Developing Farmer Capacity and Performance Through Cyber Extension: A Review of Digital Governance

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Abstract. This study explores the role of cyber extension in enhancing farmers' capacity and performance through the integration of digital technologies in agriculture. Using a scientometric approach, the research examines publications from 2007 to 2023, focusing on the evolution of digital agricultural practices, including precision agriculture, smart farming, and climate-smart solutions. Findings highlight the transformative potential of tools such as IoT, big data, and smartphone applications in improving productivity, resource efficiency, and resilience to climate change. Key challenges include low digital literacy, gender disparities, and high costs of technology. The study emphasizes the importance of personalized, gender-responsive, and context-specific digital advisory services, supported by sustainable policies and capacity-building programs. By addressing these barriers, digital agriculture can bridge the digital divide, foster economic growth, and enhance food security in vulnerable regions. The research underscores the critical need for strategic interventions to promote the adoption of advanced technologies and ensure sustainable agricultural practices in the face of global environmental challenges.

Keywords: Cyber Extension, Digital Agriculture, Farmer Capacity Building, Smart Farming Technologies, Climate-Smart Agriculture

1 Introduction

Cyber expansion enhances farmers' capacity and performance by utilizing digital technologies for agricultural information and services, increasing productivity and resilience, benefiting specialists and smallholders [1]. The COVID-19 pandemic has highlighted the critical role of ICTs in maintaining food production and market access, with digital solutions supporting pest control and agronomic practices among smallholders [2]. Despite the widespread use of electronic sources such as radios for extension services, barriers such as low digital literacy and high costs remain, requiring integrated digital and face-to-face methods to ensure inclusive scaling [3].

Personalized digital extension services have been linked to increased input intensity, production diversity, and crop income, demonstrating their potential to overcome information constraints and improve smallholder performance [4]. Gender-responsive

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digital extensions, particularly through telephone ownership, have increased women's access to agricultural information and decision-making, underscoring the need for targeted interventions to bridge the gender gap [5]. Successful ICT-based agriculture projects should focus on the creation of knowledge centers, capacity building, and the development of decision support systems, with measurable indicators for the impact of economic and community development [6].

Smartphone apps have proven to be more effective than traditional methods in increasing agronomic literacy and technology adoption, suggesting targeted ICT approaches to disseminate extension advice [7]. Subscribing to the WeChat public account of agriculture has significantly reduced the cost of allocation inefficiency among cotton farmers, highlighting the efficiency advantages of digital agricultural extension[8]. Meta-analyses show that digital information can improve outcomes and adoption of recommended inputs, with important public support to enhance these benefits [9]. Customized advisory services, especially those dealing with time and crop-specific shocks, have been shown to improve agricultural yields and practices, further emphasizing the importance of customized digital extensions [10].

Analyzing farmers' capacity building and performance through cyber extensions is essential because several factors converge [11]. The COVID-19 pandemic has highlighted vulnerabilities in food systems and the need for resilient farming practices, especially for smallholders facing significant disruptions in accessing markets and inputs [1]. Digital technology offers a promising solution by improving the effectiveness of agricultural extension services, reducing outreach costs, and providing personalized information tailored to farmers' needs, thereby increasing productivity and income [12]. However, the success of these digital interventions depends on addressing barriers such as low digital literacy, high internet and device costs, and gender gaps in access to technology [13].

In addition, the role of meso-scale actors such as agricultural advisors is critical in managing the uncertainties associated with smart agriculture implementation, requiring a more integrated approach to enhance their digital capacity [14]. Governments in developing countries are increasingly investing in digital public goods to support agricultural extension, recognizing the potential for significant economic and social benefits [3]. Additionally, the political economy of digital agriculture, including issues of data ownership, control, and security, must be considered to ensure fair and sustainable development [15]. The integration of digital solutions in agriculture not only helps to cross the “digital divide” but also in reducing poverty vulnerability by increasing income levels and promoting non-agricultural employment [16]. Therefore, a comprehensive analysis of digital governance in agriculture is timely and important to harness the full potential of cyber expansion in transforming agricultural practices and improving farmers' livelihoods.

