Review Article

Role of Agricultural Extension in Addressing Food Security: Examining the Contributions of Extension Services to Achieving Food Security Goals

ABSTRACT

Agricultural extension services play a pivotal role in global efforts to achieve food security, acting as a critical link between research, farmers, and policymakers. This comprehensive review examines the multifaceted contributions of agricultural extension to food security goals, drawing on theoretical frameworks, empirical evidence, and case studies from diverse global contexts. This paper explores how extension services address the four dimensions of food security: availability, access, utilization, and stability. It analyses the evolution of extension models, from traditional top-down approaches to participatory and market-led systems, assessing their relative effectiveness in enhancing agricultural productivity and food security. This review paper highlights innovative practices, including the integration of information and communication technologies (ICT), community-based approaches, and public-private partnerships, which have shown promise in overcoming persistent challenges. The case studies from both developed and developing countries provide insights into successful strategies and their impacts on crop yields, farmer incomes, and nutritional outcomes. This paper also addresses critical challenges facing extension services, including financial constraints, technological barriers, and socio-cultural issues, proposing potential solutions and policy recommendations. By synthesizing current knowledge and identifying future research directions, this review underscores the indispensable role of agricultural extension in achieving global food security goals and emphasizes the need for continued innovation and adaptation in extension practices to meet evolving challenges in the agricultural sector.

Keywords: Agricultural Extension, Food Security, Knowledge Transfer, Participatory Approaches, Agricultural Innovation

Introduction

Agricultural extension services play a pivotal role in the global efforts to achieve food security, which is defined by the United Nations as a situation when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life. As the world's population continues to grow, with projections reaching 9.7 billion by 2050, the pressure on agricultural systems to produce more food sustainably is intensifying. This challenge is exacerbated by

factors such as climate change, soil degradation, water scarcity, and socio-economic inequalities. Agricultural extension refers to the systematic process of disseminating information, skills, and technologies to farmers to improve their productivity, sustainability, and livelihoods. This process involves a range of activities, including education and training, technical assistance, and policy advocacy. Extension services aim to bridge the gap between research and practice by ensuring that farmers have access to the latest scientific knowledge and innovations that can enhance their agricultural practices. Agricultural extension services play a critical role in enhancing food security, particularly in developing regions where smallholder farmers are predominant. These services are designed to transfer knowledge, skills, and technologies from research institutions to farmers, thereby improving agricultural productivity, sustainability, and resilience (Anderson & Feder, 2004). As the global population continues to rise and climate change exacerbates agricultural challenges, the importance of effective agricultural extension services in achieving food security goals cannot be overstated. Food security, defined by the Food and Agriculture Organization (FAO) as having consistent access to sufficient, safe, and nutritious food to maintain a healthy and active life, is influenced by multiple factors: food availability, access, utilization, and stability (FAO, 2003). Agricultural extension services address these dimensions by providing farmers with the tools and knowledge needed to increase crop yields, diversify income sources, adopt sustainable practices, and improve food utilization through better nutrition education (Swanson & Rajalahti, 2010).

Historically, agricultural extension services have evolved from simple, top-down dissemination models to more complex and participatory approaches. Early models, such as the Training and Visit (T&V) system, emphasized regular, structured interactions between extension agents and farmers but often lacked flexibility and farmer involvement (Anderson & Feder, 2004). In contrast, contemporary models like Farmer Field Schools (FFS) and ICT-based extensions prioritize farmer participation, local knowledge, and technology integration to enhance learning and adoption rates (Davis et al., 2007; Birner et al., 2009).

Empirical evidence supports the positive impact of agricultural extension services on food security. For instance, extension programs have been shown to increase crop yields significantly. A study in Ethiopia revealed that participation in extension services increased maize yields by 32 percent on average, demonstrating the effectiveness of these interventions in boosting agricultural productivity (Benin et al., 2011). Furthermore, extension services contribute to improved household incomes and nutritional outcomes. In Bangladesh, extension

interventions focusing on rice cultivation led to increased farmer incomes, subsequently enhancing food security and reducing poverty (Ahmed, 2009).

Despite these successes, agricultural extension services face numerous challenges, including limited funding, inadequate infrastructure, and socio-cultural barriers. Addressing these challenges requires innovative approaches and policy support to ensure the sustainability and effectiveness of extension services. Innovations such as mobile-based advisory services and community-based extension models have shown promise in overcoming some of these barriers, providing farmers with timely and relevant information to improve their practices (Aker, 2011).

