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AI For Agriculture - A Necessity to Revitalize Indian Agriculture

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Abstract— Agriculture is the backbone of the Indian economy. Besides ensuring food security for its 1.45 billion strong population, it is also the largest provider of employment. India has the highest percentage of land under cultivation globally and is one of the leading producers of rice, milk and wheat. Despite this, India's poor ranking on food sustainability indices and the 2023 Global Hunger Index ranking India 111 out of 125 countries, emphasise the agricultural distress that repeated economic surveys have been highlighting. There is an urgent need to reinvigorate the Indian agricultural sector as it directly impacts the rural economy. This paper explores for AI can be used effectively for reviving and strengthening Indian agriculture and the challenges that need to be overcome for it to work seamlessly.

Index Terms- Intelligent agriculture, agronomic forecasting, soil water analysis, rural economy, hunger index, food security, environmental crisis, water supplies, climate change, Artificial intelligence, soil degradation

I. INTRODUCTION

India has the highest percentage of land under cultivation globally and is one of the leading producers of rice, milk and wheat. The Indian agricultural sector has been the backbone and a key contributor to the rural economy and the overall employment in India offering more than 48% of the total employment opportunities nationally and over 70% in rural India. With only 4% of the world's water resources and 2.4% of the world's land, Indian agriculture is tasked with providing food security for a total of 1.45 billion strong population which amounts to 17.8% of the world's population. This also includes 15% of the total livestock populations globally. Although the Indian agricultural sector has expanded at an impressive compounded annual growth rate (CAGR) of 3.7% between 2017-18 and 2021-22, despite the pandemic, its overall contribution to India's economy has progressively declined to less than 15% due to the high growth rates of the industrial and services sectors [1,2].

The sudden drop of the Agricultural growth rate to 1.4 per cent in 2023-24, compared to 4.7 per cent growth rate of 2022-23, mainly because of a drop in the food grain production due to delayed and poor monsoons caused by El Nino, revealed the Economic Survey Report 2023-24 tabled in the Parliament on July 22, 2024 has become a cause of serious worry against the backdrop of farmer distress and protests [3]. Overdependence on monsoon, climate change, depleting soil and water table, reduction in land holding size, poor access to financial aid, withdrawal of government subsidies and reduced government spending on the sector and import, rapid urbanisation are some of the principal causes stressing the sector.

India can ill afford a slowdown in the rural sector as nearly three-quarters of India's families depend on rural incomes and India cannot afford to compromise on food security of its population. Renowned agricultural scientist M.S. Swaminathan, known as the father of India's Green Revolution, has been the most prominent voice for reform in the agricultural sector in India that started in the 1960s and is credited with changing India's agricultural trajectory and turning India from a mass importer to a self-sufficient nation in food grain production [4,5].He was one of the strongest supporters for introducing modern technology to enhance India's agricultural productivity and to attract the educated youth to this sector at a time when most educated youth were abandoning it and farmers had begun to look at it as an unviable option. According to him Agricultural practices incorporating precision farming would help convert his concept of "evergreen agriculture revolution" into a reality [6].

For a country with a population of 1.4 billion to feed, India has no choice but to improve yield per hectare which currently is among the lowest in the world today as it has not additional cultivable land left. Even in the case of cash crops like rice and wheat, which forms the larger proportion of produce, its yields are drastically lower than even BRICS counterparts. India's rice yields for example are one-third of China's and about half of those in Vietnam and Indonesia. The same is true for most other agricultural commodities [7,8].

In response to these challenges, the World Economic Forum's Artificial Intelligence for Agriculture Innovation (AI4AI) initiative is stepping in to support India's agricultural transformation by driving the use of artificial intelligence (AI) and related technologies for agricultural advancements. Led by the Centre for the Fourth Industrial Revolution (C4IR) India, this initiative brings together government, academia and business representatives to develop and implement innovative solutions in the agriculture sector [9,10]. This paper examines how AI can be used for precision agriculture and can be employed to rejuvenate India's agricultural system.