2 Research Methods

This research uses a scientometric approach to analyze and develop farmers' capacity and performance through cyber extension. Scientometrics, as a method, allows researchers to evaluate the development of scientific literature and identify trends, patterns and relationships between relevant topics [17]. The main focus of this analysis is to understand how the integration of digital and communication technologies in agriculture can improve agricultural practices and outcomes, particularly through cyber extension targeting farmers.

The research data was retrieved from the Scopus database [18], covering publications from 2007 to 2023. To ensure the relevance and quality of the data, specific keywords such as "cyber extension", "farmer capacity", "farmer performance improvement", "communication agriculture", "agricultural extension services", "digital agriculture", "smart farming technologies", "communication farmers", "digital farmer education", and "e-government services agriculture" were used. In addition, the research was limited to English-language articles published in scientific journals with subjects in the social and environmental fields. Other criteria included publications that had reached the final stage and were indexed in a specific subject area.

To visualize and analyze the data, this study used R-Studio [19]. This tool allows researchers to create maps of conceptual structures, trends in the occurrence of research topics, and the evolution of topics over time. Using these visualizations, the researcher was able to identify the most frequently discussed topics and see how the focus of research has shifted over the years. These visualizations also help in understanding how the integration of digital and communication technologies has evolved in the context of agriculture, providing important insights for the development of better agricultural policies and practices in the future.

3 Critical review

3.1 Trends in the emergence of research topics

WordCloud analytics are useful for analyzing research trends by visually representing the frequency of words in text [20]. This tool tracks research topic evolution, identifying key themes and trends using data from various papers and databases, providing a comprehensive overview of common topics and areas of interest.

Figure 1. WordCloud
Source: Data processing using Rstudio

Figure 1 shows that the integration of technology in agriculture is becoming clearer, the study found that the most frequently highlighted topics such as “digital agriculture,” “smart agriculture,” and “precision agriculture” in scientific literature discourse. The rise of digital agriculture, mentioned 52 times, underscores the increasing reliance on technologies such as the Internet of Things (IoT), big data, and remote sensing to improve agricultural productivity and resource use efficiency [21]. Climate change, referenced 23 times, remains a critical concern, pushing research towards climate-smart farming practices to maintain productivity and reduce global warming [22].

Agricultural extension services play a crucial role in disseminating technological advancements and improving agricultural techniques, especially in areas like India where digital literacy and access are critical [23]. The adoption of AI, machine learning, and robotics is revolutionizing modern agriculture, enabling smarter decision support systems and efficient resource management [24]. Emphasizing sustainability and communication, as mentioned 16 times each, underscores the importance of environmentally conscious practices and effective information dissemination to support farmers and improve agricultural yields [7]. A study in Nepal highlights the effectiveness of smartphone applications in improving farmers' knowledge and technology adoption, demonstrating the potential of targeted ICT approaches in extension services [25].

The digital transformation of agriculture is significantly influenced by the integration of GIS, remote sensing technology, and the Internet of Things (IoT), facilitating data analysis and decision-making processes [26]. These technologies play a crucial role in improving productivity, sustainability, and resilience in agricultural systems, addressing challenges such as climate change and resource constraints [27]. The utilization of digital tools and innovative practices in digital agriculture is essential to meet the growing demand for food from a growing global population while ensuring efficient use of resources and environmental sustainability [28]. The ongoing technological revolution in agriculture underscores the importance of embracing digitalization to optimize agricultural practices and address the diverse challenges faced by the sector in the modern era.

3.2 Mapping Research Topics

Conceptual structure map is a method that uses cluster analysis to review and visualize research topics [29], identifying conceptual areas and heterogeneous patterns across different disciplines [30]. This systematic approach emphasizes the need for efficient clustering methods and scalable algorithms, which provide a comprehensive understanding of the research topic through cluster analysis [31].