In conclusion, agricultural extension services are vital for achieving global food security. They provide essential support to farmers, helping them to increase productivity, adopt sustainable practices, and improve their livelihoods. By examining the contributions of extension services to food security goals, this paper aims to highlight the importance of continued investment and innovation in agricultural extension to address the ever-evolving challenges of global food security.

Historical Perspective of Agricultural Extension Services in Addressing Food Security

The historical development of agricultural extension services reflects a continuous adaptation to the evolving needs of farmers and the broader agricultural sector. From the early days of informal knowledge sharing to the modern era of digital extension, these services have played a crucial role in enhancing food security. By understanding this history, policymakers and practitioners can draw lessons to design effective and sustainable extension systems that address current and future food security challenges. Agricultural extension services have evolved significantly over the past century, adapting to the changing needs of farmers and the agricultural sector. This evolution has been driven by the necessity to address food security, which remains a critical global challenge. Understanding the historical development of these services provides valuable insights into their current role and future potential in enhancing food security.

Early Beginnings: From Informal Knowledge Sharing to Formal Extension

The concept of agricultural extension services can be traced back to informal knowledge sharing among farmers. In the early 19th century, formal agricultural education and extension began to take shape in Europe and North America. For instance, in the United Kingdom, the establishment of agricultural societies and the dissemination of best practices through pamphlets and lectures were early forms of extension (Jones & Garforth, 1997).

In the United States, the Morrill Act of 1862 laid the foundation for the land-grant university system, which played a pivotal role in agricultural research and extension. The

Smith-Lever Act of 1914 formally established the Cooperative Extension Service, linking land-grant universities with federal and state governments to provide agricultural education to farmers (Rasmussen, 2002).

The Green Revolution: Transformative Impact on Food Security

The mid-20th century witnessed the Green Revolution, a period marked by significant advancements in agricultural technology, including the development of high-yielding crop varieties, synthetic fertilizers, and pesticides. Agricultural extension services were crucial in disseminating these innovations to farmers, particularly in developing countries. The Rockefeller and Ford Foundations supported extension programs that facilitated the adoption of these technologies, leading to dramatic increases in crop productivity and food security in countries like India, Mexico, and the Philippines (Evenson & Gollin, 2003).

Role of Agricultural Extension in the Green Revolution

Agricultural extension services were instrumental in disseminating the knowledge and technologies of the Green Revolution to farmers. These services provided critical support in the following areas:

1. Technology Transfer: Extension agents facilitated the introduction and adoption of HYVs by providing farmers with seeds, demonstrating new farming techniques, and educating them about the benefits of these innovations. This direct interaction was essential in building farmer confidence and willingness to adopt new technologies (Feder, Just, & Zilberman, 1985).

2. Training and Capacity Building: Training programs were conducted to educate farmers on the proper use of chemical fertilizers and pesticides, as well as advanced irrigation practices. These programs were often delivered through workshops, field demonstrations, and farmer field schools (FFS), which allowed for hands-on learning and peer-to-peer knowledge exchange (Feder et al., 2001).

3. Advisory Services: Extension services provided ongoing advisory support to farmers, helping them troubleshoot issues related to pest management, soil fertility, and crop diseases. This support was crucial in ensuring that farmers could effectively implement new practices and achieve the desired yield improvements (Anderson & Feder, 2004).

4. Access to Inputs and Credit: Extension agents often played a role in linking farmers to sources of credit and agricultural inputs, such as fertilizers and seeds. By facilitating these connections, extension services helped overcome financial barriers to the adoption of Green Revolution technologies (Ruttan, 2002).

Impact on Food Security

The impact of the Green Revolution on food security was profound, particularly in developing countries such as India, Mexico, and the Philippines. The introduction of HYVs and improved agricultural practices led to substantial increases in crop yields, which in turn contributed to enhanced food availability and reduced hunger.

1. Increased Crop Yields: The adoption of HYVs resulted in significant yield increases for staple crops. For example, wheat yields in India nearly doubled from the mid-1960s to the mid-1970s, largely due to the adoption of Green Revolution technologies (Evenson & Gollin, 2003). Similar yield improvements were observed for rice in the Philippines and Mexico.

2. Enhanced Food Availability: The substantial increase in crop production contributed to greater food availability at both national and household levels. Countries that implemented Green Revolution technologies were able to achieve self-sufficiency in staple food production, reducing their dependence on food imports and enhancing food security (Hazell, 2010).

3. Economic Growth and Poverty Reduction: The productivity gains from the Green Revolution translated into higher incomes for farmers, particularly smallholders who adopted the new technologies. This increase in income not only improved household food security but also stimulated rural economies, leading to broader poverty reduction (Hazell & Ramasamy, 1991).