II. USES OF AI IN AGRICULTURE

4.1 Accurate weather pattern predictions:

Weather plays a very crucial role in maximising agricultural output and increase crop yields. Most crops grown in fields rely entirely on rain and sunshine for their survival and hence if the farmers get the timing wrong, they can suffer huge losses. High temperatures, low rainfall, flooding, and sudden freezes negatively affect crops, particularly during the most vulnerable stages of plant growth, such as seed germination. The weather also has an indirect impact on output, in terms of soil moisture, nitrogen uptake and the spread of pest populations. Soil erosion and nutrient deficiency due to heavy rain and the opposite phenomenon, soil salinization during the dry spell, are all examples of the indirect impact of weather on agriculture [11]. Accurate weather forecasting can help farmers take more precise decisions regarding sowing, irrigation, fertilizers, irrigation weeding, pest control etc [12]. A greater proportion of the total annual crop loss results from aberrant weather. Also crop and animal disease are greatly influenced by weather. In all, weather accounts for approximately three fourth of the annual loss in farm production both directly and indirectly [13]. Farmers most frequently use short-range forecasts, which are predictions made between 1 and 7 days in advance. In the meantime, medium range (up to a month), long-range (up to a year), and hazardous weather forecasts for agriculture can all be extremely helpful in field activity planning.

AI weather forecasting tools have been found to predict weather with more accuracy than the industry gold-standard weather simulation system – the High-Resolution Forecast (HRES), produced by the European Centre for Medium-Range Weather Forecasts (ECMWF).Traditional forecasting works by using Numerical Weather Prediction (NWP), whose starting point are physics equations that simulate atmospheric behaviour through principles like fluid dynamics and thermodynamics. Using observational data from weather stations and satellites, including temperature and wind speed, these models then process the data with complex and time-consuming calculations performed by supercomputers. In contrast, deep learning ushers in a new era in weather forecasting by taking an entirely different approach to solving the problem. These AI generated weather forecasts use data instead of physical equations to create a weather forecast system.

In 2023, Google's DeepMind claimed that GraphCast, a state-of-the-art AI model claimed ability to make medium-range weather forecasts with unprecedented accuracy. GraphCast predicts weather conditions up to 10 days in advance more accurately and much faster than the industry gold-standard weather simulation system – the High-Resolution Forecast (HRES), produced by the European Centre for Medium-Range Weather Forecasts (ECMWF).It can also offer earlier warnings of extreme weather events. It can predict the tracks of cyclones with great accuracy further into the future, identifies atmospheric rivers associated with flood risk, and predicts the onset of extreme temperatures [14,15,16].

Existing weather forecasts are based on mathematical models, which use physics and powerful supercomputers to deterministically predict what will happen in the future. These models have slowly become more accurate by adding finer detail, which in turn requires more computation and therefore ever more powerful computers and higher energy demands. Google DeepMind says that making 10-day forecasts with GraphCast takes less than a minute on a high-end PC, while HRES can take hours of supercomputer time. And GraphCast isn't the only AI tool for weather prediction. Google DeepMind and Google Research have also developed a Nowcasting model that produces forecasts up to 90 minutes ahead, and MetNet-3, a regional weather forecasting model that is already being used in some parts of the US and Europe, produces more accurate 24-hour forecasts than any other system. Ite energy efficiency, makes it financially viable too [17,18].

4.2 AI for soil technology and evaluation:

Soil is for the farmer what the pulse is for the doctor. It helps them take decisions about when to irrigate, when and what to sow, use nutrients and so on [19]. Poor understanding or information on the soil can lead to poor decisions regarding crop selection, fertilizers, irrigation, and other necessary inputs required for an optimal yield. India is already paying a price for overuse of chemical fertilizers which tend to harden the soil, reduces soil fertility, pollutes air, water, and soil, and lessens important nutrients of soil and minerals, thereby damaging the environment [20]. Chemical fertilizers are used when the farmer hasn't studied the soil well. The Constant use of chemical fertilizers can alter the pH of soil, increase pests, acidification, and soil crust, which results in decreasing organic matter load, humus load, useful organisms, stunting plant growth, and even become responsible for the emission of greenhouse gases [21]. Moreover, there is a strong relationship between soil quality, human health, and ecosystem services[22]. Poor quality soil or the wrong choice of a crop may force the farmer to use inorganic aids to improve yield and that can reduce the nutrition value of the produce. In India, the availability or access to food and the nutritional quality of food are becoming a huge cause of concern for the growing population. India is ranked 101 out of 116 countries in the Global Hunger Index (GHI) 2021. A comprehensive national nutrition survey (CNNS) involving 112,316 children below 16 years of age conducted during 2016-2018 across 30 states of India revealed that more than 15% of the children between 1-4 years, 5-9 years and 9-16 years showed deficiencies in vitamin A, vitamin B12, vitamin D, folate, and Zinc [23]. A lot of this is happening because of faulty farming practices.