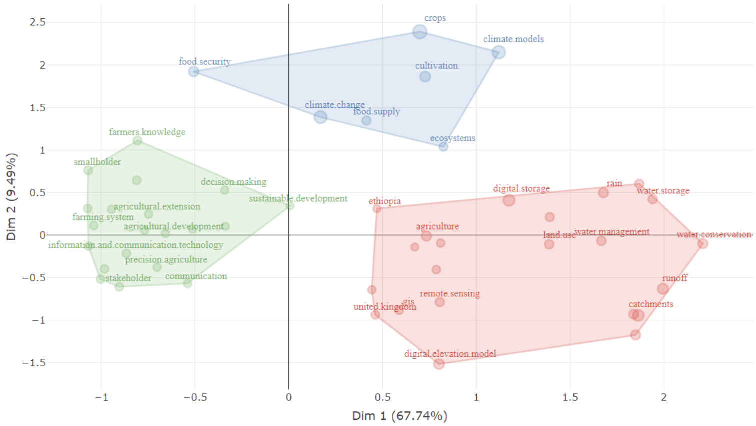

Figure 2. Conceptual Structure Map

Source: Data processing using RStudio

Cluster 1 (red) in factorial analysis, the study found that these topics focused on digital technologies, such as digital storage, remote sensing, agricultural robots, and soil moisture monitoring, can improve farmers' capacity and agricultural performance in agriculture and water resource sustainability. The cluster delves into optimizing water use efficiency, implementing water-efficient irrigation technologies, and promoting sustainable agricultural practices, aligning with the global trend of digital agriculture and the need to mitigate the impact of climate change on food security and agricultural productivity. Digital solutions are critical in advancing agricultural practices and ensuring sustainable water management in the face of environmental challenges [32]. These solutions offer increased productivity, reduced environmental footprint, and higher resilience in agricultural systems.

Implementing a Water Reuse Risk Management Plan (WRRMP) and digital solutions can facilitate the safe use of reclaimed water in agriculture, addressing governance complexities and a lack of social trust [33]. Digital tools in rural areas optimize water consumption, improve communication with local communities, and contribute to green economy initiatives [34]. Digital agriculture technology is essential in mitigating the impact of climate change on food security by reducing greenhouse gas emissions, increasing productivity, and ensuring equitable distribution. Digital groundwater monitoring initiatives have shown success in promoting water-efficient irrigation behaviors among farmers [35].

Cluster 2 (blue) in factorial analysis, the study found that these topics focused on climate change, climate models, crops, cultivation, ecosystems, food supply, and food security in line with the broader discourse on the vulnerability of food systems to climate variation. The study underscores the significant implications of climate change on crop productivity and food security, especially in areas already grappling with hunger and malnutrition. The research highlights the need to adapt food systems to reduce the impact of climate change on food security, emphasizing the importance of sustainable agricultural practices [36]. Efficient management of the effects of climate change is essential for food security. Climate models are increasingly being recognized as a tool to understand and address the impacts of climate change on food security [37]. Integrating climate models into decision-making allows stakeholders to make informed decisions and implement strategies to improve resilience in agricultural systems, ultimately protecting food production and nutrient security for vulnerable populations.

Cluster 3 (green) in factorial analysis, the study found that the topics focused on “agricultural extension,” “precision agriculture,” “agricultural technology,” “digitalization,” and “technology adoption.” This cluster explores how digital technology and innovation can increase the capacity of farmers through cyber expansion. The research topic highlights the impact of factors such as age, gender, education, access to credit, and external factors such as the Covid-19 pandemic on farmers' adoption of digital technology [38]. They also highlighted the role of professional agricultural extension workers in promoting precision farming practices and the effectiveness of communication methods such as smart phone applications in disseminating important information [39]. These findings point to the need for strategic interventions and support systems to facilitate the adoption of digital technologies in agriculture, leading to increased productivity and sustainability.

3.3 Evolution of Research Topics

Sankey diagrams and RStudio provide a comprehensive view of research topics, enabling researchers to track common interests, predict future trends, and extract topic-related relationships [19].

