

RECONCEPTUALIZING AGRICULTURAL AND LIVESTOCK EXTENSION EDUCATION: A COMPREHENSIVE REVIEW OF TRANSFORMATIVE LEARNING, RURAL CAPACITY BUILDING, AND SUSTAINABLE DEVELOPMENT

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ABSTRACT

This is an extensive review that critically considers the development, present status, and directions of agricultural and livestock extension education systems in the context of transformative learning, rural human capital development, and sustainable development. This review is based on a systematic analysis of peer-reviewed literature published mainly from 2022 to 2026 and collates evidence of extension education's transformative potential in relation to tackling challenges of global food security, climate change adaptation, and the reduction of rural poverty. Agricultural extension services have shifted from the colonial-period 'technology transfer' model to become more participatory, digitalized, and multi-sectoral. The key findings highlight the benefits of transformative extension education, such as farmer field schools and participatory approaches, that can greatly improve the uptake of knowledge, farmer empowerment, and sustainable agriculture. Despite this, extension systems remain underdeveloped and face problems of insufficient investment, policy coordination and integration, gender gaps, and a lack of digital skills in the majority of developing countries. The introduction of new technologies and innovations in the field of information and communication technologies (ICT), artificial intelligence, and climate-smart agriculture are new opportunities for scaling extension services. This review highlights three key gaps in the research: (1) the need to research the longitudinal impacts, (2) the lack of education research on livestock, and (3) the lack of interdisciplinary research integration. Policy implications highlight the importance of a robust national extension system, better public-private partnerships, digital inclusion initiatives and gender-sensitized capacity building. While future extension education should include digital innovation, it should also focus on participatory and locally contextualized approaches and take into consideration structural inequalities to meet the targets for inclusive sustainable development and global food security.

Keywords: Extension Education, Transformative Learning, Rural Capacity Building, Sustainable Agriculture, Livestock Extension, Digital Extension, Farmer Field Schools, Participatory Learning, Food Security, Climate Adaptation

1. INTRODUCTION

1.1 Background: The Global Agricultural Imperative

Extension education is being challenged in unprecedented ways on the global stage, due to a series of interrelated issues that are impacting agriculture. With a world that is increasingly populous and as the income of developing nations keeps increasing, their demand for food and agricultural commodities keeps increasing (Ewane et al., 2026), and climate change and the degeneration of resources and emerging pest pressures put pressure on productivity. Even after decades of investments in research, the smallholder farming population in South Asia and sub-Saharan Africa faces a significant productivity gap between actual and potential yields in agriculture, where agriculture is still the main livelihood for hundreds of millions of smallholder farmers. Such farmers work in knowledge-constrained settings in which the availability of reliable, actionable and place-specific agricultural knowledge is a key factor in their productivity, food security, and livelihoods.

The transition towards knowledge-based agriculture stands out as a radical paradigm change in the way agriculture needs to be thought of. Finally, knowledge-based systems require farmers to be lifelong learners, adapting and innovating in a dynamic environment of changing environmental, economic and social conditions, compared to centralized industrial agriculture with its external inputs and standardized practices. In this paradigm shift, agriculture extension is not just a mechanism for disseminating technology but a strategic tool for rural transformation, human capital development, and sustainable livelihood systems.

1.2 Conceptual Framework of Agricultural and Livestock Extension Education

Agricultural extension education is defined as a systematic process of imparting knowledge and skills to farmers and providing assistance to the adoption of new technologies in agriculture using the different formal and informal approaches. Extension education is very different from simply providing information about agriculture; it focuses on the process of learning, changing behaviors, and building capacity through the use of structured, intentional educational approaches. Livestock extension is a specialized area of animal husbandry education, veterinary advice and livestock production management systems that serve dairy, poultry, small ruminant, and other livestock enterprises that are important to rural economies (Ewane et al., 2026).

Extension education is not one-size-fits-all; it comes in a variety of forms and levels of formality. Formal systems are usually organized by government agricultural organizations, universities, and training institutes and provide structured courses by trained personnel. Informal systems arise via farmer networks, community-based organizations, and the old-fashioned means of knowledge transfer. The best extension systems of the current era realize that there are synergies between formal and informal approaches and develop pluralistic extension systems where multiple extension actors (government agencies, non-governmental organizations, private sector actors, farmer associations and community groups) work together to improve the accessibility and relevance of knowledge.

1.3 Historical Evolution of Extension Systems

The past history of extension education mirrors the general course of development paradigms and educational philosophies. Colonial extension models, which were mostly developed in Asia and Africa in the early decades of the twentieth century, reflect prescriptive and top-down thinking, focusing on the transfer of standard technology packages to passive audiences of farmers. These systems were based on assumptions that farmers were not knowledgeable, innovative, nor had agency in their decision-making, which were subsequently fully challenged by subsequent research.

The Training and Visit (T&V) model, which has been actively encouraged by the World Bank and bilateral donors since the 1970s, tried to streamline extension service activity by implementing a structured and systematic contact between the extension and the farmer groups. T&V had some impressive successes in specific circumstances, particularly in cereal production in South Asia, but the model's strict levelled structure, focus on external inputs, and exclusion of farmers proved limiting when it came to meeting the needs of complex, context-specific problems.

Farmer Field Schools (FFS) were introduced in Southeast Asia in the 1980s and represented a shift in paradigm away from prior approaches to emphasizing discovery and experiential learning in the farmers' field. The farmer's expertise, integration of local knowledge, group learning dynamics and iterative experimentation with sustainable practices were all strengthened by the FFS approaches. Expansive growth of FFS occurred over the next few decades, and as of the beginning of the twenty-first century, there were at least ten million farmers involved in FFS in ninety countries.

Extension services in the twenty-first century are increasingly adopting participatory, multi-stakeholder approaches which cross the research-extension-farmer innovation divide. The university-based extension system, private sector involvement, digital platforms and farmer-led networks operate in parallel in contexts that are quite diverse, and are far removed from the 20th-century models based on government monopolies.