Traditional lab-based soil evaluation techniques are not only laborious and time consuming, but due to the diversified data available, it is very difficult to establish and study the effects of all influencing factors on soil parameters [24,25] This creates a huge hurdle in getting a complete insight into the influencing parameters and making further decisions for intelligent agricultural practices manually [26]. Moreover, the processing time of conventional techniques can be delayed and this effects the quality of farmer response and can affect yield. Smallholder farmers face challenges accessing viable soil testing laboratories and moreover, it is time-consuming as it takes mostly over 14 days for the result to be available, and a professional soil scientist is needed to operate the equipment for accurate soil analysis results. Traditional methods use sieving, sedimentation, and soil analysis, which is time-consuming, sometimes inaccurate, and requires skilled professionals and specialist tools. Most smallholder farmers use traditional process to check/make soil assessment which is a manual guess work that can affect the proper development of crop growth and development as wrong analysis of soil can cause overfertilization or under fertilization which can directly reduce crop production and impact negatively on the environment [27]. The amateur approach is basically a hit and try system and further depletes the soil reducing the quantity and quality of food produced [27]. Globally, over 20% of the total arable land has undergone degradation due to unsustainable and ineffective farming practices leading to low food production and causing environmental problems.

AI empowered low-cost portable AI-powered devices can help farmers check their soil health status and analyze its fertility on the field in real-time. These low-cost portable AI-powered soil testing devices help smallholder farmers check their soil health status and analyse its nutrients in a few minutes at the location itself and they can take proper decisions in terms of cropping , fertilizers and irrigation to efficiently manage their crop growth and soil. The device uses sensors with advanced algorithms and machine learning to provide a comprehensive soil or water analysis in real-time. AI and ML techniques collect data from extensive soil sampling and historical data to create comprehensive predictive soil maps. AI can process enormous amounts of data that can be linked to historical soil data to establish patterns and relationships and used to make predictions or classifications of soil types along with other features help predict nutrient levels, Ph value, determine soil moisture, assess soil erosion risk etc. The test result is used to develop data-driven tailored decisions on sustainable soil and crop management practices via their mobile phones to recommend the most suitable crop types and how to efficiently apply fertilizer to improve crop productivity[27,28,29]. AI is also useful in early detection and management of crop diseases and pests. By analysing data from sensors and cameras placed in fields, AI algorithms can identify unusual patterns and symptoms that might indicate the presence of diseases or pests. This enables farmers to take swift action, such as targeted pesticide application, minimising the use of chemicals and preserving soil health [29].

4.3 AI for irrigation and water conservation:

India accounts for about 2.45 per cent of world's surface area, 4 per cent of the world's water resources and about 16 per cent of world's population [30].

Freshwater is renewed through the water cycle, but excessive consumption can cause shortages in the supply [31]. India is one of those that is already in the red in terms of this. Severe water shortages in India could hurt the country's sovereign credit strength, according to Moody's Ratings, warning that the water crisis could lead to social unrest if the agriculture and industrial sectors are disrupted [32] .

Agricultural production is responsible for nearly 70% of that withdrawal volume, while the industrial sector and the domestic uses are responsible for 22% and 8% of that volume, respectively [33]. Therefore, it is clear that agriculture is the most water-intensive sector, thereby contributing extensively to freshwater scarcity [34]. In an agrarian country like India, water and agriculture are intrinsically linked, with 90% of water withdrawals stemming from excessive agricultural usage [35].

Over the past 50 years, policies have allowed what amounts to a free-for-all in groundwater development. Estimates put India's groundwater use at roughly one-quarter of the global usage with total usage surpassing that of China and the United States combined. With farmers provided electricity subsidies to help power the groundwater pumping, the water table has seen a drop of up to 4 meters in some parts of the country. This unfettered draining of groundwater sources has accelerated over the past two decades with aggressive pumping, particularly in rural areas, where agriculture provides the livelihood for upwards of 600 million Indians [36].

