 2020). The biggest problem in the Indian agricultural sector is its low efficiency resulting in low agricultural yield in terms of productivity, due to the traditional agricultural

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