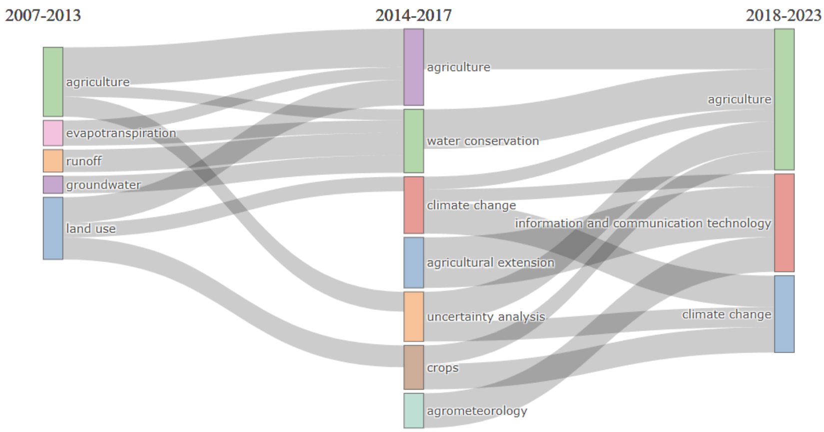

Figure 3. Sankey Diagram of Thematic Evolution
Source: Data processing using RStudio

Figure 3 explains the thematic evolution from 2007 to 2023, highlighting the shifts and trends that have emerged in the research topic. In the period from 2007 to 2013, agricultural research mainly focused on fundamental aspects such as water management and land use [40]. Themes such as evapotranspiration and runoff underscore the importance of the water cycle in agricultural practices, which aim to optimize the use of natural resources to increase agricultural productivity [41]. In addition, the emphasis on groundwater and land use highlights the importance of sustainable resource management strategies in agriculture, reflecting a concerted effort to understand and optimize resource utilization for long-term agricultural sustainability [42]. This era sees concentrated research efforts to understand and improve the use of natural resources to improve agricultural yields, with a particular focus on water-related processes and sustainable land management practices.

The thematic evolution in agricultural research from 2014 to 2017 reflects a comprehensive approach to addressing agricultural challenges, including the impact of climate change on agriculture[43]. The existence of topics such as water conservation and agricultural extension signifies a high emphasis on sustainable practices and farmer education in adopting modern techniques [44]. In addition, the incorporation of uncertainty analysis and agrometeorology points towards more scientific and analytical methods of managing agricultural risks and understanding weather patterns [45]. This shift highlights the growing awareness of the importance of sustainable agriculture, climate change adaptation, and the need for sound decision-making in agricultural practices to improve resilience and productivity in the face of changing environmental conditions.

From 2018 to 2023, the evolution of themes in agriculture, ICT, and climate change has become important, highlighting the increasing role of digital technologies in agriculture [46]. ICT integration signals the adoption of cyber extension methods to improve farmers' capacity and performance, indicating a shift towards more tech-savvy agricultural practices [47]. Climate change remains a significant concern during this period, emphasizing the ongoing need to address its impact on agriculture and food security [32]. The continued focus on agriculture during these years demonstrated a consistent goal to improve agricultural practices and outcomes, with advances in digital tools and methods supporting this overarching goal.

4 Conclusions

The study highlights the growing importance of technology integration in agriculture, especially in areas such as digital agriculture, smart agriculture, and precision agriculture. The study emphasizes the use of IoT, big data, and remote sensing to improve productivity and resource efficiency. Climate change is a major concern, driving research towards climate-smart agriculture practices. Agricultural extension services are very important in spreading technological advances, especially in areas with low digital literacy. AI, machine learning, and robotics are revolutionizing modern agriculture by supporting smarter decisions and efficient resource management.

The study also highlights the effectiveness of smartphone applications in increasing knowledge and technology adoption among farmers in Nepal. This research underscores the need for digital solutions and strategic interventions to advance sustainable agricultural practices and face global environmental challenges.

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