There is an urgent need for better agricultural-water management practices making the use of Internet of Things (IoT) and precision agriculture solutions, the practical way to contribute to mitigating climate change from several perspectives, including water footprint (WF) reductions [37]. Use of AI for precision farming has the potential for improving water efficiency in agriculture.AI in agriculture is becoming the bedrock of automation. It helps automate simple and mundane tasks such as gathering field information, labelling and analysing data, developing reports, and sending notifications [38].

The quality of crops depends on the appropriate amount of watering since overwatering and under watering may damage crops or hinder their growth. Additionally, the soil must be moist, and the required humidity must be maintained. However, it is still difficult for farmers to determine the right amount of water to get the preferred yield and quality. Moreover, due to global climate and geospatial land design, soil texture, soil–water content (SWC), and other parameters vary greatly; thus, real time, robust, and accurate soil analytical measurements are difficult to be developed. Conventional statistical analysis tools take longer to analyse and interpret data, which may not be useful for real time decisions making the farmer either over or under water their fields which affect yield and also have a long term bearing on efficient use of water [39].

The most crucial factor in irrigation decisions is the soil water content (SWC) or soil moisture is the amount of water present in the soil. It influences plant growth, soil temperature, transport of chemicals and groundwater recharge [40]. The optimal SWCs are closely associated with carbon allocation, plant growth, nutrient recycling, photosynthetic rate, and microbial activity. The regulation of these parameters has also invariably been linked with the physicochemical properties of water that are held in soil [41]. This water-holding capacity against the gravitational pull feeds the crop during water scarcity posed by low precipitation. The Soil–water holding capacity (SWHC) is mainly affected by soil texture, which is further dependent upon pH, temperature, microbial community, precipitation, type of soil, and other relatable factors. Since the data is so diversified and involves a large number of variables that may vary from farm to farm literally, traditional methods are unable to provide timely information and the critical time to perform a management response may have surpassed. While conventional statistics play a significant role in this irrigation decision-making process, the relative analysis is consistently and flawlessly present [42].

Artificial intelligence (AI) has been found to process non-numerical data, such as images, videos, text, and voice data with greater perfection. Therefore, there is a need to align the geophysical influence data on soil quality with artificially intelligent systems to process the decision-making more robustly [43,44].Moreover, the soil has the property of water anchorage, which may change with physicochemical texture and climate and its water-holding capacity of soil can vary among different types of soil. Combining AI based soil analysis with a range of data sets such as satellite imagery, temperature, humidity, climate, and weather predictions can help build a new automation control for an irrigation system. This will aid farmers in making optimal water management decisions to waste less water while conserving energy. this combines with more accurate AI based weather forecasting help farmers estimate and improve the assessment of daily rainfall and potential evapotranspiration, and this combined with the crucial SWC and soil analysis information makes their irrigation more efficient which is also good for the crops besides helping in efficient water management.

Besides, tools like Sprinkler Irrigation which use AI-based irrigation system collects data from thermal and acoustic rain sensors that measure the intensity of rainfall to schedule the next irrigation. Upon analysis and calculation of this data, the system sends automated notifications to sprinklers to prevent overwatering or extensive use of water [45]. The Center Pivot Irrigation with field sensors provide data insights to the AI-based system controls circle irrigation sprinklers and adjusts the stream or angle of water flow to help reach plants that are far from the water source. Drip and Micro Irrigation uses AI algorithms to precisely control the amount of water to be applied for a specific crop. Depending on the type of data to be captured – soil, light, weather, and plant, IoT sensors can be used in AI-based irrigation systems capable of delivering strategic insights into the most appropriate times to water crops, use fertilizers or pesticides, etc. Located at important points across the field, soil-based sensors collect relevant data of volumetric water content, salinity, and other crucial parameters that help gain quick insights into soil's needs and predict irrigation needs in real-time [45,46,47,48].

Agriculture accounts for around 70% of all water withdrawals globally according to the World Bank, and approximately 60% of that is wasted, largely due to inefficient applications according to the UN's Food and Agriculture Organisation (FAO). With water increasingly valuable against the backdrop of a rising human population and climate change, AI tools are becoming the future [49]. Studies have shown that the wastage in water used for agriculture goes beyond optimized irrigation systems and the prevention of overwatering. One area that remains a key concern for farmers is the ability to detect malfunctions such as leaks in the irrigation system without the help of personal inspection. This is where interconnected devices are increasingly used in the irrigation system, allowing the software to send an alert when something is wrong suspicious. Irrigation sensors can thus discover any irregularity in real-time and connect it to the root issue, enabling farmers to take immediate action [50,51].

