-RESEARCH ARTICLE-

THE IMPACT OF ADVANCED ROBOTICS IMPLEMENTATION AND INTELLIGENT IRRIGATION ADOPTION ON COST REDUCTION: MEDIATING THE ROLE OF TECHNOLOGIES IN THE FOURTH INDUSTRIAL REVOLUTION

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─**Abstract**─

Cost reduction is crucial for the survival of sectors that require a focus on new researchers. This study investigates the effects of implementing advanced robotics and adopting intelligent irrigation on cost reduction in Iraq's agricultural sector. This study examines the relationship between advanced robotics implementation, intelligent irrigation adoption, and cost reduction in the agricultural sector in Iraq. It also investigates the mediating role of technologies of the fourth industrial revolution in this relationship. The study collected primary data from the Iraqi agricultural department through surveys. The study examines the relationship between variables and data reliability using smart-PLS. The results suggest a positive correlation between the implementation of advanced robotics and the adoption of intelligent irrigation, and a reduction in costs. The findings suggest that the technologies associated with the fourth industrial revolution play a significant role in facilitating advanced robotics implementation, intelligent irrigation adoption, and cost reduction in Iraq's agricultural sector. The study guides policymakers in formulating cost reduction policies through the utilisation of technologies from the fourth industrial revolution, such as advanced robotics and intelligent irrigation.

Keywords: Technologies of the Fourth Industrial Revolution, Advanced Robotics Implementation, Intelligent Irrigation Adoption, Cost Reduction, Agricultural Sector.

INTRODUCTION

The potential of modern technology to revolutionise traditional agricultural practices in the desert regions of Iraq, which have historically played a crucial role in the country's economy and way of life, is significant. These technologies mitigate resource scarcity and water shortages. Through the utilisation of advanced robotics and intelligent irrigation systems, Iraq can enhance food security, promote sustainable development, and boost agricultural productivity amidst the challenges of post-conflict reconstruction and economic revitalization (Bahn, Yehya, & Zurayk, 2021). The agriculture industry in Iraq, historically referred to as the "Fertile Crescent" and associated with ancient civilizations, has faced challenges in recent years such as water scarcity, political unrest, environmental degradation, and violence (Kalkhan, 2019). The agricultural output of Iraq has been limited by inefficiencies, inadequate infrastructure, and limited access to new technology. However, Iraq possesses significant agricultural potential due to its favourable climate, fertile soils, and the presence of the Tigris and Euphrates rivers. Pathirana & Carimi (2022) found that there is a growing recognition of the need for modernization and change in Iraq's agricultural industry to optimise resource utilisation, enhance productivity, and promote sustainable growth. To achieve this goal, novel technology and techniques are being implemented.

Advanced robotics has the potential to completely transform agricultural production systems by automating repetitive tasks, increasing operational efficiency, and lowering production costs. Khriji et al. (2021) argue that the adoption of advanced robotics in agriculture can enhance competitiveness, boost yields, and mitigate risks linked to labour shortages, escalating input expenses, and volatile commodity prices. This technology presents a promising solution to the challenges faced by farmers in the context of manual labour and conventional farming methods. Robotic technologies offer Iraqi farmers the potential to enhance agricultural resilience and reduce production costs amidst economic and environmental uncertainties. These technologies include precision planting, autonomous harvesting, and soil monitoring (Osrof et al., 2023). These technologies can optimise resource allocation, minimise waste, and maximise profitability.

Similarly, intelligent irrigation systems have the potential to significantly enhance agricultural sustainability and address water scarcity problems in Iraq. Intelligent irrigation systems utilise IoT sensors, AI algorithms, and big data analytics to accurately monitor soil moisture levels, weather patterns, and crop water requirements (Gzar, Mahmood, & Al-Adilee, 2022). We facilitate data-driven decision-making and adaptive irrigation techniques. Furthermore, the mediating role of technology in the Fourth Industrial Revolution enhances the potential for implementing intelligent irrigation and advanced robotics in Iraq's agriculture sector. The integration of AI, IoT, big data analytics, and cloud computing has enhanced the capabilities of robotic systems and

intelligent irrigation systems, enabling them to optimise operations, reduce costs, and foster innovation (Wanyama et al., 2024). Using these technologies can enable Iraqi farmers to optimise their operations, enhance decision-making processes, and increase efficiency throughout the entire agricultural cycle, from planting to harvesting and beyond.

This study seeks to analyse the impact of intelligent irrigation and advanced robots on cost reduction in Iraq's agriculture industry. The second objective is to examine the role of Fourth Industrial Revolution technologies as mediators in shaping this connection. This research aims to analyse the potential of new technologies in enhancing agricultural productivity, addressing resource limitations, and promoting sustainable development in Iraq. This study aims to offer insights for strategic planning, policy formulation, and technology adoption initiatives to promote inclusive and resilient agricultural growth in Iraq during the post-conflict reconstruction and economic revival phase. The approach involves the use of empirical research and data-driven analysis. This study addresses knowledge gaps regarding the potential cost-saving benefits of intelligent irrigation and advanced robots in Iraq's agriculture industry. The exploration of the mediating function of technology in the Fourth Industrial Revolution provides insights for informed policy choices and the development of sustainable agriculture.