4. Nutritional Improvements: The increased availability of staple foods, combined with higher incomes, enabled households to diversify their diets and improve their nutritional status. This was particularly important in addressing malnutrition and micronutrient deficiencies in developing countries (Pingali, 2012).

Challenges and Criticisms

Despite its successes, the Green Revolution also faced several challenges and criticisms, particularly regarding its long-term sustainability and equity:

1. Environmental Degradation: The intensive use of chemical fertilizers and pesticides led to soil degradation, water pollution, and loss of biodiversity. These environmental impacts posed challenges to the sustainability of Green Revolution practices (Tilman et al., 2002).

2. Socio-Economic Disparities: The benefits of the Green Revolution were not uniformly distributed. Wealthier and larger farmers were often better positioned to adopt new technologies, leading to increased socio-economic disparities in rural areas. Smallholders and marginalized farmers sometimes faced barriers to accessing inputs and credit (Freebairn, 1995).

3. Dependence on External Inputs: The reliance on chemical inputs raised concerns about the vulnerability of farming systems to fluctuations in input prices and availability. This

dependence also had implications for the economic sustainability of farming practices (Pretty, 1995).

Lessons Learned and the Way Forward

The experiences of the Green Revolution offer valuable lessons for future agricultural extension and food security initiatives:

Holistic and Sustainable Approaches: Future extension efforts should adopt holistic approaches that integrate environmental sustainability, economic viability, and social equity. This includes promoting integrated pest management, organic farming, and agroecological practices (Pretty, 2008).

Participatory and Inclusive Extension Models: Extension services should prioritize participatory approaches that involve farmers in decision-making processes and leverage local knowledge. Inclusive models that address the needs of smallholders, women, and marginalized groups are essential for equitable development (Davis, 2008).

Leveraging Technology and Innovation: Advances in information and communication technologies (ICT) provide new opportunities for modernizing extension services. Mobile-based advisory services, digital platforms, and precision agriculture technologies can enhance the reach and effectiveness of extension programs (Aker, 2011).

The Training and Visit (T&V) System: Structured Knowledge Transfer

In the 1970s and 1980s, the Training and Visit (T&V) system emerged as a prominent model for agricultural extension. Developed by the World Bank, T&V aimed to provide regular, structured visits by extension agents to farmers, ensuring the timely transfer of knowledge and technology. While the T&V system had successes, particularly in increasing agricultural productivity, it faced criticism for its top-down approach and lack of farmer participation (Anderson et al., 2006).

Participatory Approaches and the Rise of Farmer Field Schools

In response to the limitations of the T&V system, the 1990s saw a shift towards more participatory approaches in agricultural extension. The Farmer Field School (FFS) model, pioneered by the Food and Agriculture Organization (FAO) in Southeast Asia, emphasized experiential learning and farmer-to-farmer knowledge transfer. FFS programs empowered farmers to conduct their own experiments and make informed decisions based on local conditions. This approach proved effective in promoting integrated pest management and sustainable agricultural practices (Pontius et al., 2002).

ICT and Digital Extension: Modernizing Knowledge Dissemination

The 21st century has brought about significant advancements in information and communication technologies (ICT), revolutionizing agricultural extension services. Mobile phones, the internet, and digital platforms have enabled real-time information dissemination and interactive learning. ICT-based extension services provide farmers with timely weather forecasts, market prices, and best practices, enhancing their ability to make informed decisions and improve productivity (Aker, 2011).

Current Trends: Pluralistic and Inclusive Extension Systems

Contemporary agricultural extension services are characterized by pluralism and inclusivity, involving multiple stakeholders, including government agencies, NGOs, private sector entities, and farmer organizations. This pluralistic approach recognizes the diverse needs of farmers and leverages the strengths of different actors to provide comprehensive support. Additionally, there is a growing emphasis on gender-sensitive and youth-inclusive extension services, addressing the unique challenges faced by women and young farmers (Birner et al., 2009).

Historical Perspective of Agricultural Extension Services

Participatory Approaches of Extension Services for Food Security

Participatory approaches in agricultural extension services have emerged as effective strategies to enhance food security, particularly in developing countries. These approaches prioritize farmer involvement, local knowledge, and collaborative learning, addressing the limitations of traditional top-down extension models. Participatory approaches in agricultural extension have made substantial contributions to food security by enhancing productivity, sustainability, and resilience. By continuing to innovate and address existing challenges, these approaches can play a vital role in achieving global food security goals.