1.4 Rationale and Significance of the Review

While the role of extension education is well recognized, the existing literature on agricultural extension is disjointed, with the former directed at agricultural issues relating to production outcomes and the latter at pedagogical issues without regard to the agricultural context. The extension of livestock knowledge and production systems is less well researched than extension for crops, leaving gaps in knowledge about the effectiveness of livestock extension, livestock extension pathways, and the integration of livestock extension and sustainability. The gap between extension practice and educational theory is not sufficiently tight, which restricts theory development and also restricts extension practitioners from having access to education innovations they need to be pedagogically innovative in their work.

Transformative learning theory, which focuses on critical reflection, perspective change and personal development, provides rich conceptual tools for understanding extension education in a new light as a process of human transformation, not information transfer. However, the idea of transformative learning has not been fully incorporated into the field of extension education, especially in developing countries. Also, the concepts of sustainable development are increasingly focused on the need to explicitly consider the environmental constraints, equity issues, and livelihood resilience aspects of the challenge, aspects that were poorly served by older extension paradigm.

1.5 Review Objectives and Research Questions

This review covers the following five key objectives:

1. To synthesize critically the theories behind and development of agricultural and livestock extension education; and
2. To evaluate transformative learning's applicability and effectiveness as an extension education framework
3. To evaluate the proven contributions of extension education in the development of human resources and building capacity in rural areas.
4. To analyze the effectiveness of digital and innovative extension models and equitable access to them
5. To summarize findings regarding key barriers and enablers to extension system strengthening, propose future directions for strengthening the extension system.

The core research questions for this review include: How has extension education changed and how do effective extension education systems look in the twenty-first century? What theories of education best explain the transformative potential of extension education? What are the most significant impediments to the effectiveness of extension education systems and what institutional, technological and policy innovations hold promise? How can extension education systems be conceptualized to better meet the 21st century challenges of agriculture?

2. METHODOLOGY

2.1 Review Design

This comprehensive literature review uses narrative synthesis methodology, a method that allows critical synthesis of evidence from a range of different study designs, contexts, and outcome measures, while remaining theoretically rich and dealing with complexity. Instead of dogma-laden meta-analyses, narrative synthesis allows for consideration of the qualitative aspects, context, and program implementation differences that are present in natural settings of extension systems.

2.2 Literature Search Strategy and Scope

Combinations of keywords were used to systematically search literature from five databases (Scopus, Web of Science, ScienceDirect, Google Scholar): agricultural extension education; livestock extension; farmer field schools; transformative learning; rural capacity building; digital extension; climate-smart agriculture; participatory extension; extension systems; "and" "or" combinations of terms were used. Searches were conducted on peer-reviewed articles and publications from the years 2022 to 2026 with the understanding that extension education literature comes from various fields of research, including agronomy, education, rural development, economics, anthropology and sustainability science.

2.3 Inclusion and Exclusion Criteria

Studies that met the following criteria were included: (1) they concerned agriculture or livestock extension education generally; or (2) they concerned specific approaches to extension; (3) they addressed extension impacts on farmer knowledge; or extension impacts on practice adoption; or (4) extension impacts on livelihood outcomes; or (5) extension impacts on extension actors' empowerment; (6) they analyzed extension education methods, pedagogies or theoretical approaches in agricultural contexts; (7) They evaluated agricultural extension system effectiveness, agricultural extension system barriers, or the institutional dimensions of agricultural extension; (8) They examined the contributions of agricultural extension to sustainable agriculture, food security, climate adaptation, or gender equity. The geographic scope was intentionally global, acknowledging both global principles of extension and the local adaptations. Agriculture reports that had no extension/education content and were purely technical were not included in the review, as were non-peer-reviewed reports, research that was conducted in languages other than English, and duplicated research.

3. THEORETICAL AND CONCEPTUAL FOUNDATIONS OF EXTENSION EDUCATION

3.1 Foundational Concepts: From Information Transfer to Human Development

The basic concept of extension education has completely changed. Previous frameworks regarded extension more as technology transfer, which involved the transfer of research from scientists to farmers for adoption. Modern scholarship acknowledges that extension is a multidimensional human development process that involves knowledge sharing, skills building, strengthening of community capacities, mobilization and strengthening of institutions.

This re-imagining is an explicit recognition of extension as an educational activity. There are differences between "training" (capacity building for a specific purpose), "extension" (knowledge sharing and assisted adoption) and "learning" (inculcation of knowledge and capacity building). Modern extension is more multi-dimensional and focuses on the principles of adult learning, on emotional involvement and behavioral change, rather than simply gaining knowledge.

3.2 Educational Theories Undergirding Extension Practice

3.2.1 Transformative Learning Theory

The transformative learning theory suggests that learning is a process of basic paradigm change, or changes in the way people sense, interpret, and understand meaning and realities. Transformation takes place when there are "disorienting dilemmas" that call into question the status quo which forces critical reflection and perspective changing. In agriculture, climate variability or market changes or pest pressures put into a confusing dilemma if one needs to have new understandings and behaviors.

Extension education based on transformative learning sets the intention to provide a safe learning environment for farmers to challenge practices' assumptions. Facilitators do not prescriptively recommend adoption, but rather, reflect on what is already known, what is

missing, what other approaches might be available and what the implications of change are. This means that there are shifts needed in the nature of extension agent training, beyond content to facilitative skills that aid in thinking critically, examining perspectives, and changing behavior.

3.2.2 Experiential Learning Theory

Experiential learning is based on learning cycles of concrete experience, reflective observation, abstract conceptualization and active experimentation. The extension modules based on demonstration plots, farmer-led trials and field-based practice are of their nature experiential learning-based extension systems. Studies show that learning by doing and learning by doing together create an even deeper understanding and higher potential for adoption than a lecture. Farmer field schools are a good example of experiential learning because farmers run demonstration sites during growing seasons, observe outcomes, share with each other and the facilitator, hypothesize how things work, and implement innovations in subsequent seasons. This discovery-based approach will build farmer confidence, problem-solving skills, and create innovations that are specific to their context.