4.4 AI for efficient pest management

About 30-35% of the annual crop yield in India gets wasted because of pests, according to the Indian Council of Agricultural Research. Nematodes (microscopic worms many of which are parasites) had recently emerged as a major threat to crops in the country and they caused loss of 60 million tonnes of crops annually. This loss directly impacts the livelihoods of the farmers and the country's food security [52] . Left with no choice, the farmers use large quantities of pesticides to protect their crops and to improve their storage life. This regular and careless use of pesticides to overcome losses has resulted in issues like pesticide resistance, secondary pest outbreaks, breakdown of host plant and soil degradation, and potential high-risk diseases to consumers [53]. Conventional method involves monitoring the insect pest by manual identification by subject experts. This causes delays and is subject to error. Moreover, it is impossible to identify the microscopic strains until their have caused visible damage [54,55].

AI introduces a transformative approach by enabling targeted interventions that minimize ecological repercussions while maximizing efficacy. AI detection systems automate pest identification and monitoring using cameras and sensors that collect data such as heat, movement, and sound. Machine learning algorithms analyze these data points against massive datasets, enabling AI to identify pests and recommend treatment plans [56,57,58]. By replacing costly and time-consuming manual pest detection, farmers can get real time information and early and accurate detection of pests, hence reducing the need for excessive pesticides. AI stops infestations before they happen by predicting pest populations weeks, months, or even years in advance. AI algorithmically processes vast amounts of data, such as weather patterns, pest life cycles, and past outbreaks, to generate predictive models. An example is the Anticimex SMART Digital Rodent Control System, which combines digital traps with sensors that monitor rodent activity. The system uses that activity data to build trend curves predicting nearby mice and rat populations [59,60].AI powers the development of precision pest control strategies by analyzing datasets as diverse as pest behavior, environmental conditions, and historical infestation patterns. It finds insights such as where and when an infestation will likely begin and what entry points and routes pests will likely use — or may already be using allowing timely prevention [61]. AI can also monitor environments in real-time by placing sensors and cameras into traditional pest control devices. Slovenian company Trapview, for instance, developed a pheromone trap that photographs insects it catches [62]. That data powers AI to make real-time predictions, such as how the pests will spread so that field technicians can intervene swiftly with a targeted response. ML algorithms can automate the process of identifying pest species based on various data inputs, such as images, DNA sequences or acoustic signals [63]. IoT enabled traps capture pests and transmit images to central systems for identification [64], integrating artificial intelligence with Entomology for effective & timely management and forecasting of pests and diseases.

4.8 AI for optimization of supply chain management:
The agricultural supply chain is complex and involves multiple stakeholders from agribusinesses and distributors to retailers and to the end consumers. AI technologies optimise this chain by enhancing logistics, reducing waste, and improving quality control. AI algorithms can optimise transportation routes to minimize delivery times and costs, thereby reducing spoilage and ensuring fresher produce reaches consumers promptly [65].

Furthermore, AI-powered sorting and grading systems enhance quality control by identifying defects and sorting produce according to specific quality criteria, thereby enhancing market value and profitability. QR code-based technology facilitates real-time tracking of goods, ensuring transparency and efficiency throughout the supply chain which ultimately works for the benefit for all the stakeholders in the value chain especially the farmers who now can track the value chain and not have middlemen make larger gains at their expense. From deploying Telematics sensors attached to fresh goods which monitor product environments throughout transit, triggering alerts when adverse conditions threaten shelf life, to monitoring air quality and temperature readings in storage facilities, technology can be a great tool to improve efficiency and maximise profits [66, 67, 68].

CONCLUSION

70% of India's 1.45 billion strong population lives in rural India where Agriculture continues to be the predominant source of livelihood. The slowdown in the agricultural incomes and the stagnating wages in rural India are a distress signal of unequal economic growth. Since India's economy is demand driven, low incomes have a ripple effect leading to a slowdown in investment and consumption [69]. Agriculture in India needs to revitalise as it not only takes care of India's food security but also provides livelihood to large swathes of its young population.