The Evolution of Participatory Extension Approaches

Participatory approaches in agricultural extension gained prominence in the 1980s and 1990s as a response to the shortcomings of conventional extension methods, such as the Training and Visit (T&V) system. Traditional models often failed to address the specific needs of smallholder farmers and were criticized for their lack of flexibility and farmer engagement (Anderson & Feder, 2004). In contrast, participatory approaches emphasize farmer empowerment, local context, and sustainability.

Key Participatory Approaches

Farmer Field Schools (FFS): Originating in Southeast Asia in the late 1980s, Farmer Field Schools (FFS) have become a widely adopted participatory approach in agricultural extension. FFS programs involve groups of farmers who meet regularly throughout the cropping season to learn about and experiment with new agricultural practices through hands-on activities. This

method encourages experiential learning, peer-to-peer knowledge exchange, and problem-solving (Pontius, Dilts, & Bartlett, 2002). FFS has been particularly successful in promoting integrated pest management (IPM), sustainable agriculture, and climate-resilient practices. Studies have shown that FFS participants often achieve higher crop yields, improved pest management, and increased income (Van den Berg & Jiggins, 2007).

Participatory Technology Development (PTD): Participatory Technology Development (PTD) involves collaboration between farmers, researchers, and extension agents to develop and adapt agricultural technologies suited to local conditions. This approach ensures that technologies are relevant, acceptable, and sustainable for the target communities (Chambers, Pacey, & Thrupp, 1994). PTD has been effective in addressing site-specific challenges, such as soil fertility management, crop variety selection, and water conservation. By involving farmers in the research and development process, PTD enhances the likelihood of technology adoption and long-term impact (Reijntjes, Haverkort, & Waters-Bayer, 1992).

Farmer-to-Farmer Extension: Farmer-to-Farmer (F2F) extension leverages the knowledge and experience of lead farmers to train and support their peers. This decentralized approach increases the reach and sustainability of extension services by building local capacity and fostering community leadership (Scarborough et al., 1997). F2F extension has proven effective in disseminating best practices in diverse contexts, from sustainable agriculture and agroforestry to livestock management and conservation agriculture. It enhances social capital and community resilience, contributing to improved food security (Selener et al., 1997).

Participatory Rural Appraisal (PRA): Participatory Rural Appraisal (PRA) is a set of participatory tools and methods used to engage communities in assessing their needs, resources, and potential solutions. PRA techniques, such as mapping, seasonal calendars, and focus group discussions, enable farmers to articulate their priorities and participate in planning and decision-making processes (Chambers, 1994). PRA has been widely used in agricultural extension to design context-specific interventions, enhance community ownership, and ensure the relevance of extension programs. It has facilitated the successful implementation of projects related to crop diversification, soil conservation, and water management (Chambers, 1997).

Impact Participatory Approaches in Agricultural Extension on Food Security

Participatory approaches in agricultural extension have demonstrated significant positive impacts on food security through various mechanisms:

Increased Agricultural Productivity: By tailoring technologies and practices to local conditions, participatory approaches improve crop yields and productivity. For example, FFS

programs have led to yield increases of 10-15 percent for rice and 20-25 percent for vegetables, contributing to greater food availability (Godtland et al., 2004).

Enhanced Adoption of Sustainable Practices: Participatory approaches promote the adoption of sustainable agricultural practices, such as conservation agriculture, agroforestry, and organic farming. These practices improve soil health, water use efficiency, and resilience to climate change, ensuring long-term food security (Pretty, 2008).

Improved Knowledge and Skills: Participatory extension enhances farmers' knowledge, skills, and decision-making abilities. Empowered farmers are better equipped to manage risks, optimize resource use, and respond to changing conditions, leading to more stable and secure food systems (Pretty, 1995).

Strengthened Social Capital and Community Cohesion: By fostering collaboration, trust, and mutual support, participatory approaches build social capital and strengthen community cohesion. This social infrastructure enhances collective action, resource sharing, and resilience to shocks, contributing to food security (Meinzen-Dick et al., 2004).

Challenges and Future Directions

While participatory approaches have proven effective, they also face challenges such as:

- **Resource Intensity:** Participatory methods often require significant time, effort, and resources, which can limit their scalability and sustainability.
- **Institutional Support:** Effective implementation of participatory approaches depends on supportive policies, institutional frameworks, and capacity building for extension agents and facilitators.
- **Inclusivity:** Ensuring the inclusion of marginalized groups, such as women, youth, and ethnic minorities, remains a critical challenge for participatory extension programs.