3.2.3 Diffusion of Innovations Theory

Diffusion of innovations frameworks describe the diffusion process in populations and identify factors that affect the adoption decisions. Extension uses diffusion theory to appreciate the characteristics of the innovations (relative advantage, compatibility, trialability, observability, complexity), the groups of adopters (innovators through laggards), and the channels for transmitting knowledge (how to). These factors can inform extension professionals in designing more effective adoption promotion strategies, tailoring messages to various segments of farmers, and harnessing farmers' peer networks to drive adoption.

3.2.4 Constructivist and Participatory Learning Approaches

Constructivism focuses on students actively building knowledge through experience and reflection, and social interaction, instead of simply accepting information that is passed on. Participatory approaches acknowledge the farmers as people who hold knowledge and whose experience, observations and innovations are equal contributors to the learning processes as technical skills. Integration of indigenous knowledge is a crucial constructivist application as it allows extension systems to respect and value indigenous knowledge, which can be linked to scientific knowledge (Pedzisai, 2026).

3.2.5 Adult Learning Theory (Andragogy)

The principles of adult learning are also considered by farmers as autonomous learners, who are the agents of their own learning; experiences and values are valued; practical problem solving is encouraged rather than theoretical learning; and farmers' motivation and aspiration are taken into consideration. Extension education based on andragogy principles uses learning contracts, extends the concept of peer teaching, builds a collaborative learning atmosphere instead of a hierarchical one, and connects extension to farmers' priorities. The research project conducted in buffalo husbandry training shows that the targeted training can effectively create big knowledge gain with maximal improvement in the practical training areas such as feeding and nutrition, breeding and marketing etc., and minimal in more complex areas (Makarabbi et al., 2025).

4. EVOLUTION OF AGRICULTURAL AND LIVESTOCK EXTENSION EDUCATION SYSTEMS

4.1 Traditional Extension Systems: Characteristics and Limitations

Older agricultural extension systems were based on the principles of hierarchy, one-way communication and technology transfer, and their approach had little farmer involvement in the decision-making process. These were systems that gained a great deal during the Green Revolution when they succeeded in boosting cereal yields to a dramatic degree by

disseminating improved varieties of cereals, packages of fertilizers, and irrigation technology. But these traditional methods showed some key weaknesses: the lack of responsiveness to farmer problems, a lack of focus on variation at the local level, a lack of farmer agency and innovation, a lack of a sustainability focus, and the failure to deal with problems that required multi-domain solutions.

4.2 Training and Visit (T&V) Model: Structure, Achievements, and Criticisms

The T&V system institutionalized extension services delivery using farmer group extension contact schedules, the subjects training system, and the focus on real technology transfers. Despite the potential in targeted areas and crops for high productivity, especially with regards to technologies that farmers could readily adopt because they benefited them visibly, T&V systems suffered from a number of persistent shortcomings: a lack of flexibility due to rigid technology packages, excessive staffing needs making them unsustainable in many countries, underrepresentation of smallholder farmers and women farmers, limited incorporation of farmer innovations and low attention paid to sustainability and environmental issues.

4.3 Farmer Field Schools: Experiential Learning and Empowerment

Farmer field schools began as intentional innovations in the 1980s to overcome traditional extension constraints by combining participatory, season-long, and field-based learning groups. FFS approaches use discovery learning methods in which farmers carry out field experiments, observe the results, analyze the information and then draw conclusions of their own, applicable to their own situation. Facilitators facilitate learning processes without offering solutions, design opportunities to express farmer knowledge and engage in farmer problem solving.

The effectiveness of FFS has been documented extensively through research, including in relation to improving farmer knowledge, encouraging sustainable practices (especially IPM), improving diet diversity (nutrition sensitive agriculture) and developing empowerment outcomes such as farmers' self-confidence, leadership capacity and collective action capacity. Important to note, however, is that knowledge gains is the most consistent FFS outcome, whereas more diffuse longer-term adoption and scaling effects are more variable across contexts, underscoring the need for additional institutional and policy support. In the past three decades, FFS expansion has been amazing, from early use in East Asia to hundreds of thousands of schools in Africa, South Asia, Latin America and the Pacific. However, there is still a lot of room for differences in the quality, fidelity and cost-effectiveness of FFS.

4.4 Participatory Extension Approaches and Community Mobilization

In addition to FFS, participation-based extension systems promote farmers' participation in problem diagnosis, solution design, and implementation. Participatory technology development processes involve farmers at every stage of the innovation process: from problem identification, to testing technologies, to scaling up technologies that are successful. The methodologies of participatory rural appraisal (PRA) allow communities to analyze their situation, to establish their priorities, and to come up with solutions suited to local needs. Community based extension models involve the use of community members as extension facilitators, thereby lowering expenses but harnessing the social capital and trust.

Participatory methods work very well for “messy” problems that need a multi-layered approach, multiple farmer preferences or a high level of emphasis on strong sustainability. But participatory processes take time, facilitation expertise and institutional buy-in – which is sometimes underestimated in extension planning.

4.5 Privatization of Extension Services and Diversified Actors

Extension service delivery has been going through a gradual shift since the 1990s, from reliance on government extension staff to the involvement of non-governmental organizations (NGOs), private agribusiness sector and farmer organizations. This pluralization is driven by several

factors, such as constraints on government budgets, the supposed performance gains of specialized providers, sectoral/technological concentration and ideology. The growth of NGO extension has been widespread with many cases of innovation, flexibility, and community involvement, yet is frequently constrained by concerns about sustainability issues and geographic gaps.

In the private sector, extension may be delivered by input suppliers, commodity traders and processors, and are always focused on product uptake and customer service, however, with farmer wellbeing considerations being secondary, there is the risk of misalignment. Agribusiness extension is becoming more focused on capital and resource-rich commercial farmers and ignoring the small farmers, which can exacerbate rural inequalities (Briones & Espineli, 2022).