In the next section of this study, we will investigate the relevant literature review, provide a research methodology, and conduct a full empirical analysis to test the proposed hypotheses.

LITERATURE REVIEW

The integration of robotic machines across various sectors represents a paradigm shift due to the evident correlation between their utilisation and substantial cost reductions. The symbiotic relationship between advanced robotics and cost reduction stems from the multiple advantages that robotic technology offers across various industries. The accuracy and efficiency of modern robotic systems directly contribute to higher output and lower operating costs (Javaid et al., 2021). As per the research conducted by Marinoudi et al. (2019), it has been found that robots have the advantage of completing repetitive tasks at a faster pace and with greater consistency compared to human labour. This leads to a reduction in production time and an increase in overall output. This increased efficiency helps minimise errors and optimise resource utilisation, resulting in cost savings by avoiding rework or defects.

In addition, according to Goel & Gupta (2020), the flexibility of modern robotic platforms allows for easy integration into existing manufacturing processes. This promotes automation in the production line and improves workflow management. Consequently, businesses can achieve economies of scale by reducing labour costs and

reallocating employees to more crucial roles that value creativity and problem-solving abilities. In addition, fostering interaction between humans and machines in shared workspaces, the emergence of collaborative robots, or co-bots, underscores the significant cost-saving possibilities of advanced robotics (Ronzoni et al., 2021). Collaborative robots not only enhance worker safety by handling hazardous tasks, but they also boost productivity through effective teamwork, optimising resource utilisation and minimising downtime (Gardecki et al., 2023).

Further, as stated by Ronzoni et al. (2021), the advancement of machine learning algorithms and artificial intelligence (AI) has enabled robots to acquire cognitive abilities. This empowers them to independently enhance their performance and adjust to dynamic circumstances. Over time, these adjustments lead to significant financial benefits because of improved operational efficiency and reduced need for manual intervention. In addition to manufacturing, the integration of robotics in supply chain management and logistics can greatly improve order fulfilment, reduce transportation expenses, and optimise warehousing and inventory management for cost savings (Marinoudi et al., 2019). In addition, the utilisation of drones and autonomous cars for last-mile delivery results in reduced fuel expenses and transportation costs, as well as faster delivery times. According to Chougule & Mashalkar (2022), robotic automation has the potential to minimise resource waste, increase crop production, and enhance patient care in sectors such as healthcare and agriculture. These advantages reduce operational expenses while simultaneously improving the quality of service.

Moreover, implementing advanced robotics often involves significant initial financial investments. However, in the long run, reduced expenses and higher profits balance these factors out. Robots are highly beneficial in optimising operations, reducing labour costs, and enhancing manufacturing processes. Although the upfront expenses of acquiring and implementing robotic systems may appear significant, the long-term return on investment (ROI) becomes increasingly evident (Goel & Gupta, 2020). In recent years, advancements in robotics have made robotic solutions more accessible and affordable, particularly for small and medium-sized businesses (SMEs) (Javaid et al., 2021). This has made automation more accessible and enabled businesses of all sizes to reap the cost-saving benefits. In addition, companies may gradually expand their automation efforts thanks to the scalability of robotic systems. This helps minimise financial risk and ensures a seamless transition to a future that embraces more automation. Therefore, we propose that,

H1: *There is a positive relationship between the implementation of advanced robotics and cost reduction.*

There is a clear link between the implementation of intelligent irrigation systems and significant cost savings, suggesting a pivotal moment in agricultural operations. The

connection between cost-effectiveness and intelligent irrigation is a result of the wide range of benefits these advanced solutions offer for various agricultural environments. Firstly, as stated by Khriji et al. (2021), intelligent irrigation systems utilise advanced technologies such as automation, data analytics, and sensors to achieve highly precise optimisation of water consumption. By closely monitoring soil moisture levels, weather patterns, and crop water requirements, these systems enable farmers to tailor irrigation schedules and volumes to match crop demands. This helps minimise water waste and decrease related expenses. In addition, according to a study by Wanyama et al. (2024), the use of intelligent irrigation systems reduces the labour hours required for manual irrigation system monitoring and adjustment. This is due to the automation capabilities of these systems, which help streamline irrigation operations.

Through this approach, farmers can lower labour costs while also optimising the allocation of their workers to other crucial tasks, resulting in increased productivity and operational efficiency. Intelligent irrigation systems can reduce costs by optimising water management techniques to enhance agricultural yields and quality (Bwambale, Abagale, & Anornu, 2022). These systems help prevent both inadequate and excessive irrigation, which can result in crop quality degradation or production losses. They ensure that crops receive the correct amount of water at the right time. Moreover, Sinha & Dhanalakshmi (2022) argue that advanced irrigation systems enhance plant nutrient absorption and facilitate healthier and faster development by maintaining optimal soil moisture levels. Farmers experience financial benefits from the resulting improvements in crop yield and quality, which also reduce the reliance on costly inputs such as pesticides and fertilisers for managing water-related stresses (Khriji et al., 2021).

