

DEPLOYMENT OF INFORMATION AND COMMUNICATION TECHNOLOGY (ICT) FOR SUSTAINABLE FOOD AND RAW MATERIALS PRODUCTION – A REVIEW

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ABSTRACT

Studies have shown that the scale of agricultural production must be increased in order to meet the food and raw material needs of the ever-increasing world population. This can be achieved by effective gathering of valuable information, prompt, effective, and efficient dissemination of the information among stakeholders in the sector, error-free processing of this information, and prompt feedback to the relevant actor for action. This has been made possible by the deployment of Information and Communication Technology (ICT) in agriculture. Beyond just the traditional exchange of information between farmers, service agencies, and researchers, this study aims to explore wide areas to which ICT can be deployed for the overall goal of increasing agricultural productivity. This study is an expository review of the use of remote sensing, geographical information systems, and data science in agriculture. This is with a view of highlighting the strength of these ICTs in data gathering, processing, and application; mapping, spatial analyses, and visualization; and integration of the collected field information, as well as how these technologies can be deployed. This study showed that great potentials also lie in increased computing skills in data science, such as deep learning, machine learning, and artificial intelligence in improving agricultural modelling for far-reaching results. In conclusion, the application of ICT in agriculture in Nigeria has the potential to revolutionize the sector by increasing productivity, efficiency, and profitability.

Keywords: *remote sensing, machine learning, deep learning, data science, agriculture*

INTRODUCTION

Agriculture has been an essential sector of the Nigerian economy, accounting for 23% of the country's Gross Domestic Product (GDP) (Food and Agricultural Organisation (FAO) *et al.*, 2022). In recent years, there has been an increasing application of Information and Communication Technology (ICT) in the agricultural sector in Nigeria. Information and Communication Technology (ICT) has revolutionized many aspects of modern society, including agriculture. The use of ICT in agriculture has brought about significant benefits in terms of efficiency, productivity, and sustainability. With the world's population expected to reach 9 billion by 2050 (Alexandratos and Bruinsma, 2012; Sadhu *et al.*, 2021), the role of ICT in agriculture becomes even more critical, as it

provides a means to meet the growing demand for food while preserving natural resources. Sustainable agriculture means an integrated system of plant and animal production practices having a site-specific application to satisfy human food and fiber over a long term (Singh *et al.*, 2018).

Information and communication technology refers to any device, tool, or application that allows the exchange and collection of data through interaction and transmission, and it includes anything from radio to satellite imagery to mobile phones to electronic money transfer (World Bank, 2011). Agricultural production will need to increase by 60 percent from its 2005/2007 levels to meet this additional food demand (FAO, 2017). ICT applications can make a

significant contribution to meeting these future global food needs. Information and Communication Technology can do so by collecting and sharing timely and accurate information on weather, inputs, markets, and prices; by feeding information into research and development initiatives; by disseminating knowledge to farmers; by connecting producers and consumers, and through many other avenues.

ICT includes all digital technologies that facilitate the electronic capture, processing, storage, and exchange of information (Dufty and Jackson, 2018). The use of ICT is important in removing the information gap among critical stakeholders in agriculture value chains, servicing agencies, and researchers. Various ICT devices such as radio, television, mobile phones, computers, and more advanced tools such as satellite systems and remote sensing have helped in facilitating different farming activities and intercultural operations (Muinde, 2009; Pande and Deshmukh, 2015). Research studies reveal that ICT has reformed the traditional agricultural system and made significant contributions in increasing agricultural productivity and sustainability by empowering farmers with the correct information at the right time and place. Crop disease detection before the symptoms manifest has made tremendous success through computer vision (Zhang *et al.*, 2021), soil water management (Neupane and Guo, 2019) and networking between stakeholders in agricultural business (Singh *et al.*, 2017) are also being made easy through studies and the use of machine learning technology.