4.6 Digital Transformation in Extension Education

Extension opportunities have changed radically in the 21st century, due to the revolution in information access, communication technologies and data analytics capabilities. Today, with the proliferation of mobile phones, the expansion of the Internet and the new applications of artificial intelligence, extension opportunities that were unimaginable 20 years ago are available. SMS advisory systems provide farmers with weather information, pest information and market prices directly on their phones. Crop disease diagnosis, pest identification, and crop management solutions via mobile applications are available anywhere at any time. Video platforms help facilitate farmer-to-farmer learning over distance. Satellite data, weather information, and historical records are fed into AI algorithms to provide tailored advice for individual fields (Priya et al., 2025).

Digital extension offers great potential benefits such as better scalability, cost reduction per farmer achieved, delivery of information in real time, and geographical access to farmers in remote areas. However, digital divides (such as limited access to the internet, poor electricity networks, lack of digital literacy, and language barriers) limit the benefits to wealthier and more educated populations. Investment in digital infrastructure, farmer digital literacy, translation of digital resources into local languages and integration with complementary extension services are all key in a digital extension strategy.

5. EXTENSION EDUCATION'S CONTRIBUTION TO RURAL CAPACITY BUILDING AND HUMAN CAPITAL DEVELOPMENT

5.1 Knowledge Enhancement and Technical Skill Development

Extension's most direct role can be knowledge transfer and skill building in agriculture. The farmers' knowledge of improved varieties, sustainable practices, climate-smart agriculture, and enterprise management are well documented to be highly associated with extension contact. Farmer field school have an even more significant knowledge gains, as 50% knowledge improvement in farmer field schools' participants compared to non-participants is documented in India. Knowledge enhancement takes place not just the content but also by understanding the mechanisms so that farmers can troubleshoot issues and be able to tailor recommendations to local conditions.

Skill developments include a variety of skills, such as agronomic practices (planting, fertilization, pest management), livestock husbandry (breeding, feeding, health care, milk quality), post-harvest management, soil and water conservation, and farm business management. Extension education can enhance skill competency through demonstration, guided practice and feedback on performance, pedagogies that work well for enhancing skills. Synthesis from buffalo husbandry training indicates that targeted training creates significant knowledge gains, particularly in practical areas (feeding and nutrition, breeding, marketing) and less in the more complex areas (Makarabbi et al., 2025).

5.2 Farmer Empowerment and Enhanced Agency

Extension education also helps farmers to become empowered, defined by an improved ability to take decisions, improve their livelihood and engage in processes that can impact on their lives beyond knowledge and skills. Empowerment is defined across a number of fronts, including the economic (earning employment income); the social (the respect and voice that they have in communities); the psychological (self-confidence); and the political (participation in decision making).

Extension's contributions to empowerment on dimensions of extension are documented in research. The addition of farmer field schools' boosts farmers' perceived self-efficacy and self-confidence, improves farmers' problem-solving skills and their desire to try innovations. Gender-transformative extension strategies that explicitly aim to change social norms that affect gender equality lead to tangible improvements in empowerment. Leadership development is another dimension of empowerment, and extension is playing a role in farmers' empowerment as leaders of farmers groups, community extension facilitators and leaders of farmer organizations.

Empowerment results vary, however, and are dependent upon context. Extension programs on empowerment may also need to be complemented by institutional support in terms of group membership, policy support, access to credit and market linkages to achieve ongoing livelihood gains.

5.3 Gender and Youth Inclusion in Agricultural Extension

Women farmers and young people have been traditionally neglected in extension systems, even though they play significant roles in agricultural production and contribute to sustainable agriculture in the future. Multiple barriers account for the lower extension access of women farmers, such as cultural norms that limit women's access to fields, male extension agents' discomfort in interacting with female farmers, the lack of focus on crops and enterprises that are of particular interest for women, and the limited availability of women farmers' time because of their reproductive responsibilities.

Gender-inclusive extension education deliberately reaches out to women, provides women with equal opportunities to access information and participation in extension, takes into account gender-specific challenges (such as credit access, land access, workload), and fosters women-to-women peer groups. Numerous studies have found that gender-inclusive extension leads to increased uptake of sustainable practices by women, better household food security, and greater empowerment in income control and decision-making for women (Ayuya et al. 2025).

A youth-involvement in agriculture is another important priority. Agricultural sustainability and rural livelihoods are at risk if the young generation in rural areas are not interested in farming. If the young generation in rural areas are not interested in agriculture, it jeopardizes the sustainability of agriculture and the rural livelihoods. Youth extension requires a new approach using strategies focused on youth entrepreneurship, technology uptake, youth market connections, and matching youth aspirations for income and social status. Youth-inclusive extension holds promise to draw young people into viable agricultural business avenues and add innovation and vitality.

5.4 Community-Based Capacity Building and Collective Action

Extension increasingly functions at community level, developing the capacity to act together, to strengthen farmer groups, and innovate institutions. In the extension approach that emphasizes community, participatory learning, peer teaching, community problem diagnosis, and community solution design are integral components. Community extension facilitators, who are drawn from the community, use social capital, cultural familiarity and the fact that they are constantly present that external extension workers are not able to use.

Farmer cooperatives and farmer organizations are platforms for extension delivery and also contribute to social capital, access to inputs, farmer marketing, and increased voice in policy processes. Extension's role in strengthening cooperatives and improving farmer organization effectiveness is well documented, contributing to improved access to markets and inputs and to production sharing.

5.5 Integration of Indigenous and Local Knowledge Systems

Indigenous and local knowledge are now considered as part of the scientific knowledge and have value in contemporary extension, as the farmers have developed their ecological knowledge, through generations, to be of a sophisticated level (Pedzisai, 2026). The integration approaches focus on facilitating dialogue between the two knowledge systems (indigenous and scientific) so that farmers can critically assess both knowledge systems and create locally appropriate solutions that combine the two knowledge sources.

Extension benefits from integration in terms of cultural appropriateness, increased farmer confidence and involvement, the recognition of local knowledge and experience, and the potential for innovations that would not be created by either knowledge system alone. But there is a need to be conscious of inequalities in power dynamics between indigenous and scientific knowledge if we are not interested in unintentional tokenism.