To address these challenges, future efforts should focus on:

- **Scaling Up Successful Models:** Leveraging ICT and digital platforms to scale up participatory extension models and reach more farmers.
- **Building Institutional Capacity:** Strengthening the capacity of extension institutions and agents to implement participatory approaches effectively.
- **Promoting Inclusivity:** Designing targeted interventions to ensure the active participation and benefits of all community members, particularly marginalized groups.

Digital Revolution and ICT Integration in Agricultural Extension for Food Security

The digital revolution and the integration of information and communication technologies (ICT) have significantly transformed agricultural extension services. These advancements have enhanced the efficiency, reach, and impact of extension services, contributing to improved food

security. They have significantly enhanced food security by providing timely information, improving market access, and promoting sustainable practices. The continued efforts to address challenges and leverage new technologies will further strengthen the role of ICT in achieving global food security goals.

The Rise of Digital Technologies in Agriculture

The advent of digital technologies has revolutionized various sectors, including agriculture. Key technologies include mobile phones, the internet, satellite imagery, geographic information systems (GIS), big data analytics, and artificial intelligence (AI). These technologies offer new opportunities for improving agricultural practices, market access, and decision-making processes (Aker, 2011).

ICT Integration in Agricultural Extension

ICT integration in agricultural extension involves using digital tools and platforms to disseminate information, provide advisory services, and facilitate knowledge exchange among farmers and extension agents. Key ICT-enabled extension approaches include:

Mobile-Based Advisory Services: Mobile phones have become ubiquitous in many developing countries, providing a powerful tool for delivering agricultural information and services. SMS and voice-based services offer timely and location-specific advice on weather forecasts, pest and disease management, crop management practices, and market prices (Qiang et al., 2011). Examples include services like mKisan in India and Esoko in Ghana, which have demonstrated significant impacts on farmers' knowledge, practices, and productivity (Aker, 2011).

Digital Platforms and Apps: Digital platforms and mobile applications provide comprehensive services, including farm management tools, e-commerce, and access to financial services. These platforms facilitate the efficient dissemination of extension messages and enable farmers to interact with experts and peers (Trendov, N.M., Samuel, V., and Meng., Z., 2019). Platforms such as Digital Green, which uses video-based training, and the Plantix app, which offers AI-driven crop diagnostics, have proven effective in enhancing farmers' skills and decision-making (Vasilaky & Leonard, 2015).

Geographic Information Systems (GIS) and Remote Sensing: GIS and remote sensing technologies enable the collection and analysis of spatial data on soil health, crop conditions, and environmental factors. This information supports precision agriculture, allowing extension agents to provide tailored recommendations to farmers (Zhang & Kovacs, 2012). Projects like the FAO's E-Agriculture Strategy Guide emphasize the integration of GIS and remote sensing in extension services to improve resource use efficiency and sustainability (FAO, 2016).

Social Media and Online Communities: Social media platforms and online communities facilitate peer-to-peer learning, knowledge sharing, and collaboration among farmers, extension agents, and researchers. These platforms provide a space for farmers to seek advice, share experiences, and access diverse sources of information (Rodriguez et al., 2018). The initiatives like the African Farmer Network on Facebook have shown how social media can empower farmers by connecting them with a broader community and resources (Heeks, 2017).

E-Learning and Webinars: E-learning platforms and webinars offer opportunities for continuous learning and capacity building for farmers and extension agents. These online resources provide access to training materials, courses, and expert presentations on various agricultural topics (Klerkx, 2020). Platforms like Coursera and edX offer courses on sustainable agriculture, climate-smart practices, and agricultural entrepreneurship, contributing to the professional development of extension workers and farmers alike (Klerkx, 2010).

Impact Digital Revolution and ICT on Food Security

The integration of ICT in agricultural extension has shown significant positive impacts on food security through various mechanisms:

Timely and Accurate Information: ICT-enabled extension services provide farmers with timely and accurate information on weather conditions, pest and disease outbreaks, and best practices. This information helps farmers make informed decisions, reducing crop losses and increasing productivity (Mittal, Gandhi, & Tripathi, 2010).

Improved Access to Markets: Digital platforms facilitate better access to markets by providing real-time price information, connecting farmers with buyers, and enabling e-commerce. This improves farmers' income and market participation, enhancing their economic stability and food security (Trendov, N. M., Varas, S., & Zeng, M., 2019).