Intelligent irrigation systems have the potential to significantly reduce energy consumption associated with water pumping and distribution, resulting in substantial cost savings. According to Wanyama et al. (2024), these systems assist farmers in reducing energy costs by employing energy-efficient pumping technology and scheduling irrigation during periods of low electricity demand. This is particularly advantageous in regions where energy costs constitute a significant portion of operational expenses. Intelligent irrigation systems optimise water distribution networks, thereby reducing water conveyance losses from evaporation and leakage. This not only lowers costs but also conserves energy (Barkhordari et al., 2020). Farmers may optimize overall farm profitability by making data-driven decisions about crop selection, planting dates, and resource allocation due to the integration of intelligent irrigation systems with cutting-edge data analytics platforms. According to Barkhordari et al. (2020), farmers can find ways to increase resource efficiency, reduce production costs, and optimize returns on investment by examining past irrigation data, weather forecasts, market trends, and other related variables. Moreover, farmers may adjust their irrigation infrastructure to changing crop needs and environmental circumstances due to the scalability and modularity of intelligent irrigation systems, which guarantees

ongoing cost savings and operational flexibility (Monteiro et al., 2023). Therefore, we make a hypothesis that,

H2: *There is a positive relationship between the adoption of intelligent irrigation and cost reduction.*

The Fourth Industrial Revolution has significantly transformed contemporary industry. The integration of advanced technologies and robotics has significantly transformed the relationship between robotics implementation and cost reduction, ushering in a new era. The convergence and interaction of key technical pillars, including cloud computing, big data analytics, artificial intelligence (AI), and the Internet of Things (IoT), are crucial to this paradigm shift (Aceto, Persico, & Pescapé, 2020). The combination of these technologies provides robotic systems with exceptional levels of intelligence, adaptability, and connectivity, fundamentally disrupting traditional approaches to production and operational management. Artificial intelligence, which enables robotic systems to possess cognitive abilities and make autonomous decisions, plays a central role in this groundbreaking collaboration. According to Goel & Gupta (2020), robots can now perform real-time data analysis, learn from experience, and adapt their behaviour to increase efficiency and reduce costs. These capabilities are enabled by advanced AI algorithms and machine learning methodologies. According to Rossi, Rossi, & Dautenhahn (2020), robots possess cognitive abilities that enable them to perform tasks with greater efficiency, adapt to dynamic situations, and autonomously navigate complex environments. These abilities enhance operational efficiency and optimise resource utilisation.

Robotic platforms using Internet of Things technologies can achieve seamless connectivity and communication with other intelligent systems and devices in the industrial ecosystem (Vermesan et al., 2022). By equipping robots with Internet of Things sensors and actuators, organisations can obtain real-time data on equipment performance, ambient conditions, and production metrics. The data-driven approach enables the implementation of predictive maintenance methods, which proactively detect abnormalities and potential breakdowns. This approach not only reduces maintenance costs but also extends the equipment's lifespan by minimising downtime (Wen et al., 2022). Big data analytics platforms utilise the vast amount of data generated by IoT devices and robotic systems to enhance ongoing improvement initiatives, streamline workflows, and derive valuable insights. Researchers analyse large datasets to identify patterns, trends, and correlations that can reveal inefficiencies, bottlenecks, and opportunities for optimisation in the production chain (Seyedan & Mafakheri, 2020). Data-driven insights enable decision-makers to efficiently allocate resources, optimise workflows, and strategically invest, resulting in reduced operating costs and improved output and quality. Therefore, we say that,

H3: *Technologies of the Fourth Industrial Revolution mediate the relationship between advanced robotics implementation and cost reduction.*

The Fourth Industrial Revolution is transforming agriculture through the adoption of intelligent irrigation systems. These advanced technologies are revolutionising traditional farming methods and leading to cost savings in various operational aspects. The Internet of Things (IoT), artificial intelligence (AI), big data analytics, and cloud computing are key technologies that have converged to establish the foundation of this transformative connection (Aceto et al., 2020). Intelligent irrigation systems incorporating Internet of Things (IoT) sensors enable real-time monitoring of crucial environmental factors such as crop water needs, weather conditions, and soil moisture levels (Biswas et al., 2021). Chen, Sun, & Wang (2022) propose that incorporating artificial intelligence (AI) algorithms into irrigation systems enables the collection and analysis of data. This data can then be used to adjust watering schedules and quantities in real-time, aiming to optimise resource efficiency and minimise waste. Intelligent irrigation systems offer precise control, allowing farmers to reduce utility costs and mitigate the environmental impact of over-irrigation.