6. LIVESTOCK EXTENSION EDUCATION SYSTEMS AND CAPACITY DEVELOPMENT

6.1 Livestock Extension: Concept, Scope, and Significance

Livestock extension includes education and advising in the dairy, poultry, small ruminant, beef and fish production systems. In drylands, livestock plays a central role in food security, livelihoods generation, asset building and risk management, with livestock accounting for 20-40% of farm income in developing countries. Although livestock have played an important role in the economic life of the nation, the role of livestock has been given less attention than the production of crops and only in the pastoral and mixed farming areas.

The production of livestock is different from the production of crops in several ways: it takes longer to produce a livestock product, there is a higher capital investment component, more biological complexity, and the integration of livestock and crop and natural resource management. Extension is at the forefront of critical livestock health concern; zoonotic disease prevention, biosecurity management and vaccination uptake all have an impact on herd productivity, food safety, and rural wellbeing (Teshome & Maraim, 2025).

6.2 Dairy Extension and Productivity Enhancement

Dairy is a significant extension focus due to its role in the nutritional portfolio, income generation, rural livelihoods and women's economic engagement. The major topics of dairy extension education are breeding (genetic improvement through artificial insemination and bull selection), feeding (balanced nutrition for production and reproduction), health management (prevention, vaccination and treatment of diseases), milk quality and safety, reproduction management, and enterprise economics.

Extension effects on dairy productivity are documented – better genetics, nutrition and health in smallholder dairy systems lead to 20-40% increases in productivity. The gender dimensions of dairy extension are worthy of special attention as women play a significant role in milk production and processing in many areas, but they lack access to extension. Women-centric dairy extension that creates knowledge on animal feed, breeding and management practices of animal health has been shown to positively influence nutrition outcomes and women's income control (Pathak et al., 2025).

6.3 Poultry and Small Ruminant Extension

As an extension of other farming enterprises, poultry and small ruminant extension are important livelihoods for resource-poor farmers, women and youth due to the relatively low

capital needed when compared to dairy and cattle production. Poultry extension includes breed selection, feeding and nutrition, disease prevention (Newcastle disease vaccination, biosecurity), housing and entrepreneurship. For sheep and goats (small ruminant extension) similar domains are addressed in addition to management of the specific production characteristics of small ruminants.

Backyard poultry systems, common in many developing countries, are a specific case that shows great potential to be a starting point for extension to the poultry-keeping household, especially women. Extension implements simple management practices, like providing adequate housing, improved feeding, vaccinating and implementing biosecurity, which result in substantial productivity gains at low capital cost (Mithun et al., 2026).

6.4 Livestock Health and Biosecurity Education

Animal health is a key frontier for extension. Livestock diseases represent a huge economic cost to developing country agriculture and zoonotic disease transmission poses public health concerns. Extension on biosecurity (farm management practices to prevent disease introduction and spread) is a high impact and underutilized intervention. Farmer-led research reveals limited biosecurity uptake in smallholder systems, due to gaps in knowledge and competing livelihood needs (Teshome & Maraim, 2025).

The need for antimicrobial stewardship education is a new extension imperative. Underuse, overuse and non-essential self-treatment of poultry by consumers, as well as overuse for growth promotion purposes, contribute to the spread of antimicrobials resistance, which poses a risk to human and animal health worldwide. Extension and judicious use of antimicrobials, focus on vaccinations, and better husbandry represent a critical public health intervention (Das et al., 2025).

6.5 Climate-Smart Livestock Extension

The impacts of climate change are especially significant to the livestock sector (changing pasture availability, more heat stress, changing disease patterns, water scarcity). Climate-smart livestock extension supports adaptations such as better feed resources (forage conservation, crop residue management, supplementary feeding), reproductive management, better breed adapted to heat and disease tolerance, water harvesting, and integrated crop-livestock systems. Extension interventions that support these adaptations can be effective in increasing productivity and climate resilient (Pranadita & Purwanti, 2026).

6.6 Challenges in Livestock Extension Delivery

Livestock extension faces unique problems in comparison to crop extension. Limitations in veterinary workforce, especially in developing countries where veterinary professional scarcity affects availability of services reduces extension capacity. Improvements often necessitate behavior change, capital investment or a threat to traditional practices and therefore farmer adoption of livestock innovations can be slow to follow. Extension effectiveness is limited in remote livestock areas by infrastructure related constraints such as poor extension facilities, lack of demonstration capacity and transport problems.

7. DIGITAL TRANSFORMATION AND SMART EXTENSION SYSTEMS

7.1 Information and Communication Technology Integration

Digital technologies have revolutionized extension potential and availability to farmers. In many developing regions, farmers possess mobile phones that are owned by 80-90% of them and are used to deliver real-time information (Priya et al., 2025). SMS advisory systems are those that send farmers information on weather, pest, market prices, and management advice to their mobile phones. Mobile applications give full agri-information ranging from crop disease diagnosis using image recognition, identification of pests and diseases, pesticide recommendations and market linkage information, to weather related planting advisories.

The opportunity to scale ICT extension is illustrated by the mKisan project in India, digital agriculture projects in Africa, and the global presence of Digital Green. Results from studies in various regions show that the effectiveness of mobile-based advice is supported by evidence of increased access to information, quicker decision making, lower waste of inputs, and higher productivity gains of 20-30% by the farmers themselves. Farmer-to-farmer learning, which was previously difficult to scale, is made possible with WhatsApp and social media, allowing farmers to share knowledge and create peer support groups.

7.2 Artificial Intelligence and Data-Driven Extension

AI uses in extension are a new frontier. The AI systems can process a wide range of information, such as weather data, satellite imagery, soil properties, crop history, and market trends, and provide tailored advice for individual farms and farmers. Machine learning algorithms are able to learn from the data they have accumulated, making better recommendations over time. The chatbots offer round-the-clock assistance, answering farmers' inquiries and offering advice in local languages.