Enhanced Knowledge and Skills: E-learning platforms, mobile apps, and digital advisory services enhance farmers' knowledge and skills, promoting the adoption of improved agricultural practices. This leads to higher yields, better resource management, and increased resilience to climate change (Klerkx, 2010).

Increased Efficiency and Sustainability: Precision agriculture enabled by GIS, remote sensing, and big data analytics helps optimize input use, reduce waste, and improve environmental sustainability. This contributes to long-term food security by ensuring the sustainable use of natural resources (Zhang & Kovacs, 2012).

Empowerment and Inclusivity: ICT tools empower smallholder farmers, women, and marginalized groups by providing access to information and services previously unavailable to them. This inclusivity enhances community resilience and overall food security (Heeks, 2017).

Challenges and Future Directions

Despite the benefits, the integration of ICT in agricultural extension faces several challenges:

Digital Divide: Limited access to digital technologies and internet connectivity in rural areas remains a significant barrier. Addressing this divide requires investments in infrastructure and affordable access to digital tools.

Capacity Building: Farmers and extension agents need training to effectively use digital tools and interpret digital information. Capacity-building programs are essential for maximizing the benefits of ICT integration.

Data Privacy and Security: Ensuring the privacy and security of farmers' data is critical. Policies and regulations must be developed to protect sensitive information and build trust in digital platforms.

Sustainability: The long-term sustainability of ICT-enabled extension services depends on financial viability, institutional support, and continued innovation.

Future efforts should focus on:

Bridging the Digital Divide: Investing in rural infrastructure, affordable internet access, and digital literacy programs to ensure all farmers benefit from ICT integration.

Enhancing Capacity Building: Developing comprehensive training programs for farmers and extension agents to build their digital skills and knowledge.

Promoting Public-Private Partnerships: Encouraging collaboration between governments, private sector, and non-governmental organizations to develop and scale ICT solutions for agriculture.

Ensuring Data Security: Establishing robust data governance frameworks to protect farmers' data and build trust in digital platforms.

Agricultural Extension and Food Security: A Theoretical Framework

To understand the role of agricultural extension in addressing food security, it is essential to explore the theoretical framework that underpins this relationship. Food security is a complex, multi-dimensional issue that encompasses the availability, access, utilization, and stability of food. Agricultural extension services contribute to food security by addressing these dimensions through various mechanisms. Agricultural extension services play a crucial role in enhancing food security by transferring knowledge, skills, and technologies to farmers.

Conceptualizing Food Security

Food security is a multifaceted concept defined by the Food and Agriculture Organization (FAO) as a state in which "all people, at all times, have physical and economic access to

sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO, 1996). Food security comprises four key dimensions:

1. **Availability:** The physical presence of sufficient quantities of food of appropriate quality.
2. **Access:** The economic and physical access to food, encompassing purchasing power and infrastructure.
3. **Utilization:** Proper biological use of food, requiring a diet that meets nutritional needs and proper food processing and storage.
4. **Stability:** The consistency of the other three dimensions over time, ensuring that food security is not periodically compromised.

Role of Agricultural Extension in Food Security

Agricultural extension services are designed to enhance agricultural productivity and sustainability through education and the dissemination of innovations. The theoretical framework links agricultural extension to food security through several pathways:

1. Knowledge Transfer and Capacity Building:

- **Human Capital Theory** posits that investment in education and training enhances productivity. Agricultural extension provides farmers with knowledge about modern farming techniques, pest management, and climate-smart practices, thus improving their human capital (Schultz, 1961).
- **Diffusion of Innovations Theory** (Rogers, 1962) explains how new ideas and technologies spread within a community. Extension services act as change agents, facilitating the adoption of innovations that can enhance food production and security.

2. Technology Adoption:

- The **Technology Acceptance Model (TAM)** (Davis, 1989) suggests that perceived usefulness and ease of use determine technology adoption. Extension services help farmers understand and utilize new technologies, such as improved seeds, fertilizers, and irrigation systems, increasing agricultural productivity.
- **Economic Theory of Technological Change** (Griliches, 1957) highlights the role of technology in agricultural productivity growth. Extension services reduce information asymmetry and transaction costs associated with new technologies, encouraging their adoption.

3. Resource Management and Sustainability:

- **Resource-Based View (RBV)** (Barney, 1991) emphasizes the importance of resource management for competitive advantage. Extension services guide farmers in the

sustainable management of soil, water, and biodiversity, contributing to long-term food security.

- **Sustainable Livelihoods Framework (SLF)** (Chambers & Conway, 1992) considers livelihood assets (human, natural, financial, social, and physical capital) and the vulnerability context. Extension services enhance these assets and mitigate vulnerabilities, promoting sustainable agricultural practices.