ICT has also been found to be very useful in the supply chain management of grains, which serve as raw materials, to agri-food industries (Kumal, 2019). He observed that supply chain management and ICT are positively related. Though ICT has in most cases been deployed for arable crops, its

impact equally remains important for long term cash crops production and animal husbandry. ICT such as phones and mobile applications like Facebook, Instagram, and WhatsApp are being increasingly used by cocoa farmers to get information on the management of pests and disease-infected farms, improve varieties of the crop, and issues relating to pesticide and fertilizer applications (Tham-Agyekum and Ankuyi, 2023). Using a convolutional neural network, accurate disease detection in citrus has been enhanced (Shastri *et al.*, 2023). Also, a data-trained image recognition model that has the capacity to detect diseases in cocoa fruit using a mobile application is being developed (Morales *et al.*, 2024)

An effective ICT system provides useful and timely information on weather conditions and forecasts, soil nutrient conditions and land suitability for crops, seeds requirement and market price and advisories on agricultural products. Adequate application of ICT in agriculture involves the use of tools that range from nano sensors to satellites for data collection and the use of high-power computing and data-reliant modelling technologies. This then leads to deployment of artificial intelligence, automation, and robotics (Abria *et al.*, 2023). It is evident from the work of Dokic *et al.* (2020) that these advanced digital technologies in agriculture are nearly nonexistent or not adequately used in Nigeria and most other parts of Africa. This research article will explore the application of ICT to agriculture. The objective of this study was to highlight the importance of ICT in agriculture and areas where they can be deployed

USEFULNESS OF ICT IN AGRICULTURE

Every stage, operation, and process in the agriculture production chain can be boosted by the deployment of ICT. This includes:

- a. **Decision support:** Farmers need to make informed decisions per time to ease the production process and ensure efficient deployment of resources to create market awareness. ICT does not only provide the right information but also protects the farmers from rumors and misinformation (Hiltz *et al.*, 2013). Based on appropriate information from field and soil conditions, sowing and harvest time, information on crops' diseases and pests, cultural activities, price of agricultural products and market availability, farmers can decide on the type of crop to plant. Various groups like agricultural producers, extension agents, crop consultants, forest managers, and even policy makers in the agricultural value chain may use the ICT in the decision-making process on the basis of forecasts (Tony *et al.*, 2013). Toward achieving a decision support system for optimizing fertilizer's use in Indian agriculture for instance, various ICT tools have been proposed (Premasudha and Leena, 2020). They include a Cloud-based web GIS Server, mobile applications, and a kiosk System. If these interactive tools are deployed, they offer the farmers at any level of advancement in their farming capacity to real time fertilizer recommendations by just providing data on their soil test. Appropriate ICT, hands-on tools, and devices could be developed by every country for their local e-agriculture to make decisions and enhance the distribution of resources.
- b. **Precision farming:** One of the significant areas where ICT has been applied in agriculture in Nigeria is in precision farming. Precision farming involves using ICT tools and techniques to optimize crop yields while minimizing the use of inputs such as fertilizers, pesticides, and water. This approach involves the use of sensors, drones, and other technologies to gather data on soil moisture, temperature, nutrient levels, and other factors that affect crop growth. The data is then analyzed to provide farmers with insights into the optimal planting and harvesting times, the right amount of water and fertilizers to use, and other critical factors that affect crop growth.
- c. **Reduction of agricultural risks:** Farming is a very risky enterprise as a result of several unforeseen circumstances and occurrences that might not be part of the planning and implementation processes. However, with adequate data-driven technology, most of these "unforeseen circumstances and occurrences" can be forecasted, and hence, their impacts can be reduced or completely prevented. Usually, farmers face climate uncertainties as a result of global climate change, and most of the smallholder farmers do not have the resources or wherewithal to cope with the associated shocks during the production process, leading to a reduction in productivity. The farmers also face risks of new disease and pest outbreaks, and market vagaries (Harvey *et al.*, 2014; Komarek *et al.*, 2020). Locally generated weather conditions and soil properties information help farmers in identifying opportunities and reducing risks that are associated with changes occurring in their locality (Wratt *et al.*, 2006). With a correct and reliable climate forecast and information on disease incidence, farmers can choose resilient crop varieties and manage diseases and pest problems. With the help of weather forecast information received through ICT tools, farmers can adjust their sowing dates of different crops and reduce their on-farm risks.
- d. **Strengthening coordination and collaboration:** ICT is important in enhancing collaboration of stakeholders

in the agricultural chain. These include networking between farming communities and government ministries and agencies, research institutes, colleges and universities, non-governmental organizations, and private companies through its wide networking (Singh *et al* ., 2017). A good information network is required between farmers and extension agents in communicating advances in technology to the end users. The use of advanced data-driven technology tools such as machine learning, Artificial Intelligence and Robotics is increasingly becoming a necessity to generate, process, analyze, and make predictions. The use of these data science and technologies usually relies on large data, and this can be made available by creating a database that is freely assessable and made available for use by researchers. Farmers can access the information generated by various private sector companies and organizations working in the required field. These data can be collected from simple ICT tools like phones, computers, cloud computing, and satellite imagery. ICT tools such as mobile phones, applications, software and tablets for the collection of data, monitoring and evaluation purpose of the project, and working in close contact with the rural communities and taking their feedback (Cespedes, 2013).

