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DEVELOPMENT OF DIGITAL EXTENSION PLATFORMS AS A DIRECTION OF DIGITAL TRANSFORMATION OF AGRICULTURAL PRODUCTION

Abstract. The article examines modern approaches to digital transformation in agricultural extension, including digital extension platforms, semantic technologies,

and artificial intelligence. Traditional agricultural extension faces several limitations, including its strong dependence on human resources, regional shortages of qualified specialists, and logistical barriers. These challenges indicate the need to move from conventional information support models toward intelligent decision support systems aligned with the concept of "Agriculture 5.0". Modern information and communication technologies offer a scalable, cost-effective approach to disseminating practical agricultural knowledge. Recent research demonstrates that intelligent chatbots can help reduce the cost of extension services, optimize the use of technological resources, minimize transaction costs for agricultural enterprises, and support timely managerial decision-making in response to biotic and climatic threats. The introduction of such intelligent assistants transforms the role of an extension advisor, shifting it from a provider of reference information to an expert consultant who supports complex managerial decisions and helps address non-standard production challenges. Within the framework of the research project No. 0126U000765 at Dmytro Motornyi Tavria State Agrotechnological University, a conceptual approach to developing an intelligent extension environment is proposed. The approach integrates semantic wiki technologies, ontology modeling, and generative artificial intelligence. The proposed concept involves developing and applying a specialized ontology, the Advisory Learning Ecosystem (ALE), to formalize unstructured agronomic knowledge. Integrating the ALE ontology with the Semantic MediaWiki platform and large language models creates the foundation for a flexible digital environment that supports networking among researchers, extension advisors, and farmers.

Keywords: agricultural extension, digital transformation, Agriculture 5.0, generative artificial intelligence, ontology modeling.

Formulation of the problem. The current stage of global economic development is characterized by large-scale digitalization and the increasing intellectualization of production processes, in where rapid access to relevant knowledge and expert information has become a key factor in ensuring competitiveness. For Ukraine's agricultural sector, which operates under conditions of heightened risk, climate change, logistical constraints, and a shortage of qualified personnel, the ability to make scientifically grounded managerial decisions promptly is essential for sustainable operations and further development. Geographical and social factors, including ongoing military operations in Ukraine, further intensify these challenges.

The traditional agricultural extension system, which relies primarily on direct interaction through face-to-face consultations, seminars, and telephone communication, is ineffective in the current environment. Such an approach cannot provide the scalability, continuity, or responsiveness required to meet the needs of thousands of small and medium-sized agricultural producers. Consequently, a gap exists between farmers' demand for immediate, accurate, and context-specific knowledge and the limited capacity of existing extension services.

One possible solution to this challenge is transitioning from conventional consulting practices to the development of intelligent digital extension platforms. Such platforms should serve not merely as static databases or informational web resources, but as dynamic knowledge management ecosystems. Modern knowledge engineering approaches, particularly ontology modeling, combined with artificial intelligence capabilities, enable the automation of knowledge structuring, information retrieval, and personalized content delivery. This approach transforms extension activities from a traditional consulting service into a modern instrument for agricultural modernization, facilitating the integration of agricultural science, education, and practical experience.

The integration of information and communication technology (ICT) tools with artificial intelligence (AI) creates new opportunities for delivering personalized extension services in real time. However, practical solutions in this field vary considerably depending on national contexts, the level of digital maturity of the agricultural sector, and the organizational characteristics of extension activities. These differences highlight the need for a systematic analysis of digital platform development trends is required to identify pathways for their evolution into fully-fledged intelligent extension systems of a new generation.

The digital transformation of agricultural extension has attracted considerable attention from both Ukrainian and international researchers.

As noted by V. Hranovska, L. Kononenko, V. Savchenko, R. Fabregas, T. Harigaya, and other scholars, current trends in agricultural development are closely associated with the widespread adoption of information and communication technologies (ICT) to support sustainable development and improve services for smallholder farmers. The theoretical and methodological foundations of the Ukrainian agricultural extension system and its contribution to enterprise development and agricultural cooperation have been examined in the studies of O. Smulka, A. Sviatoshniuk, R. Bezus, and M. Dubchak. At the same time, the institution of agricultural extension requires systematic modernization to address current geographical, economic, and social challenges. In this context, Yu. Bakun, A. Skrypnyk, and S. Saiapin argue for the development of an integrated binary extension system based on specialized web platforms. Similarly, Ol. Olagunju, Ol. Adetarami, and other international researchers emphasize the role of digital technologies in reducing information gaps, particularly during emergencies. M. Sithole, I. Agholor, and their colleagues also demonstrate that integrating digital technologies throughout the agricultural production cycle can substantially reduce production costs while improving farm productivity.