The government must become more proactive in ensuring that the benefit of AI reaches across the agricultural sector and especially to the farmers with smaller land holdings that are facing major distress. Artificial intelligence (AI) can revolutionize the agricultural sector by helping farmers optimize their methods, increase yields, reduce water and pesticide usage, and promote sustainability. By adopting AI technologies throughout the agricultural value chain, farmers can improve their yield per hectare which as of now is amongst the lowest in the world. AI technology is crucial in making precise planting, irrigation, and fertilization methods possible. By combining information from different sources like satellite pictures, weather forecasts, and soil samples, AI algorithms can give farmers useful advice. These technologies not only make better use of resources but also promote sustainable farming by reducing waste and environmental damage.

However, cost of buying equipment and software, large scale education of farmers to train them to use the technology effectively and lack of dependable and affordable internet access are some key challenges that need to be worked upon. Technology enabling companies and the government need to join hands to ensure that the farmers can avail the benefits of technology. Any delay in prioritising large-scale adoption can have a serious impact on the rural economy, increase farmer distress, and economic disparity, worsen the environmental degradation; all of which directly impact India’s socio-economic future.

REFERENCES

[1] https://economictimes.indiatimes.com/news/economy/agriculture/share-of-agriculture-in-indias-gdp-declined-to-15-in-fy23-govt/articleshow/106124466.cms?from=mdr

[2] https://www.downtoearth.org.in/agriculture/economic-survey-2024-agri-growth-rate-falls-to-14-from-47-in-2022-23

[3] https://www.business-standard.com/industry/agriculture/agri-gva-growth-slowest-in-5-years-after-poor-rains-last-monsoon-124053101765_1.html

[4] https://economictimes.indiatimes.com/news/economy/agriculture/farmers-protests-what-is-swaminathan-committee-and-what-did-it-recommend/articleshow/107663624.cms?from=mdr

[5] https://india.mongabay.com/2023/10/architect-of-indias-green-revolution-agricultural-scientist-m-s-swaminathan-passes-away

[6] https://www.thehindu.com/news/national/kerala/technology-vital-to-food-security-swaminathan/article3462582.ece

[7] https://economictimes.indiatimes.com/news/economy/agriculture/indias-crop-yields-lower-than-us-europe-and-china/articleshow/55558872.cms?from=mdr

[8] https://www.livemint.com/Opinion/nw9JKiPrDPpqCuWfmoibPN/Indias-agricultural-yield-suffers-from-low-productivity.html

[9] Home - AI4AI (weforum.org)

[10] C4IR India (weforum.org)

[11] https://eos.com/blog/weather-in-agriculture/

[12] Anderson JR. Agricultural advisory services, 2008

[13] Liliane TN, Charles MS (2020). Factors affecting yield of crops. In: Amanullah (ed.) Agronomy: Climate change and Food security. IntechOpen, Rijeka, DOI: 10.5772/intechopen.90672

[14] https://deepmind.google/discover/blog/graphcast-ai-model-for-faster-and-more-accurate-global-weather-forecasting/

[15] https://www.climateforesight.eu/articles/reacting-to-the-ai-revolution-in-weather-forecasting/

[16] https://www.newscientist.com/article/2402556-deepmind-ai-can-beat-the-best-weather-forecasts-but-there-is-a-catch/

[17] Nowcasting the next hour of rain - Google DeepMind

[18] MetNet-3: A state-of-the-art neural weather model available in Google products (research.google)

[19] https://dst.gov.in/new-soil-monitoring-technology-can-help-farming-decisions

[20] N. Basak, B. Mandal, A.K. Rai, P. Basak -Soil quality and productivity improvement: Indian story- Proc. Indian Natl. Sci. Acad., 87 (1) (2021), pp. 2-10

[21] Pahalvi, H.N., Rafiya, L., Rashid, S., Nisar, B., Kamili, A.N. (2021). Chemical Fertilizers and Their Impact on Soil Health. In: Dar, G.H., Bhat, R.A., Mehmood, M.A., Hakeem, K.R. (eds) Microbiota and Biofertilizers, Vol 2. Springer,

Cham. https://doi.org/10.1007/978-3-030-61010-4_1

[22] R. Nieder, D.K. Benbi, F.X. Reichl, Soil Components and Human Health, Springer, Berlin, Germany (2018), pp. 223-225