In addition, Singh et al. (2022) suggest that farmers can gain valuable insights from the vast amounts of data generated by intelligent irrigation systems by utilising big data analytics platforms. By analysing historical irrigation data, market trends, and crop performance parameters, farmers can optimise irrigation plans, increase crop yields, and maximise profitability. Cloud computing infrastructure also simplifies the storage, analysis, and processing of agricultural data, providing farmers with remote access to up-to-date information and the capability to utilise decision support tools driven by AI (Javaid et al., 2023). Through the utilisation of cloud-enabled agility, farmers can lower operating expenses and enhance farm output by making informed decisions, efficiently allocating resources, and managing risks effectively. Shaikh, Rasool, & Lone (2022) study underscores the potential of intelligent irrigation systems, digital farming platforms, and precision agricultural technology in facilitating data-driven decision-making and comprehensive farm management. By leveraging AI-driven insights and predictive analytics, farmers can optimise their crop choices, planting dates, and fertiliser treatments. This allows them to maximise their yields while minimising input costs (Khriji et al., 2021). This data-driven approach aims to minimise environmental risks, encourage the adoption of sustainable farming practices, and enhance overall farm profitability. Therefore, we say that,

H4: *Technologies of the Fourth Industrial Revolution mediate the relationship between intelligent irrigation adoption and cost reduction.*

RESEARCH METHODOLOGY

This study investigates the effects of implementing advanced robotics and adopting intelligent irrigation on reducing costs in the agricultural sector in Iraq. It also explores how the technologies of the fourth industrial revolution mediate these effects. The study collected primary data from the Iraqi agricultural department using surveys. The study employed a series of inquiries to assess the constructs. The following questions are derived from previous studies. The topic of advanced robotics implementation is covered in five questions (Bartosiak et al., 2022), while intelligent irrigation adoption is explored through five questions as well (Teha & Jianjun, 2021). The technologies of the fourth industrial revolution are examined in six questions (Mahmood & Mubarik, 2020), and cost reduction is addressed in four questions (Sanders, Yang, & Li, 2021).

Furthermore, the study chose the employees of the agricultural department as the participants. The respondents are selected using a method called simple random sampling. The surveys were distributed to the employees through in-person visits. We sent out a total of 578 surveys, but unfortunately, we only received 357 surveys in return. This represents a response rate of approximately 61.76 percent. In addition, the article examines the relationship between variables and data reliability using smart-PLS. This tool is widely utilised for analysing primary data and producing effective outcomes, even when researchers employ complex models (Hair Jr, Howard, & Nitzl, 2020). The study includes two predictors called advanced robotics implementation (ARI) and intelligent irrigation adoption (IIA). In addition, there is a mediating variable called technologies of the fourth industrial revolution (TFIR) and a dependent variable called cost reduction (CR). The variables are provided in the model shown in Figure 1.
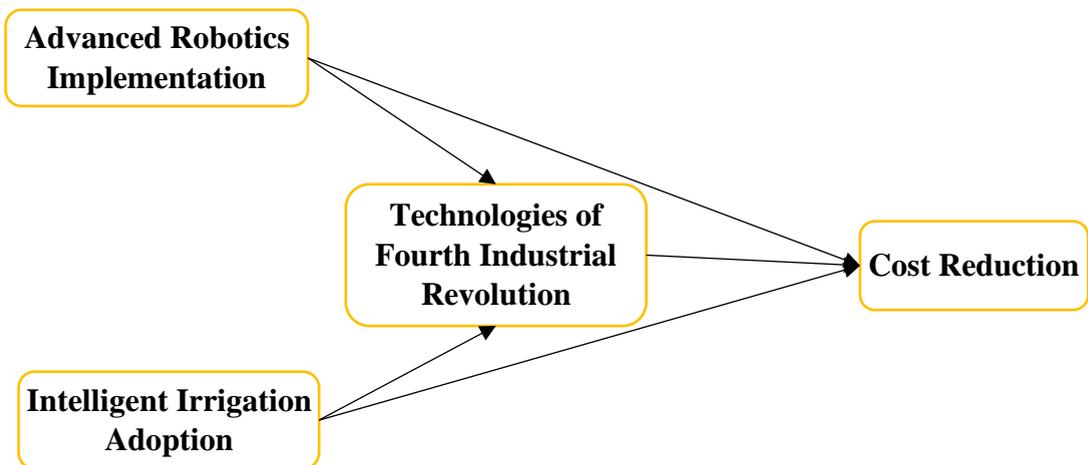

Figure 1: Theoretical Model.

RESEARCH FINDINGS

This study investigates the relationship between the items known as convergent validity. The investigation involves the use of Alpha and composite reliability (CR) to determine values that are greater than 0.70. In addition, the study also examines the factor loadings and average variance extracted (AVE), focusing on values that exceed 0.50. The values revealed a strong correlation between the items. The values can be found in Table 1.

Table 1: Convergent Validity.