- e. **Widening market access:** Farmers must be updated on commodity prices, prospective buyers, and the place to sell.

ICT has the enormous potential to expand the marketing horizon of farmers directly to the off-takers for maximum benefit. Farmers may attach directly to many users, connecting to the market sitting at home. Effective communication between farmers and consumers can also enhance feedback, leading to the improvement of produce quality in line with the specifications of consumers and other end users. ICT has also been found to enhance feedback in the form of support with farm input and technologies.

Some broad areas in which ICT plays role in the agricultural sector are shown in Figure 1. The figure shows the all-inclusive roles of ICT in the agricultural value chain. With the effective use of the right technologies, a synergy can be easily established among the actors in the chain. Also, most of the challenges, such as climate change, disease, soil water, and nutrient deficiency, can be easily managed through real-time data generation, processing, and analysis and the subsequent communication of the feedback to the right persons or agencies of government. ICT also comes in handy in market planning and forecasting, as well as capacity building, financial inclusion, and insurance against any risks. Hence, ICT is the nucleus of effective, efficient, and adaptive modern agriculture. This underscores the advancement in food and raw materials production in countries where a high premium is placed on studies on how ICT can be used to improve agricultural activities.



Figure 1: Roles of ICT in Agriculture
 Source: FAO-ITU E-agriculture Strategy Guide

PRECISION AGRICULTURE

Precision Agriculture, also known as predictive farming, describes farming management that perceives, measures, and analyzes the needs of discrete fields and crops. It is also defined as a system that integrates information with crop production that is designed to increase long-term, site-specific, as well as whole farm production efficiency, productivity, and profitability while minimizing unintended impacts on wildlife and the environment (Earl *et al.*, 1996, Kushwaha *et al.*, 2024). It collects and uses data for managing and enhancing the production of crops. Predictive farming is comparable to taking a pill to target a disease.

The operational goals of precision farming include better management of inputs such as seeds, fertilizers, pesticides, herbicides, and water using right amounts of inputs at the right place, and at the right time. Several crucial tools and systems such as Global

Positioning System (GPS), Global Information System (GIS), and Remote Sensing (RS) are required for the collection of timely geospatial information on soil-plant-animal requirements towards mining insights followed by leveraging those insights for prescribing and applying site-specific treatments towards improving agricultural productivity while contributing to sustainability and protecting the environment (Strickland *et al.*, 1998; Goswami *et al.*, 2012; Balafoutis *et al.*, 2017)

Importance of GIS and RS in Precision Agriculture

- i. **Remote sensing:** Technologies such as satellites, aerial photography, unmanned aerial vehicles (UAVs), and drones are remote sensing tools that can be used in gathering data about crop yields, soil health, land use, and incidences of pests

and diseases. An example of the use of satellites is the European Space Agency's Sentinel-2 which aims at field monitoring (Segarra *et al.*, 2020). It gathers data along the growing season. The profitability of Sentinel-2 multi-temporal data for crop-type monitoring is very crucial as it reaches up to 91–95 percent overall accuracies in various crop classifications (Vuolo *et al.*, 2018). Most of the data required for crop monitoring used in machine learning algorithms are large volumes of image data sourced by remote sensing.

- ii. **GIS:** For mapping, spatial analyses, visualization and integration, GIS is more suitable. It integrates data from sources such as maps and remote sensing technology into a single unified system. It allows analysis of data from multiple perspectives and makes relationship and patterns in data clearer. GIS also very useful for proximity analysis, network analysis, and spatial statistics (Aguba *et al.*, 2024).