Big data and precision agriculture technologies (remote sensing, soil moisture sensors and variable-rate application systems) allow for the generation of vast amounts of data that can be used to inform management decisions. Extension professionals need skills in data interpretation, technology handling and in assisting farmers to interpret and implement data-based recommendations and suggestions, which are becoming more common.

7.3 Precision Agriculture and Sensor-Based Technologies

Precision agriculture involves sensors, GPS and data analysis for site specific management. The sensors (IoT – Internet of Things) provide real-time data on soil moisture, temperature, nutrient levels and pest populations to farmer's phone or computer. Crop stress, disease and pest issues can be detected with drone-based remote sensing, allowing for targeted interventions. Weather station networks deliver hyperlocal weather information to enhance agricultural decision-making. These technologies allow significant cuts in input and higher yields with better conservation of resources (Singh, 2026).

However, the availability of precision agriculture technology is still restricted due to cost, digital literacy and infrastructure. Extension systems need to be strengthened to facilitate the farmers' ability to understand and adopt technology.

7.4 Informal Learning, Social Media, and Peer Networks

Farmers are now getting agricultural information from social media, You Tube agriculture channels and Facebook farmer communities, besides formal digital platform. The channels of informal learning allow knowledge to be shared between peers, created by the farmers themselves and spread quickly. Farmer influencers, early adopters who share their experiences in social media can be more powerful models than formal extension messages.

Whilst there is a need for deliberate extension system integration with social media, this will involve quality content promotion, monitoring misinformation, building peer networks and assisting farmers to manage digital information environment. For the knowledge sharing power of social media to be effective, risks associated with unchecked information and technology hype need to be managed.

7.5 Digital Extension Opportunities and Risks

The impact of digital extension is undeniable: it offers a dramatic improvement in scalability, a lower cost for each farmer, real-time information and geographical reach for remote farmers. However, the benefits of digital divides (low access to internet, low quality of electricity services, low level of digital literacy, language barriers) are felt by the favored population the most (Priya et al., 2025).

The risks identified are that digital extension is overrated in terms of impact and underrated in terms of implementation; it can create greater rural–urban and rich–poor gaps if digital

extension services benefits the better off farmers; there is a lack of human connection and contextual understanding in digital extension; the sustainability of digital extension services in terms of funding of the platforms and capacity development; a risk of private company domination of digital extension that affects the autonomy of farmers.

Digital extension needs to be accompanied by investment in infrastructure, digital literacy, content localization, and face-to-face extension integration. The use of digital and traditional extension is not competitive.

8. EXTENSION EDUCATION FOR SUSTAINABLE DEVELOPMENT

8.1 Extension and Sustainable Agriculture Paradigms

Sustainable agriculture is the reconceptualization of agriculture at a basic level to becoming environmentally responsible, economically viable and socially just. The extension education for sustainable agriculture fosters natural resource conservation, soil health, less use of external chemicals, biodiversity protection, and livelihoods resilience. Conservation agriculture (minimized tillage, crop residue retention, crop rotation) cuts down on erosion, water needs, and labour expenses and keeps yields up.

Agroecological approaches involve the use of ecological principles in farming systems, substituting external inputs for ecosystem services. Farmer field schools focused on agroecology are effective in supporting sustainable intensification, whereby productivity gains can be achieved with better management practices, while minimizing the environmental footprint. The use of pesticides is minimized, and pest control is achieved through ecosystem approaches, using extensive extension programs for Integrated pest management.

8.2 Extension Education and Food Security

Food security is enhanced via multiple pathways of Extension, including production enhancement to increase food availability within households, diversified production to increase dietary diversity and nutrition, food storage and processing to decrease post-harvest losses, market engagement to generate income for food purchases, and decreasing production risks for regular food access.

Nutrition-sensitive agriculture extension explicitly includes nutrition goals in agriculture extension. Nutrition-sensitive approaches build in dietary diversity both with homestead food production and women's participation (due to women's centrality in nutrition decisions) as well as by growing nutrient rich crops, rather than prioritizing productivity. Nutrition-sensitive agriculture extension has been well documented to increase dietary diversity and decrease stunting, especially the impact on women and children.

8.3 Climate Change Adaptation Education

Climate change is likely one of the main agricultural extension issues of the next few decades. Extension plays critical roles to help farmers understand climate change, adopt climate-smart practices and improve their adaptive capacity for livelihoods resilience in the face of climate variability and change.

Extension for Climate Smart Agriculture (CSA) focuses on practices that have multiple impacts such as productivity improvement, adaptation to climate change and mitigating greenhouse gas emissions. Specific practices include agroforestry, soil conservation, efficient irrigation, crop diversification, drought resilient varieties and better livestock management. Farmer confidence and adoption is fostered by extension that demonstrates effectiveness of climate-smart practice using farmer field trials, demonstration plots and farmer testimonials.

8.4 Extension's Contributions to Sustainable Development Goals

Extension education is directly linked to several SDG's. Extension increases the productivity of agriculture and incomes in the rural sector (SDG 1 (No poverty)). Extension is a key part of SDG 2 (Zero Hunger). Extension has the potential to contribute to SDG 4 (Quality Education) through extension of lifelong learning and digital literacy. Women empowerment through

gender transformative extension is a good example of the benefit of SDG 5 (Gender Equality). In the SDG 13 (Climate Action) SDG directly relies on extension enabling climate adaptation and mitigation. Extension contributions include SDG water, economic growth, health and ecosystem protection.

8.5 Circular Economy and Green Extension Systems

Circular economy strategies are new ideas that rethink the way in which agriculture is done, shifting from open loop systems in which waste is generated to closed loop systems in which resources are maximizing cycled. Byproducts (crop residues, manure) can be used as inputs instead of wastes, and this is what extension promoting bio-economic circularity will help farmers do. Circular approaches with multiple benefits include integrated crop-livestock systems, agroforestry – a combination of trees and crops, and aquaponics – which involves fish production and vegetable cultivation.