4. Market Access and Economic Opportunities:

- **Market-Led Extension (MLE) Theory** advocates for aligning extension services with market demands, helping farmers improve product quality and access markets (Anderson & Feder, 2004). Extension services provide market information and link farmers to value chains, enhancing their economic access to food.
- **Value Chain Development (VCD) Framework** (Kaplinsky & Morris, 2000) focuses on improving value chain efficiency and inclusivity. Extension services support farmers in engaging with value chains, increasing their income and food security.

5. Risk Management and Resilience:

- **Risk and Uncertainty Theory** (Knight, 1921) distinguishes between calculable risks and incalculable uncertainties in agriculture. Extension services help farmers adopt risk management strategies, such as crop diversification and insurance, enhancing resilience.
- **Resilience Theory** (Holling, 1973) examines the capacity of systems to absorb disturbances and reorganize. Extension services strengthen agricultural resilience by promoting adaptive practices and building community capacity.

Integrating Extension Services and Food Security Dimensions

The theoretical framework integrates agricultural extension into the four dimensions of food security:

1. Availability: Extension services increase food availability by promoting high-yield and resilient crop varieties, improving agricultural practices, and reducing post-harvest losses through better storage and processing techniques (Anderson & Feder, 2004).

2. Access: Economic access is enhanced through improved productivity and income diversification. Extension services link farmers to markets, provide market information, and support value addition, increasing farmers' purchasing power (Davis, 2008).

3. Utilization: Extension services improve food utilization by educating farmers about nutrition, food safety, and proper food storage and preparation methods. This ensures that the food produced meets dietary needs and preferences (FAO, 2016).

4. Stability: Stability is achieved through the promotion of sustainable agricultural practices, risk management strategies, and climate-smart agriculture. Extension services enhance the capacity of farming systems to withstand shocks and stresses, ensuring consistent food security (Trendov, N. M., Varas, S., & Zeng, M., 2019).

Models of Agricultural Extension for Food Security

Several models of agricultural extension have been developed and implemented globally, each with its unique approach and emphasis. Understanding these models helps in appreciating the diversity and adaptability of extension services in different contexts.

Training and Visit (T&V) Model:

The T&V model, developed by the World Bank in the 1970s, focuses on regular training of extension agents and systematic visits to farmers. This model emphasizes a top-down approach where extension agents act as intermediaries between research institutions and farmers. Despite its structured methodology, the T&V model has been criticized for its rigidity and limited farmer participation.

Key Features:

- Extension agents receive regular training sessions to update their technical knowledge.
- Agents conduct scheduled visits to farmers, providing them with timely advice and feedback.
- The system is hierarchical, with clear lines of supervision and accountability.

Impact on Food Security:

- The T&V system has improved agricultural productivity by disseminating high-yielding varieties and modern farming techniques (Feder, Willett, & Zijp, 2001).
- It has contributed to food security by increasing crop yields and reducing knowledge gaps among farmers.
- However, its top-down approach has been criticized for being rigid and not sufficiently responsive to farmers' diverse needs (Anderson, J., 2006).

Farmer Field Schools (FFS):

The FFS model, initiated by the Food and Agriculture Organization (FAO), is a participatory approach that emphasizes learning through experience. Farmers meet regularly in groups to observe, analyze, and make decisions about their agricultural practices. This model fosters a bottom-up approach, empowering farmers to take control of their learning and decision-making processes.

Key Features:

- Farmers learn by doing, conducting experiments, and making observations in their fields.
- FFS sessions are usually conducted over a growing season, covering various aspects of crop management.
- The approach fosters peer learning and collective problem-solving.

Impact on Food Security:

- FFS has been effective in promoting sustainable agricultural practices and integrated pest management (Davis, 2006).
- It empowers farmers with critical thinking and decision-making skills, leading to improved agricultural productivity and food security (Braun et al., 2006).
- The participatory nature of FFS ensures that the content is relevant to local conditions and farmers' needs.

Demand-Driven Extension:

Demand-driven extension or Market-Led Extension (MLE) models focus on responding to the specific needs and demands of farmers. These models prioritize farmer participation in setting the agenda and determining the services they require. This approach often involves a combination of public and private sector providers and is characterized by its flexibility and responsiveness.

Key Features:

- MLE focuses on market-oriented skills and knowledge, such as quality standards, post-harvest handling, and market information.
- It involves linking farmers to markets, agribusinesses, and financial services.
- The model promotes value addition and entrepreneurship.