Constructs	Items	Loadings	Alpha	CR	AVE
Advanced Robotics Implementation	ARI1	0.797	0.901	0.927	0.718
	ARI2	0.876			
	ARI3	0.854			
	ARI4	0.892			
	ARI5	0.812			
Cost Reduction	CR1	0.781	0.794	0.866	0.617
	CR2	0.808			
	CR3	0.781			
	CR4	0.771			
Intelligent Irrigation Adoption	IIA1	0.908	0.904	0.929	0.723
	IIA2	0.815			
	IIA3	0.810			
	IIA4	0.823			
	IIA5	0.892			
Technologies Fourth Industrial Revolution	TFIR1	0.831	0.860	0.896	0.591
	TFIR2	0.825			
	TFIR3	0.735			
	TFIR4	0.773			
	TFIR5	0.760			
	TFIR6	0.678			

The study explores the relationship between the variables known as discriminant validity. The investigation utilised the Heterotrait Monotrait (HTMT) ratio to analyse values that were found to be less than 0.90. The values revealed a weak correlation between variables, and the discriminant validity was confirmed. The values are provided in Table 2.

Table 2: Discriminant Validity.

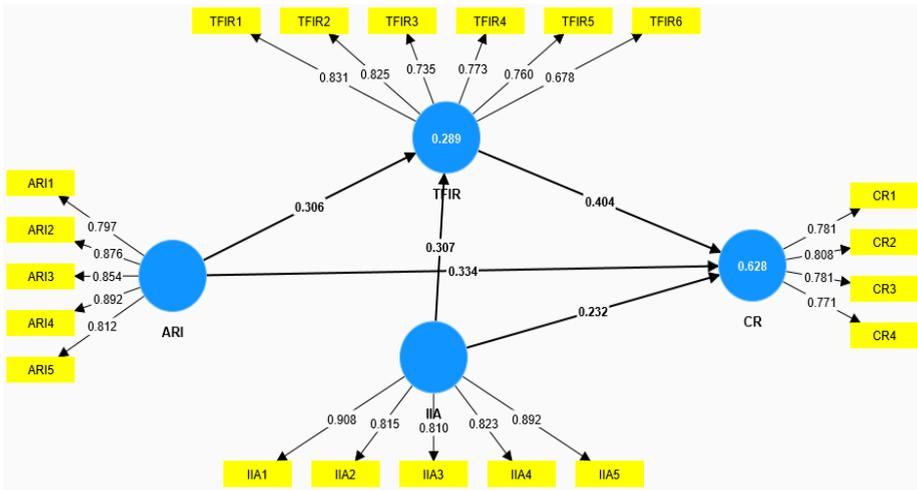|	ARI	CR	IIA	TFIR
ARI				
CR	0.761			
IIA	0.599	0.712		
TFIR	0.525	0.794	0.530	

Figure 2: Measurement Model Assessment.

Ultimately, the results showed that the integration of advanced robotics and intelligent irrigation systems is linked to a decrease in costs, confirming the hypotheses H1 and H2. Furthermore, the findings also suggest that the advancements in technology have a significant impact on the agricultural sector in Iraq. Specifically, the implementation of advanced robotics and intelligent irrigation systems has led to cost reduction. These results support the hypotheses H3 and H4. The values are provided in Table 3.

Table 3: Path Analysis.

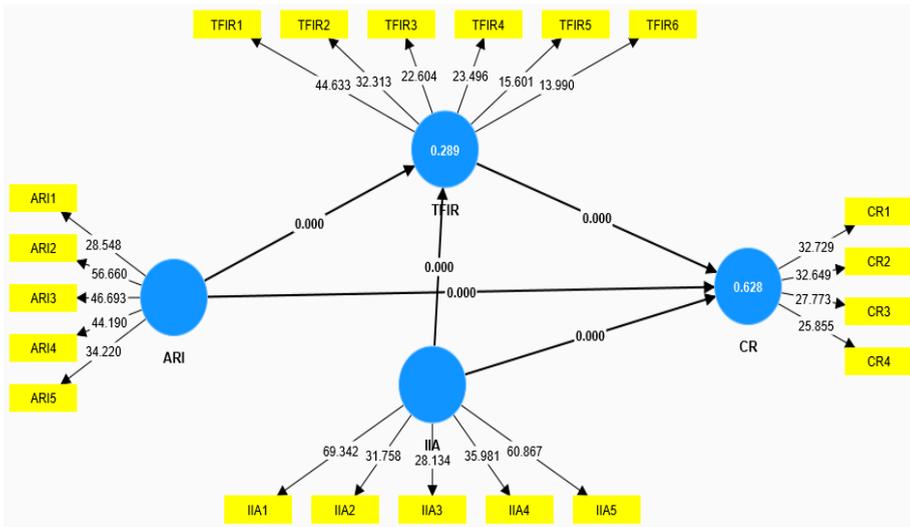| Relationships	Beta	Standard deviation	T statistics	P values
ARI -> CR	0.124	0.029	4.205	0.000
IIA -> CR	0.124	0.025	4.916	0.000
ARI -> TFIR -> CR	0.124	0.029	4.205	0.000
IIA -> TFIR -> CR	0.124	0.025	4.916	0.000

Figure 3: Structural Model Assessment.