Green extension systems are intentional systems that promote environmental sustainability—a sign of extension's transformation to explicitly address ecological concerns. The central challenge in green extension is to shift the focus of agricultural issues from production to more encompassing issues such as health of ecosystems, water quality, conservation of biodiversity, and effects on climate change (Teshome & Maraim, 2025).

9. CHALLENGES, BARRIERS, AND CONSTRAINTS IN EXTENSION EDUCATION

9.1 Institutional and Governance Challenges

The endemic institutional limitations to effectiveness are a problem for extension systems. Extension service delivery is limited by weak governance, which is defined as unclear policies, limited accountability and poor coordination. Lack of policy coordination between agricultural extension, research and development sectors results in misaligned objectives and multiplication of efforts. Extension systems' history of collaboration with production oriented ministries does not sufficiently incorporate sustainability and livelihood resilience perspectives.

Decentralization, in the form of institutional fragmentation, where extension is provided by multiple public organizations, NGOs and/or private organizations with no clearly established lines of coordination, leads to duplication, gaps and inefficiency. Public-private partnerships can have the potential to be effective, but they can be just as informal and unsustainable if they are not deliberately structured to have governance.

9.2 Financial Constraints and Sustainability Challenges

The greatest constraint for extension is unmet funding needs, in all parts of the world. In many countries, there is no increase or even a decrease in government extension budgets while demands are increasing. There is not enough funding to recruit and retain extension staff, farmers' contact is limited, there is a lack of demonstration capacity and the ability to adopt modern technologies and pedagogies is limited.

Sustainability issues are raised by donor dependence, as extension heavily relies on project-based external funding. Programs thrive with the funding and die with the funding. Extension financing is often regressive, and cost-sharing arrangements that seek to involve farmers in extension financing further limit poor farmers' access to extension. Financing mechanisms for sustainable extension are still underdeveloped, and are a balance between public funding and farmer/user payments.

9.3 Human Resource Limitations and Extension Worker Capacity

HR issues are critical for Extension systems. Extension agent numbers are also often too low (1:1000 or more in developing countries) to limit reach. Qualities are limited due to the lack of extension workers' pedagogical skills, involvement of farmers and the lack of knowledge on sustainability issues. Inadequate compensation and lack of career opportunities lead to agent turnover and institutional knowledge loss and service discontinuity.

Extension workers, especially in developing countries, are typically less than 20% female, limiting extension's ability to reach women farmers. Extension staff is, at best, not representative of the communities they serve, and the recruitment and inclusion of minorities is limited.

9.4 Socioeconomic Barriers Constraining Farmer Participation

Extension is limited by the socioeconomic situation of farmers. Farmers' capital is constrained by poverty to acquire inputs and adopt technology. Low levels of education and illiteracy restrict access to written information and complex information. Women's participation in extension is constrained by gender inequalities such as limited mobility, access to land, and household labour. There are differences across age groups and generations in the adoption of technology and the preference for information sources.

Extension access is highly skewed by socioeconomic factors: large landholders get five times the contact as the marginal farmers, and women, one-quarter the contact as men. These inequalities continue to drive inequality, not inclusive development.

9.5 Technological and Infrastructure Barriers

Technological and infrastructural limitations are significant problems in developing countries. Rural road conditions restrict mobility of extension agents and implementation of the demonstrations. Digital extension sustainability is impacted by unreliable electricity. Demand for water is high, limiting the availability of demonstration and on-farm technology.

Barriers to digital extension are faced are limited internet access and connectivity, not enough electricity infrastructure, not enough telephone coverage in remote areas and high technology costs. Such barriers disproportionately impact the resource-poor farmers who are most in need of extension services (Priya et al., 2025).

9.6 Policy and Governance Constraints

Extension systems function and are situated in a policy landscape that is typically not conducive to extension effectiveness. Extension policies often fail to be specific on goals, targets and quality of service. Extension has limited policy support for participatory approaches, sustainability focus, or gender equality, which limits extension's ability to focus on these goals. There is weak monitoring/assessment which affects learning and continuous improvement.

Sometimes regulatory requirements or restrictions can impede digital extension, such as agricultural laws that limit access to pesticide information, telecommunications laws that limit SMS service, or data governance policies that limit access to information. There is still limited policy co-ordination between sectors, with agricultural policies, water policies and environmental policies rarely aligned, and with no co-ordination through the extension system.

10. EMERGING TRENDS AND FUTURE DIRECTIONS IN EXTENSION EDUCATION

10.1 Smart and Digital Extension Ecosystems

Future extension more and more functions in digital ecosystems that bring together various technologies, data sources, and providers. Information access and personalization will be revolutionized with AI-driven systems, big data analytics, IoT sensors, blockchain for supply chain transparency, and digital platforms, all of which will provide unprecedented access to information and personalized services (Priya et al., 2025). Extension professionals of the future need to be equipped with the skills to facilitate technology, interpret data, and be digital citizens, not the knowledge of extension content.

Complementing digital infrastructure investments with investments in digital extension literacy, content localization, cyber security, and data governance are essential for effective digital extension ecosystems. Sustainability of digital extension requires business models that

go beyond the externally funded project to fee-for-service or government-supported systems that can provide sustainability over time.

10.2 Competency-Based Extension Education

More and more, future extension utilizes competency-based models that specify desired learning outcomes in terms of competency and measure the attainment of competency instead of just training attendance. Extension education should be based on the development of knowledge, skills and attitudes as defined in competency frameworks. Competency-based approaches provide the opportunity for focused skill development, empower adult learners to be self-directed, and enhance accountability for extension effectiveness (Makarabbi et al., 2025).

Extension professional skills should cover the capabilities of being digitally literate, a climate change adaptation facilitator, inclusive educator, systems thinker, and adaptive manager. Climate-smart agriculture skills, digital tools, resource management and entrepreneurial skills for agricultural transformation are relevant farmer competencies.

10.3 Climate-Resilient Extension Systems

Extension education has a new role, to teach adaptation, mitigation and resilience to climate change and not just productivity maximization. Climate-resilient extension education is the incorporation of climate science, seasonal forecasting, crop-livestock diversification, water management, and renewable energy into extension programming. Extension services need to move from a blanket advisory to a more participatory approach to risk assessment and adaptation planning, taking into account farmer indigenous knowledge, climatic projections and livelihood diversification strategies, and tailored to the location.