Usefulness of GIS technology

1. **Biomass assessment:** GIS, in combination with remote sensing, can be a great tool for precise identification and assessment of the crop residues and for planning a given region's feedstock material for renewable energy.
2. **Supply chain management:** An important application for which GIS was used is the analysis of supply chain patterns and description of spatial components of safe crop products (Qu *et al.*, 2007). By using the spatial functions provided by GIS such as representation, location, analysis, traceability coding, and other techniques, the tracing and retracing of the quality of safe crop product (SCP) was achieved.
3. **Livestock management:** GIS can be used to map pasture and grazing lands,

and also to track the movement and health of livestock with a view to testing the efficiency of livestock management.

4. **Pest and disease management:** For tracking the spread of disease and pests and mapping the areas affected.
5. **Irrigation management:** For mapping and analyzing crop water needs and consequently optimizing irrigation and water use, etc.

THE RELEVANCE OF DATA SCIENCE AS AN IMPORTANT ICT COMPONENT FOR AGRICULTURAL DEVELOPMENT

The possibility of automation in agriculture was suggested more than 50 years ago, but this did not seem realistic until the beginning of the twenty-first century when computing knowledge was rising (Dokik *et al.*, 2020). The realization of this dream centers on data science and this provides a ground for all forms of current advances in technology in agriculture. Farmers in advanced nations use ICT for the mechanization and automation of processes in their homesteads and farms. This has been achieved by substantial computing ability. Data Science is playing a significant part in providing these computerized farming solutions with high accuracy. These have brought about data science techniques such as Machine learning (ML), Artificial intelligence (AI), Neural Networks, Deep Learning, and others. There is still a great measure of potential in agricultural transformation through these data science and technology.

There are great potentials in Machine learning (ML), Artificial intelligence (AI), and Robotics deployment in easing data gathering, visualization, processing, analyses and modelling. Chlingaryan *et al.* (2018) analyzed machine learning for crop yield prediction in agriculture with a focus on nitrogen management. They also concluded that ML and sensing usage have rapidly

advanced during the last ten years. Jha *et al.* (2019) believed that a combination of sensors and the Internet of Things (IoT) in data acquisition and ML could be used to automate processes in agriculture, and this is believed to be one of the various steps and techniques in achieving precision agriculture. After having analyzed several papers that deal with ML algorithms for agricultural machine vision systems, Rehman *et al.* (2019) suggested that the use of ML technology for weed detection, plant diseases and stress detection, yield prediction and estimation, plant water content determination, grading and sorting; soil analysis and real-time field operations may become routine operation in near future agriculture.

According to a review by Dokic *et al.* (2020), considering six databases (Science Direct, Scopus, Springer, Web of Science, Association for Computing Machinery, ACM, and Institute of Electrical Electronic and Engineers, IEEE) indicated that publications that use AI, computer vision (CV), machine learning (ML) and deep learning (DL) are increasing. This is especially so in China, USA, UK, India and a number of countries in Europe, North and South America but none was obtained in Africa. This shows that the deployment of these technologies has not been well developed in Africa. Nevertheless, ICT has been used through smartphones in rural areas of Asia and Africa to disseminate information from extension agents to farmers and to pass information on market access, climate change, and financial inclusion (FAO, 2017). In Nigeria, an innovative mobile wallet relying on database of about 11 million farmers have been used by the Federal Government in procuring and distributing fertilizers to farmers at one-sixth the cost, if it were to take the usual procurement and distribution channel (World Bank Group, 2016). However, innovative

data science technologies relying on primary data have, to a large extent, not been used in Nigeria and other African regions. This is probably because these technologies rely on large local data input.

CONCLUSION

The application of ICT in agriculture in Nigeria has the potential to revolutionize the sector by increasing productivity, efficiency, and profitability. The development of precision farming, mobile applications, e-extension services, and precision irrigation systems can make a significant impact on the sector. With further investment in locally sourced data-driven ICT, Nigeria's agricultural sector is poised for significant growth in the coming years, thereby contributing to the country's economic development.