[23] FAO, IFAD, UNICEF, WFP and WHO, Transforming Food Systems for Food Security, Improved Nutrition and Affordable Healthy Diets for all, The State of Food Security and Nutrition in the World 2021, FAO, Rome (2021), pp. 169-181

[24] Zhai Y, Thomasson JA, Boggess JE, Sui R (2006) Soil texture classification with artificial neural networks operating on remote sensing data. Comput Electron Agric 54(2):53–68

[25] Zhang M, Shi W (2019) Systematic comparison of five machine-learning methods in classification and interpolation of soil particle size fractions using different transformed data. Hydrol Earth Syst Sci Discuss 2019:1–39

[26] Pernet CA, Ribi Forclaz A (2019) Revisiting the Food and Agriculture Organization (FAO): international histories of agriculture, nutrition, and development. Int Hist Rev 41(2):345–350

[27] https://solve.mit.edu/challenges/climate-adaptation-challenge/solutions/76832

[28] https://thebetterindia.com/318062/iit-bombay-scientist-dr-rajul-patkar-innovates-portable-soil-testing-device-for-farmers/

[29] https://www.openaccessgovernment.org/article/agriculture-harnessing-ai-for-healthier-soils/173895/

[30] https://www.worldbank.org/en/country/india/brief/world-water-day-2022-how-india-is-addressing-its-water-needs

[31] Motoshita M., Itsubo N., Inaba A. Development of impact factors on damage to health by infectious diseases caused by domestic water scarcity. Int. J. Life Cycle Assess. 2011;16(1):65–73.

[32] https://www.cnbc.com/2024/06/27/indias-worsening-water-crisis-will-hurt-credit-strength-moodys.html

[33] Aivazidou E., Tsolakis N., Iakovou E., Vlachos D. The emerging role of water footprint in supply chain management: a critical literature synthesis and a hierarchical decision-making framework. J. Clean. Prod. 2016;137: 1018–1037

[34] Pellegrini G., Ingrao C., Camposeo S., Tricase C., Contò F., Huisingh D. Application of water footprint to olive growing systems in the Apulia region: a comparative assessment. J. Clean. Prod. 2016;112:2407–2418.

[35] https://www.sattva.co.in/ski/water-efficiency-indian-agriculture-dcm-shriram-sattva-knowledge/

[36] https://siwi.org/latest/water-crisis-india-everything-need-know/

[37] Chazarra-Zapata J., Parras-Burgos D., Arteaga C., Ruiz-Canales A., Molina-Martínez J.M. Adaptation of a traditional irrigation system of micro-plots to smart agri development: a case study in Murcia (Spain) Agronomy. 2020;10(9):1365.

[38] https://www.farmerp.com/ai-in-agriculture-smart-water-management-using-agritech

[39] Awais, M., Naqvi, S.M.Z.A., Zhang, H. *et al.* AI and machine learning for soil analysis: an assessment of sustainable agricultural practices. *Bioresour. Bioprocess.* 10, 90 (2023). https://doi.org/10.1186/s40643-023-00710-y

[40] https://extension.okstate.edu/fact-sheets/understanding-soil-water-content-and-thresholds-for-irrigation-management.html

[41] Wang H, Garg A, Ping Y, Sreedeep S, Chen R (2023) Effects of biochar derived from coconut shell on soil hydraulic properties under salt stress in roadside bioretention. Waste Biomass Valorization 14(3):1005–1022

[42] Bormann H (2010) Towards a hydrologically motivated soil texture classification. Geoderma 157(3):142–153

[43] Liu X et al (2022) PiLSL: pairwise interaction learning-based graph neural network for synthetic lethality prediction in human cancers. Bioinformatics 38:ii106–ii112

[44] Liu X-F, Zhu H-H, Wu B, Li J, Liu T-X, Shi B (2023) Artificial intelligence-based fiber optic sensing for soil moisture measurement with different cover conditions. Measurement 206:112312

[45] sshttps://www.dripworks.com/blog/the-role-of-artificial-intelligence-ai-in-smart-irrigationsystems