Extension's role in climate adaptation is not limited to just providing technical information, but also involves helping institutions innovate, value chains adapt, and ecosystem services are conserved, all of which are important for long-term agricultural sustainability in the face of climatic variability.

10.4 University–Extension–Industry Linkages

The triple helix collaboration model has been increasingly emerged where universities, extension systems and private sector actors are collaborating to generate innovations, develop technologies, and provide farmer education with market orientation (Ewane et al., 2026). These partnerships combine the ability of the university to carry out research, the extension system for outreach, and agribusiness for market access, which allows for rapid innovation scaling. A triple helix collaboration, however, is not a simple task and has to be governed with a public interest protection, equity of farmer benefits, and small-holder inclusion besides commercial goals.

10.5 Personalized Farmer Learning Systems

Adaptive learning platforms are new platforms that use farmer characteristics (farm size, crops grown, digital literacy, farmer learning preferences) to tailor extension messages, delivery channels and intensity of services. The use of personalized systems enhances relevance and uptake potential and takes into consideration farmer diversity. AI-powered platforms that process farmer information can provide personalized farming management advice, anticipate farmer information requirements and adjust service delivery as needed.

10.6 Research Gaps and Future Research Priorities

Despite the importance of extension education, there are still significant gaps in the research that hinder the ability to make evidence-based system improvements. Longitudinal studies with the consequences of extension education on farmer livelihoods and food security and environmental sustainability are still limited, especially in the context of developing countries. The studies that combine education and agricultural and social science are still inadequate, which hinders the theoretical development and innovation of practice.

Although livestock play an important role in developing country food security and rural livelihoods, livestock extension education research is still rather underdeveloped compared to crop extension. Further research is needed to assess the effectiveness of digital extension, specifically in terms of the accessibility and uptake of the extension services by small-holder farmers. Extension education's contributions to sustainability, in the context of climate adaptation and protection of ecosystems, requires expansion of research.

11. POLICY IMPLICATIONS AND RECOMMENDATIONS

11.1 Strengthening National Extension Systems

Governments need to invest in the capacity and staffing of extension services and enhance institutional development of functional and accountable extension services that provide farmer oriented education. What is needed are long-term funding commitments instead of financing based on projects, professional training of extension educators at the university level, and a reform of extension system governance to increase responsiveness and accountability to the farmers. National extension programmes should focus on the inclusion of smallholder farmers, especially women and youth to create smallholder farmer development opportunities and establish agricultural human capital to support food security and rural development.

11.2 Digital Infrastructure and Inclusion Policies

Government investment in rural broadband infrastructure, farmer training programs on digital literacy and financial access to digital devices to ensure equity in technology adoption is complementary to digital extension expansion. Policies need to include gender, age and socioeconomic-based digital divides, and ensure women, youth, older farmers, and poor producers are able to access and benefit from digital extension services. The rules and regulations (R&Rs) that regulate the farming information and data sector should ensure innovation is encouraged, whilst also protecting the farmer and ensuring data security.

11.3 Capacity Development and Workforce Programs

Incorporate concepts on adult learning theory, climate science and the use of digital technologies and social inclusion principles within extension educator training programs for governments and development partners to prepare extension professionals for the delivery of extension in the modern era. Livestock extension capacity needs to be increased in veterinary workforce development programmes, especially in developing countries where there is a shortage of veterinary professionals. Formal extension can be extended cost effectively with support programs to enable development of farmer trainers, to engage community health workers, and to engage farmer-to-farmer extension.

11.4 Public-Private Partnership Frameworks

Governments need to develop policies to define roles, responsibilities, and farmer benefits sharing in public/private extension partnerships. These need to take into account smallholders' interests, guarantee information quality and independence, and avoid commercial bias that reduces farmer agency. Effective accountability mechanisms, which should be transparent, should be in place to track equity, effectiveness and sustainability aspects of PPP extension, to ensure that no partnership takes advantage of farmer vulnerabilities or information asymmetries.

11.5 Sustainable Financing Models

The need for extension system sustainability requires a diversity of financing models, and a reduction in reliance on international donors. Sustainable revenue streams result from fee for service extension services for commercial farmers, government-subsidized extension for smallholders, results-based financing for extension services that pay for results, and farmer cooperative self-financing. Accessibility and equity, however, must be ensured through financing mechanisms, particularly by not discriminating on fees on the basis of who needs extension assistance most, which are generally the resource poor smallholders.

12. CONCLUSION

Agricultural and livestock extension education is entering a pivotal moment where its role in traditional knowledge dissemination falls short of meeting the needs of current development challenges requiring comprehensive agricultural-pedagogical innovation, sustainability focus and inclusive digitalization. This review has highlighted evidence that extension education is evolving from transfer-of-technology to participatory, transformative and digitally supported systems, and that this comes from the broader paradigm shift in education that acknowledges farmer agency, experiential learning and the integration of contextual knowledge as essential to the effective provision of extension.

Extension education appears to be an indispensable asset for agricultural transformation, rural human capital development and achieving sustainable development given the compounding nature of food security needs, climate change adaptation needs, and the goals of rural development. To achieve this, however, institutional development, technology innovation, reform of the financing system, and policy integration are needed, all at once, to make extension systems truly responsive to farmer needs, promote sustainability, and participate equitably in rural development and food security.

Extension systems of the future will need to break out of disciplinary barriers, incorporate digital technologies, climate knowledge, and participatory extension practices, and integrate agricultural, educational, and sustainability science. This requires the participation of university/extension/industry partnerships, extension system funding and governance reforms and a focus on the farmer, with extension education being relevant to farmer needs and aspirations. In the next decade, a shift in extension education from a project-based and extensions-dependent mode to an institutionalized and farmer-driven and digitally supported and sustainability-focused mode is both necessary and great opportunity to agricultural and rural development.

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