REFERENCES

- Abiria, R., Rizanb, N., Balasundram, S. K., Shahbazic, A. B. and Abdul-Hamida, H. (2023). Application of digital technologies for ensuring agricultural productivity. *Heliyon*, 9: 1-21. <https://doi.org/10.1016/j.heliyon.2023.e22601>
- Aguha, C. C., Awuzie, A., Onwubuariri, C. N., Mgbeojedo, T. I., Njoku, J. O., Akiang, F. B. and Epuerie, E. T. (2024). Review of spatial analysis as a geographic information management tool. *American Journal of Engineering and Technology Management*, 9 (1): 8 -20. <https://doi.org/10.11648/j/ajetm.20240901.12>.
- Alexandratos, N. and Bruinsma, J. (2012). *World Agriculture towards*

- 2030/2050: The 2012. Revision (2012)
- Balafoutis, A., Beck, B., Fountas, S., Vangeyte J., Wal, T. V. and Soto, I. (2017). Precision agriculture technologies positively contribute to greenhouse gas emissions mitigation, farm productivity and economics. *Sustainability*, 9(8):1339
- Cespedes, L. M. (2013). How ICT tools are improving efficiency of agricultural development. Retrieved May 14, 2016, from <http://www.theguardian.com/global-development-professionals-network/2013/jan/24/datacollection-evaluation-technology-agriculture>
- Chlingaryan, A., Sukkarieh, S. and Whelan, B. (2018). Machine learning approaches for crop yield prediction and nitrogen status estimation in precision agriculture: A review. *Computers and Electronics in Agriculture*, 151: 61– 69.
- Dokic K., Blaskovic L. and Mandusic D. (2020). From machine learning to deep learning in agriculture – the quantitative review of trends. *Earth and Environmental Science*, 614 (2020) 012138 doi:10.1088/1755-1315/614/1/012138
- Dufty, N. and Jackson, T. (2018). Information and communication technology use in Australian agriculture. *Australian Bureau of Agricultural and Resource Economics and Sciences 2018:1-18*. ISBN 978-1-74323-406-8 ISSN 1447-8358
- Earl, R., Wheeler, P. N., Blackmore, B. S., Godwin, R. J. (1996). Precision farming: The management of variability. *The Journal of the Institution of Agricultural Engineers* 51:18-23
- FAO, European Union and CIRAD (2022). *Food Systems Profile – Nigeria. Catalysing the sustainable and inclusive transformation of food systems*. Rome, Brussels and Montpellier, France. <https://doi.org/10.4060/cc3380en>. 52p.
- Food and Agriculture Organization of the United Nations (2017). Information and Communication Technology (ICT) in Agriculture: A Report to the G20 Agricultural Deputies.
- Goswami, S. B., Matin, S., Saxena, A. and Bairagi, G. D. (2012). A review: The application of Remote Sensing, GIS and GPS in Precision Agriculture. *International Journal of Advanced Technology & Engineering Research*, 2(1):50 - 54
- Harvey, C. A., Rakotobe, Z. L. and Rao, N. S. (2014). Extreme vulnerability of smallholder farmers to agricultural risks and climate change in Madagascar. *Philosophical Transactions of the S. R., Royal Society B: Biological Sciences*, 369(1639):20130089
- Hiltz, S. R., Gonzalez, J. J. and Turoff, M. (2013). ICT support and the effectiveness of decision making in disasters: A preliminary system dynamics model. *Proceedings of the 10th International Conference on Information System for Crises Response and Management*. Baden-Baden, Germany, May 2013. Comes, T. Fiedrich, F. Fortier, S. Geldermann J. and Müller, T. eds.