DISCUSSIONS

The research provides insights into the intricate interplay of cutting-edge technologies, agricultural methods, and socioeconomic factors that have shaped the current landscape. The agricultural industry in Iraq, with its rich history as a crucial part of the Fertile Crescent, faces significant challenges exacerbated by years of political instability, environmental degradation, and armed conflict. Considering the current circumstances, the implementation of smart irrigation systems and advanced robots appears to be a viable approach to enhance productivity, alleviate resource limitations, and promote sustainable agricultural development. The research findings emphasise the significant impact these technologies can have on reducing costs in various agricultural operations, thereby promoting competitiveness and resilience in Iraq's agricultural sector.

Based on the study, there is significant potential for enhancing labour utilisation, improving operational efficiency, and reducing production costs in Iraq by implementing advanced robots in agriculture. Prior research conducted by Goel & Gupta (2020) and Javaid et al. (2021) further substantiates the theory and investigates the potential of robotic systems to enhance productivity, mitigate risks associated with human labour, and address labour shortages by automating manual tasks such as planting, harvesting, and crop monitoring. In addition, the integration of AI and machine learning algorithms allows robotic systems to adapt to varying environmental conditions, optimise resource allocation, and minimise waste. Soori, Arezoo, & Dastres (2023) have explored these capabilities, which not only help lower production costs but also enhance Iraq's agricultural resilience.

Similarly, the adoption of intelligent irrigation systems seems to be a revolutionary

innovation that will significantly affect crop production, water management, and cost reduction in Iraq's agriculture sector. Smart irrigation systems offer data-driven decision-making and adaptive irrigation methods by accurately monitoring soil moisture levels, weather patterns, and crop water requirements using IoT sensors, AI algorithms, and big data analytics (Wanyama et al., 2024). Based on the research findings, intelligent irrigation systems have been shown to improve agricultural yields and quality, while also reducing irrigation expenses, energy consumption, and water usage. In addition, the scalability and accessibility of these technologies offer opportunities to enhance water efficiency, mitigate the impacts of water scarcity, and promote sustainable agricultural practices in Iraq.

The study highlights the role of Fourth Industrial Revolution technologies in facilitating the connection between the implementation of intelligent irrigation, the utilisation of advanced robotics, and the reduction of costs in Iraq's agriculture industry. Robotic systems and intelligent irrigation systems have gained remarkable capabilities to enhance operations, reduce expenses, and foster innovation thanks to the integration of AI, IoT, big data analytics, and cloud computing (Wanyama et al., 2024). Utilising these cutting-edge technologies can greatly benefit Iraqi farmers by providing real-time data insights, streamlining decision-making processes, and enhancing operational efficiency across the agricultural value chain. The study highlights the importance of investment methods, capacity-building programmes, and policy interventions to promote technology adoption, facilitate knowledge transfer, and foster inclusive agricultural growth in Iraq.

IMPLICATIONS

The results of this study carry significant implications for Iraq's adoption of new technologies, agricultural growth, and policymaking. By clarifying the effects of sophisticated robotics and intelligent irrigation on cost reduction and emphasising the mediating role of Fourth Industrial Revolution technologies, policymakers can create focused interventions to support sustainable agriculture, increase productivity, and reduce resource constraints. In addition, the insights gained from this research can contribute to the development of technology transfer, capacity-building, and investment strategies that will promote inclusive economic growth and resilience in Iraq's agricultural sector, particularly in the context of post-conflict reconstruction and economic revitalization challenges. The study guides policymakers in formulating policies that aim to decrease costs through the utilisation of fourth industrial revolution technologies, implementing advanced robotics, and adopting intelligent irrigation methods.

LIMITATIONS

While this study aims to provide insights into the potential cost-saving benefits of advanced robotics and intelligent irrigation in Iraq's agriculture industry, it is important to acknowledge its limitations. Firstly, the study's scope and the generalizability of its results may be constrained by the limited access to and availability of data. In addition, it is important to consider various factors such as socioeconomic dynamics, technology awareness, and contextual variations, as they can influence the generalizability of the study's findings. In addition, the study's focus on quantitative approaches may have disregarded the intricacies of the context and qualitative aspects. Therefore, further investigation is required to gain a comprehensive understanding of the different aspects of technology adoption and how they impact Iraq's agricultural development.