[46] Antonis Tzounis, Nikolaos Katsoulas, Thomas Bartzanas, Constantinos Kittas, Internet of Things in agriculture, recent advances and future

challenges,Biosystems Engineering,Volume 164,2017,Pages 31-48,ISSN 1537-5110
[47] X. Dong *et al.*Autonomous precision agriculture through integration of wireless underground sensor networks with center pivot irrigation systems Ad Hoc Networks (2013)
[48] IoT-based smart irrigation systems: An overview on the recent trends on sensors and iot systems for irrigation in precision agriculture 2020, Sensors (Switzerland)
[49] https://earth.org/smart-farms-how-ai-can-solve-water-wastage/
[50] M. Ayaz, M. Ammad-Uddin, Z. Sharif, A. Mansour and E. -H. M. Aggoune, "Internet-of-Things (IoT)-Based Smart Agriculture: Toward Making the Fields Talk," in *IEEE Access*, vol. 7, pp. 129551-129583, 2019, doi: 10.1109/ACCESS.2019.2932609
[51] Unleashing the potential of IoT, Artificial Intelligence, and UAVs in contemporary agriculture: A comprehensive review -Alaoui, M.E., Amraoui, K.E., Masmoudi, L., Ettouhami, A., Rouchdi, M. Journal of Terramechanics 2024
[52] https://www.thehindu.com/news/national/pests-eat-away-35-of-total-crop-yield-says-icar-scientist/article17368426.ece
[53] Rahman, Shaik Moizur & Ravi, Gollapelly. (2022). Role of Artificial Intelligence in Pest Management. 10.9734/bpi/ctas/v7/2141B.
[54] B Kariyanna, M Sowjanya, Unravelling the use of artificial intelligence in management of insect PetSmart Agricultural Technology, Volume 8,2024,100517,ISSN 2772-3755,https://doi.org/10.1016/j.atech.2024.100517.
[55] W. Ding, G. Taylor, Automatic moth detection from trap images for pest management Comput. Electron. Agric., 123 (2016), pp. 17-28
[56] Y. Sun, X. Liu, M. Yuan, L. Ren, J. Wang, Z. C hen. Automatic in-trap pest detection using deep learning for pheromone-based dendroctonus valens monitoring Biosys. Eng., 176 (2018), pp. 140-150
[57] R. Dutta, S. Sharma,Artificial Intelligence for Sustainable Agriculture: A Comprehensive Review,IEEE Access, 8 (2020), pp. 73641-73672
[58] M. Preti, F. Verheggen, S. Angeli, Insect pest monitoring with camera-equipped traps: strengths and limitations, J. Pest Sci., 94 (2021), pp. 203-217
[59] Predicting insect outbreaks using machine learning: A mountain pine beetle case study- Pouria Ramazi, Mélodie Kunegel-Lion, Russell Greiner, Mark A. Lewis https://doi.org/10.1002/ece3.7921
[60] SMART Digital Rodent Control System for Home & Business | Anticimex
[61] M. Preti, F. Verheggen, S. Angeli, Insect pest monitoring with camera-equipped traps: strengths and limitations, J. Pest Sci., 94 (2021), pp. 203-217
[62] Can an AI-powered insect trap solve a st problem? | CNN Business
[63] B Kariyanna, M Sowjanya, Unravelling the use of artificial intelligence in management of insect pests, Smart Agricultural Technology, Volume 8,2024,100517,ISSN 2772-3755,https://doi.org/10.1016/j.atech.2024.100517.
[64] Liu B, Hu Z, Zhao Y, Bai Y, Wang Y. Recognition of Pyralidae Insects Using Intelligent Monitoring Autonomous Robot Vehicle in Natural Farm Scene. arXiv preprint ar. 2019; Xiv.1903:10827.
[65] https://gulfbusiness.com/farm-table-reinvented-ai-agricultural-value-chain
[66] Elufioye, Oluwafunmi & Ike, Chinedu & Odeyemi, Olubusola & Usman, Favour & Mhlongo, Noluthando. (2024). Ai-Driven Predictive Analytics In Agricultural Supply Chains: A Review: Assessing The Benefits And Challenges Of Ai In Forecasting Demand And Optimizing Supply In Agriculture. Computer Science & It Research Journal. X. 1-10. 10.51594/Csitrj.V5i.
[67] “Next-Gen Supply Chains: Navigating Uncertainty and Generative AI.” Economist Impact/GEP
[68] Smyth, Conn, et al. “Leveraging Artificial Intelligence to Enhance Supply Chain Resilience: Insights from the Agri-Food Industry.” *Amplify*, Vol. 37, No. 5, 2024.