- Jha, K., Doshi, A., Patel, P. and Shah, M. (2019). A comprehensive review on automation in agriculture using artificial intelligence. *Artificial Intelligence in Agriculture 2*: 1–12
- Komareka, A. M., De Pintoa, A. and Smith, V. H. (2020). A review of types of risks in agriculture: What we know and what we need to know. *Agricultural Systems*, 178 102. <https://doi.org/10.1016/j.agsy.2019.102738>
- Kushwaha, M, Singh, S., Singh, V. and Dwivedi, S. (2024). Precision Farming: A Review of Methods, Technologies, and Future Prospects. *International Journal of Environment, Agriculture and Biotechnology*, 9(2): 242- 253. DOI: 10.22161/ijeab
- Morales, M., Morocho, J., López, X. and Navas, P. (2024). Application of Convolutional Neural Networks for the Detection of Diseases in the CCN-51 Cocoa Fruit by Means of a Mobile Application. In: Meng, L. (eds) *International Conference on Cloud Computing and Computer Networks. CCCN 2023. Signals and Communication Technology*, 3-10. https://doi.org/10.1007/978-3-031-47100-1_1
- Muinde, F. (2009). Investigation of factors affecting the adoption of information and communication technologies for communication of research output in research institutions in Kenya (Unpublished doctoral dissertation). Victoria University of Wellington, Wellington, New Zealand; 2009.
- Neupane, J. and Guo, W. (2019). Agronomic basis and strategies for precision water management: A Review. *Agronomy*, 9(2) 87. <https://doi.org/10.3390/agronomy9020087>
- Pande, N. and Deshmukh, P. (2015). ICT: A path towards rural empowerment through telecommunication, e-governance, and e-agriculture. *IBMRD's Journal of Management and Research*, 2015; 4(2):47–54.
- Premasudha, B.G. and Leena, H. U. (2020). ICT Enabled Proposed Solutions for Soil Fertility Management in Indian Agriculture. *Proceedings of the International Conference on Data Engineering and Communication Technology, Advances in Intelligent Systems and Computing*, 469: 749-757. DOI 10.1007/978-981-10-1678-3_72
- Qu, X. H., Zhuang, D. F. and Qiu, D. S. (2007). Studies on GIS-based tracing and traceability of safe crop products in China. *Agricultural Sciences in China*, 6(6):724-731
- Rehman, T. U., Mahmud, M. S., Chang, Y.K., Jin J. and Shin, J. (2019). Current and future application of statistical machine learning algorithms for vision systems. *Computers and Electronics in Agriculture*, 156: 585–605
- Sadhu, K. S., Singh, R., Singh, S. and Singh, G. (2021). Data science and analytics in agricultural development. *Environment Conservation Journal*, 22: 9-19, ISSN 0972-3099 (Print) 2278-5124 (Online). DOI: <https://doi.org/10.36953/ECJ.2021.S.E.2202>.
- Segarra, J.; Buchailot M. L.; Araus J. L. and Kefauver S. C. (2020). Remote Sensing for Precision Agriculture:

- Sentinel-2 Improved Features and Applications. *Agronomy*, 10, 641; doi:10.3390/agronomy10050641
- Shastri, R., Chaturvedi, A. and Mouleswararao, B. (2023). An Automatic Detection of Citrus Fruits and Leaves Diseases Using Enhanced Convolutional Neural Network. *Remote Sensing Earth System Science* 6, 123–134. <https://doi.org/10.1007/s41976-023-00086-9>.
- Singh, S., Ahlawat, S., Sanwal, S. (2017). Role of ICT in Agriculture: Policy implications. *Oriental Journal of Computer Science and Technology*, 2017; 10(3):691–697
- Strickland, R. M., Ess, D. R. and Parsons, S. D. (1998). Precision farming and precision pest management: The power of new crop production technologies. *Journal of Nematology*, 30(4):431- 435
- Tham-Agyekum, E.K. and Ankuyi, F. (2023). Climate Change Communication among Ghanaian Cocoa Farmers: Social Media as a Driver. In: Leal Filho, W., Sima, M., Lange Salvia, A., Kovaleva, M., Manolas, E. (eds) *University Initiatives on Climate Change Education and Research*. https://doi.org/10.1007/978-3-031-25960-9_11-1
- Tonny, N. B., Palash, M. S. and Moniruzzaman, M. (2019). Use of ICT in decision making of agricultural marketing: Factors determining of farmers' involvement. *Journal of the Bangladesh Agricultural University*, 17(2):226–231
- Vuolo, F.; Neuwirth, M.; Immitzer, M.; Atzberger, C. and Ng, W.T. (2018). How much does multi-temporal Sentinel-2 data improve crop type classification? *International Journal of Applied Earth Observation and Geoinformation*, 72: 122–130.
- World Bank (2011). E-sourcebook. ICT in Agriculture: Connecting Smallholders to Knowledge, Networks, and Institutions. Report Number 64605. P. 3.
- World Bank Group (2016). Digital Dividends. *World Development Report*, 2016.
- Wratt, D. S., Tait, A. and Griffiths, G, (2006). Climate for crops: integrating climate data with information about soils and crop requirements to reduce risks in agricultural decision-making. *Meteorological Applications: A Journal of Forecasting, Practical Applications, Training Techniques and Modelling*, 13(4):305–315.
- Zhang, J., Rao, Y., Man, C., Jiang, Z. and Li, S. (2021). Identification of cucumber leaf diseases using deep learning and small sample size for agricultural Internet of Things. *International Journal of Distributed Sensor Network*, 17: 1–13.