The development of agricultural web platforms is gradually shifting from static information repositories to intelligent digital ecosystems. Comprehensive studies on the application of artificial intelligence in agricultural extension have been conducted by S. High, N. Singh, and G. Nemes. At the same time, the practical potential of the

Ukrainian AI-based system Agri1 has been investigated by P. Lykhovyd, R. Vozhehova, and L. Hranovska. Research on natural language dialogue systems, including the MkulimaGPT chatbot (T. Maginga, S. Kutuku et al.) and the Ama Krushi platform (S. Sahoo, A. Jena), demonstrates that AI technologies can provide farmers with continuous and personalized information support. Likewise, the comprehensive information management system with an integrated intelligent chatbot developed by H. Mzumara, J. Mulepa, and their colleagues illustrates how consulting activities can be automated throughout the entire crop production process, helping overcome both information and knowledge barriers.

Despite these significant advances, several issues remain insufficiently explored. In particular, further research is needed on the comprehensive digital transformation of agricultural extension through the widespread adoption of digital and intelligent technologies, as well as on the barriers that may hinder their adoption by farmers. Moreover, limited attention has been paid to the conceptual principles underlying the development of digital extension platforms as the foundation for future intelligent extension systems.

The purpose of the article to analyze current trends in the development of digital extension platforms and identify their potential to provide information and advisory support to agricultural producers.

Exposition of the main material. An analysis of recent studies [1, P. 1; 2, P. 1570; 3, P. 601] indicates that traditional agricultural extension relies heavily on human resources and the direct involvement of extension advisors, thereby limiting its scalability and service efficiency. Existing extension services often face shortages of qualified personnel, insufficient infrastructure, and geographical and logistical constraints in rural areas, making it difficult for agricultural producers to obtain timely professional advice. At the same time, many extension organizations have not established a strong digital presence and still lack official websites or social media pages [4, P. 55]. This limited online visibility restricts farmers' access to advisory services and reduces opportunities to promote extension activities. Although technological opportunities for delivering advisory services continue to expand, important challenges remain, including the shortage of specialized web resources and high-quality digital content, as well as the willingness of extension stakeholders to use digital technologies as an effective communication channel [5, P. 49].

At the same time, information and communication technologies (ICT) create new opportunities for modernizing agricultural extension. Digital extension services provide a scalable, cost-effective way to disseminate practical knowledge [6, P. 87], enabling the delivery of real-time advisory support to large numbers of users [3, P. 601]. In addition, digital technologies help extension organizations reduce transportation expenses and communication costs associated with telephone-based consulting [1, P. 2].

The rapid expansion of mobile communications and Internet access has created favorable conditions for transforming extension services by providing farmers with timely and context-specific recommendations [2, P. 1573]. Mobile technologies enable affordable, rapid, and personalized information delivery at scale [7, P. 192]. Digital technologies also expand access to advisory support for farmers in remote areas with underdeveloped infrastructure, as well as in regions affected by military conflicts or natural disasters. Another important advantage of digital platforms is that they facilitate professional interaction among agricultural producers themselves, encouraging knowledge exchange and peer-to-peer learning.

The practical application of information and communication technologies in agricultural extension has led to the development of numerous digital services and electronic resources. These solutions collectively form the foundation of modern digital extension platforms platforms that integrate informational, advisory, and educational functions. For example, A. Skrypnyk and S. Saiapin [5, P. 57] proposed a comprehensive framework for electronic agricultural extension consisting of several interconnected components: an interactive web portal presenting the resource potential and investment attractiveness of a particular region; a specialized advisory website containing scientific, technical, educational, and practical information for agricultural producers and the general public; and a distance learning system designed to support professional development, specialist certification, and lifelong learning in agriculture.

The development of sector-specific web platforms is gradually moving beyond simple information publication toward intelligent digital decision-support systems. This transition reflects the shift from the concept of Agriculture 4.0 to Agriculture 5.0, which emphasizes the broader adoption of intelligent technologies in both agricultural production and extension services [8, P. 2]. Artificial intelligence technologies including machine learning, computer vision, natural language processing (NLP), and Internet of Things (IoT) sensor systems provide the technological basis for this transformation. These technologies offer new opportunities to develop intelligent decision-support systems for precision agriculture and farm management [3, P. 601]. For agricultural extension, this means moving beyond simply distributing information toward providing intelligent services capable of analyzing data, interpreting knowledge, and supporting production-related decision-making.

Artificial intelligence also enables the automation of selected extension activities by creating interactive systems capable of delivering personalized advisory support to large numbers of users simultaneously [2, P. 1573]. To ensure natural communication with users, these systems increasingly rely on generative artificial intelligence and natural language processing technologies. Large language models (LLMs) enable adaptive responses, interpret the context of user queries, and facilitate intuitive communication with end users [9, P. 165].

One of the most promising applications of artificial intelligence in agricultural extension is the development of decision support systems implemented as question-

and-answer chatbots. These digital assistants enable rapid information retrieval, document navigation, integration of information from multiple sources, and generation of personalized responses. Their use reduces the administrative workload of extension advisors while reshaping the nature of their professional responsibilities. Rather than serving primarily as providers of information, extension specialists increasingly act as consultants who interpret the outputs of intelligent systems, evaluate proposed solutions, and assist farmers in addressing complex or non-standard production challenges.