References

Aceto, G., Persico, V., & Pescapé, A. (2020). Industry 4.0 and health: Internet of things, big data, and cloud computing for healthcare 4.0. *Journal of Industrial Information Integration, 18*, 100129. doi: https://doi.org/10.1016/j.jii.2020.100129

Bahn, R. A., Yehya, A. A. K., & Zurayk, R. (2021). Digitalization for sustainable agri-food systems: potential, status, and risks for the MENA region. *Sustainability, 13*(6), 3223. doi: https://doi.org/10.3390/su13063223

Barkhordari, S., Shahadany, S. M. H., Taghvaeian, S., Firoozfar, A. R., & Maestre, J. M. (2020). Reducing losses in earthen agricultural water conveyance and distribution systems by employing automatic control systems. *Computers and Electronics in Agriculture, 168*, 105122. doi: https://doi.org/10.1016/j.compag.2019.105122

Bartosiak, M., Bonelli, G., Maffioli, L. S., Palaoro, U., Dentali, F., Poggialini, G., et al. (2022). Advanced robotics as a support in healthcare organizational response: A COVID-19 pandemic case study. *Healthcare Management Forum, 35*(1), 11-16. doi: https://doi.org/10.1177/08404704211042467

Biswas, S., Sharma, L. K., Ranjan, R., Saha, S., Chakraborty, A., & Banerjee, J. S. (2021). Smart farming and water saving-based intelligent irrigation system implementation using the Internet of Things. In *Recent Trends in Computational Intelligence Enabled Research* (pp. 339-354). Elsevier. doi: https://doi.org/10.1016/B978-0-12-822844-9.00043-8

Bwambale, E., Abagale, F. K., & Anornu, G. K. (2022). Smart irrigation monitoring and control strategies for improving water use efficiency in precision agriculture: A review. *Agricultural Water Management, 260*, 107324. doi: https://doi.org/10.1016/j.agwat.2021.107324

Chen, J., Sun, J., & Wang, G. (2022). From unmanned systems to autonomous intelligent systems. *Engineering, 12*, 16-19. doi: https://doi.org/10.1016/j.eng.2021.10.007

Chougule, M. A., & Mashalkar, A. S. (2022). A comprehensive review of agriculture irrigation using artificial intelligence for crop production. In *Computational Intelligence in Manufacturing* (pp. 187-200). Woodhead Publishing. doi: https://doi.org/10.1016/B978-0-323-91854-1.00002-9

Gardecki, A., Rut, J., Klin, B., Podpora, M., & Beniak, R. (2023). Implementation of a Hybrid Intelligence System Enabling the Effectiveness Assessment of Interaction Channels Use in HMI. *Sensors, 23*(8), 3826. doi: https://doi.org/10.3390/s23083826

Goel, R., & Gupta, P. (2020). Robotics and Industry 4.0. In A. Nayyar & A. Kumar (Eds.), *A Roadmap to Industry 4.0: Smart Production, Sharp Business and Sustainable Development* (pp. 157-169). Springer, Cham. doi: https://doi.org/10.1007/978-3-030-14544-6_9

Gzar, D. A., Mahmood, A. M., & Al-Adilee, M. K. A. (2022). Recent trends of smart agricultural systems based on Internet of Things technology: A survey. *Computers and Electrical Engineering, 104*, 108453. doi: https://doi.org/10.1016/j.compeleceng.2022.108453

Hair Jr, J. F., Howard, M. C., & Nitzl, C. (2020). Assessing measurement model quality in PLS-SEM using confirmatory composite analysis. *Journal of Business Research, 109*, 101-110. doi: https://doi.org/10.1016/j.jbusres.2019.11.069s

Javaid, M., Haleem, A., Khan, I. H., & Suman, R. (2023). Understanding the potential applications of Artificial Intelligence in Agriculture Sector. *Advanced Agrochem, 2*(1), 15-30. doi: https://doi.org/10.1016/j.aac.2022.10.001

Javaid, M., Haleem, A., Singh, R. P., & Suman, R. (2021). Substantial capabilities of robotics in enhancing industry 4.0 implementation. *Cognitive Robotics, 1*, 58-75. doi: https://doi.org/10.1016/j.cogr.2021.06.001

Kalkhan, M. A. (2019). Environmental Decision-Making within a Recovering War Zone: The Republic of Iraq. In R. D. Lopez (Ed.), *Societal Dimensions of Environmental Science* (pp. 33-56). CRC Press. doi: https://doi.org/10.1201/9781315166827-2

Khriji, S., El Houssaini, D., Kammoun, I., & Kanoun, O. (2021). Precision irrigation: an IoT-enabled wireless sensor network for smart irrigation systems. In T. Hamrita (Ed.), *Women in Precision Agriculture: Technological Breakthroughs, Challenges and Aspirations for a Prosperous and Sustainable Future* (pp. 107-129). Springer, Cham. doi: https://doi.org/10.1007/978-3-030-49244-1_6

Mahmood, T., & Mubarik, M. S. (2020). Balancing innovation and exploitation in the fourth industrial revolution: Role of intellectual capital and technology absorptive capacity. *Technological Forecasting and Social Change, 160*, 120248. doi: https://doi.org/10.1016/j.techfore.2020.120248

Marinoudi, V., Sørensen, C. G., Pearson, S., & Bochtis, D. (2019). Robotics and labour in agriculture. A context consideration. *Biosystems Engineering, 184*, 111-121. doi: https://doi.org/10.1016/j.biosystemseng.2019.06.013

Monteiro, J., Barata, J., Veloso, M., Veloso, L., & Nunes, J. (2023). A scalable digital twin for vertical farming. *Journal of Ambient Intelligence and Humanized Computing,*

14(10), 13981-13996. doi: https://doi.org/10.1007/s12652-022-04106-2

Osrof, H. Y., Tan, C. L., Angappa, G., Yeo, S. F., & Tan, K. H. (2023). Adoption of smart farming technologies in field operations: A systematic review and future research agenda. *Technology in Society, 75*, 102400. doi: https://doi.org/10.1016/j.techsoc.2023.102400

Pathirana, R., & Carimi, F. (2022). Management and utilization of plant genetic resources for a sustainable agriculture. *Plants, 11*(15), 2038. doi: https://doi.org/10.3390/plants11152038

Ronzoni, M., Accorsi, R., Botti, L., & Manzini, R. (2021). A support-design framework for Cooperative Robots systems in labor-intensive manufacturing processes. *Journal of Manufacturing Systems, 61*, 646-657. doi: https://doi.org/10.1016/j.jmsy.2021.10.008

Rossi, S., Rossi, A., & Dautenhahn, K. (2020). The secret life of robots: perspectives and challenges for robot's behaviours during non-interactive tasks. *International Journal of Social Robotics, 12*(6), 1265-1278. doi: https://doi.org/10.1007/s12369-020-00650-z

Sanders, K., Yang, H., & Li, X. (2021). Quality enhancement or cost reduction? The influence of high-performance work systems and power distance orientation on employee human resource attributions. *The International Journal of Human Resource Management, 32*(21), 4463-4490. doi: https://doi.org/10.1080/09585192.2019.1675740

Seyedan, M., & Mafakheri, F. (2020). Predictive big data analytics for supply chain demand forecasting: methods, applications, and research opportunities. *Journal of Big Data, 7*(1), 53. doi: https://doi.org/10.1186/s40537-020-00329-2

Shaikh, T. A., Rasool, T., & Lone, F. R. (2022). Towards leveraging the role of machine learning and artificial intelligence in precision agriculture and smart farming. *Computers and Electronics in Agriculture, 198*, 107119. doi: https://doi.org/10.1016/j.compag.2022.107119

Singh, A., Mehrotra, R., Rajput, V. D., Dmitriev, P., Singh, A. K., Kumar, P., et al. (2022). Geoinformatics, Artificial Intelligence, Sensor Technology, Big Data: Emerging Modern Tools for Sustainable Agriculture. In P. Kumar, A. K. Pandey, S. K. Singh, S. S. Singh, & V. K. Singh (Eds.), *Sustainable Agriculture Systems and Technologies* (pp. 295-313). John Wiley & Sons. doi: https://doi.org/10.1002/9781119808565.ch14

Sinha, B. B., & Dhanalakshmi, R. (2022). Recent advancements and challenges of Internet of Things in smart agriculture: A survey. *Future Generation Computer Systems, 126*, 169-184. doi: https://doi.org/10.1016/j.future.2021.08.006

Soori, M., Arezoo, B., & Dastres, R. (2023). Artificial intelligence, machine learning and deep learning in advanced robotics, a review. *Cognitive Robotics, 3*, 54-70. doi: https://doi.org/10.1016/j.cogr.2023.04.001

Teha, D., & Jianjun, L. (2021). Factors Affecting Adoption of Small Scale Irrigation Technology: Insights from Sire Woreda, Oromiya Region, Ethiopia. *American Journal of Applied Scientific Research, 7*, 84-101. doi: https://doi.org/10.11648/j.ajasr.20210704.12

Vermesan, O., Bröring, A., Tragos, E., Serrano, M., Bacciu, D., Chessa, S., et al. (2022). Internet of robotic things–converging sensing/actuating, hyperconnectivity, artificial intelligence and IoT platforms. In *Cognitive Hyperconnected Digital Transformation* (pp. 97-155). River Publishers. doi: https://doi.org/10.1201/9781003337584-4

Wanyama, J., Bwambale, E., Kiraga, S., Katimbo, A., Nakawuka, P., Kabenge, I., & Oluk, I. (2024). A Systematic Review of Fourth Industrial Revolution Technologies in Smart Irrigation: Constraints, Opportunities, and Future Prospects for sub-Saharan Africa. *Smart Agricultural Technology, 7*, 100412. doi: https://doi.org/10.1016/j.atech.2024.100412

Wen, Y., Rahman, M. F., Xu, H., & Tseng, T.-L. B. (2022). Recent advances and trends of predictive maintenance from data-driven machine prognostics perspective. *Measurement, 187*, 110276. doi: https://doi.org/10.1016/j.measurement.2021.110276