Intelligent chatbots are also becoming an integral part of agricultural extension practice, particularly those based on ChatGPT technologies [10], which automate the delivery of personalized advisory services in real time [1, P. 1]. The example of the Farmer.Chat platform that combines retrieval-augmented generation (RAG) with large language models demonstrates that artificial intelligence can reduce the cost of extension services while enabling the scaling of advisory support to large numbers of agricultural producers. One of the platform's key advantages is its multimodal interface, which combines text, voice, and images to help overcome language and educational barriers [11, P. 72]. Similar capabilities are offered by other regional digital solutions tailored to their users' linguistic and social characteristics. For example, the MkulimaGPT text-and-voice chatbot operates in Swahili and combines the capabilities of large language models with localized, verified information. The use of GPT-3 and GPT-4 enables scalable service delivery, round-the-clock support, and personalized recommendations for farmers [12, P. 174].

Olagunju et al. [6, P. 86] describe a range of digital solutions designed to improve the accessibility of agricultural extension services. These include the Access Agriculture project, the e-Krishok platform, the Esoko mobile platform, and the Senekela Orange service, among others. Together, these examples illustrate that digital extension platforms vary considerably in complexity, ranging from simple information services to advanced intelligent systems capable of analyzing data, generating recommendations, and supporting managerial decision-making.

One of the most promising directions for the further development of digital extension platforms is their evolution from information repositories into knowledge management systems. Such systems are expected not only to store information but also to provide its semantic representation, analysis, and application for generating intelligent recommendations. In this context, semantic technologies and ontology modeling play a central role by enabling the formalization of domain knowledge and the explicit representation of relationships among concepts, objects, and processes.

Within the research project "Development of an Intelligent Support Environment for Agricultural Advisory Services Based on the Integration of Semantic Wiki Technologies and Artificial Intelligence" (State Registration No. 0126U000765), carried out at Dmytro Motornyi Tavria State Agrotechnological University, the concept

of a next-generation intelligent platform for agricultural extension services is being developed. The proposed approach combines knowledge engineering methods, semantic wiki technologies, and generative artificial intelligence. As a result, the digital extension platform is viewed not simply as a conventional web resource containing information materials, but as an intelligent environment in which knowledge can be accumulated, structured, continuously updated, and used to generate personalized recommendations.

The theoretical foundation of this environment involves developing and validating a specialized ontology, the Advisory Learning Ecosystem (ALE), which is a core component of the proposed platform. As a conceptual domain model, the ALE ontology enables the formal representation of knowledge related to agricultural processes, professional competencies, and the content of extension services. The practical implementation of this knowledge model includes integrating the ALE ontology with contemporary knowledge management platforms. One of the most widely used solutions for this purpose is Semantic MediaWiki, which supports the creation of semantic knowledge bases that can be collaboratively maintained and continuously updated. In the context of agricultural extension, this approach enables knowledge from agricultural researchers, extension advisors, and practitioners to be shared in a digital environment for professional collaboration.

Another important function of such a platform is supporting personalized learning for adult agricultural professionals. The proposed system is intended to take into account users' individual characteristics, including their educational background, professional experience, farm specialization, previous learning outcomes, and acquired competencies [13, P. 119]. Implementing this approach will require developing appropriate methodological guidelines for the effective use of the intelligent extension environment. In the long term, this will enable the creation of individualized professional learning pathways, ensuring that users receive relevant knowledge precisely when needed to address specific production challenges.

An intelligent extension platform can also improve agricultural producers' responsiveness to emerging production challenges. For example, analyzing information on crop conditions, weather patterns, soil characteristics, and farming operations would enable the system to generate more accurate recommendations on fertilizer application, crop protection measures, and other agronomic practices. In addition, such systems have the potential to reduce transaction costs associated with information search and the use of external consulting services. Automated access to structured knowledge and intelligent recommendations provides a foundation for improving managerial decision-making and promoting the sustainable development of agricultural production.

Conclusions. The modernization of traditional agricultural extension, constrained by shortages of qualified personnel, logistical barriers, and limited digital presence,

requires a transition from conventional information delivery to intelligent decision-support systems aligned with the Agriculture 5.0 concept. The integration of generative artificial intelligence, natural language processing technologies, and large language models into interactive chatbot solutions is reshaping the organization of extension services. These technologies provide continuous support, improve service scalability, reduce the cost of advisory activities, and help overcome educational barriers faced by farmers.

The intelligent extension environment being developed within research project No. 0126U000765 at Dmytro Motornyi Tavria State Agrotechnological University is based on integrating Semantic MediaWiki with the specialized ALE-ontology. This approach enables formalizing unstructured agronomic knowledge while bringing together researchers, extension advisors, and practitioners in a shared digital environment. The practical implementation of the proposed platform is expected to support personalized learning for adult agricultural professionals through individualized learning pathways tailored to their competencies. The platform is also expected to support more effective technological decision-making, reduce transaction costs for agricultural producers, and improve responsiveness to biotic and climatic challenges.

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