Impact on Food Security:

- MLE has improved farmers' income and economic access to food by enhancing market participation (Christoplos, 2010).
- It contributes to food security by ensuring that farmers can sell their produce at better prices, leading to increased household income and food purchasing power (Anderson & Feder, 2004).
- The market-driven approach ensures that extension services are responsive to economic opportunities and challenges.

ICT-Based Extension:

With the rise of digital technology, ICT-based extension models have gained prominence. These models use mobile phones, internet platforms, and digital media to disseminate information, provide training, and facilitate communication between farmers and extension agents. ICT-based models offer the advantages of scalability, cost-effectiveness, and real-time information delivery.

Key Features:

- Use of mobile phones, internet, and digital platforms to deliver extension messages.
- Real-time access to weather forecasts, market prices, and technical advice.
- Facilitation of online communities and peer-to-peer learning.

Impact on Food Security:

- ICT-enabled extension has improved the timeliness and accuracy of agricultural information, enhancing farmers' decision-making (Aker, 2011).
- It contributes to food security by reducing information asymmetry and improving productivity (Qiang et al., 2012).
- The digital approach ensures wider reach and inclusivity, particularly in remote areas.

The Integrated Agricultural Research for Development (IAR4D) Model

Overview: The Integrated Agricultural Research for Development (IAR4D) model integrates research, extension, and farmer participation to address complex agricultural challenges. It was developed to overcome the limitations of traditional linear models of research and extension.

Key Features:

- IAR4D involves multi-stakeholder platforms, including researchers, extension agents, farmers, and policymakers.
- It focuses on innovation systems, promoting collaborative research and knowledge sharing.
- The model addresses entire value chains, from production to market access.

Impact on Food Security:

- IAR4D has led to significant improvements in agricultural productivity and income generation (Adekunle et al., 2010).
- It enhances food security by fostering innovation and scaling up successful practices (Hawkins et al., 2009).
- The collaborative approach ensures that solutions are context-specific and sustainable.

The Agricultural Innovation System (AIS) Framework

The Agricultural Innovation System (AIS) framework views agricultural development as a complex, interactive process involving multiple actors and institutions. It emphasizes systemic change and the co-creation of knowledge.

Key Features:

- AIS involves a network of actors, including farmers, researchers, extension agents, private sector, and NGOs.
- It promotes innovation through partnerships, learning alliances, and knowledge networks.
- The framework focuses on enabling environments, such as policies and institutions, to support innovation.

Impact on Food Security:

- AIS has been successful in fostering technological and institutional innovations that enhance agricultural productivity (Klerkx, van Mierlo, & Leeuwis, 2012).
- It contributes to food security by addressing barriers to innovation and promoting sustainable practices (Spielman & Birner, 2008).
- The system-oriented approach ensures that innovations are inclusive and scalable.

Each agricultural extension model has its strengths and limitations, and their effectiveness in promoting food security varies based on context and implementation. The Training and Visit (T&V) system, while effective in systematic knowledge dissemination, often lacks flexibility. The Farmer Field School (FFS) approach excels in participatory learning but can be resource-intensive. The Integrated Agricultural Research for Development (IAR4D) model and the Agricultural Innovation System (AIS) framework emphasize collaboration and systemic change, promoting sustainable innovations. The Market-Led Extension (MLE) model aligns extension with market demands, enhancing economic access to food. E-Extension and ICT-enabled models leverage digital technologies to enhance reach and efficiency.

A hybrid approach, combining elements from various models, may be most effective in addressing the complex and dynamic challenges of food security. By integrating participatory learning, market orientation, technological innovation, and digital tools, agricultural extension services can play a pivotal role in ensuring global food security.

Case Studies and Empirical Evidence

Examining case studies and empirical evidence provides a deeper understanding of the practical impacts of agricultural extension services on food security.

Extension Services in Developed Countries

The United States: In the U.S., the Cooperative Extension System, linked to land-grant universities, has been instrumental in advancing agricultural productivity and food security. For instance, the introduction of integrated pest management (IPM) through extension services has significantly reduced pesticide use while maintaining high crop yields. Extension services have also promoted sustainable farming practices and improved farmers' access to markets through business development programs.

The Netherlands: The Netherlands is known for its advanced agricultural sector, supported by robust extension services. The Dutch extension system emphasizes innovation, sustainability, and market orientation. Extension services have facilitated the adoption of precision agriculture technologies, which optimize inputs and enhance productivity. Additionally, extension agents play a crucial role in linking farmers with research institutions and the agri-food industry, fostering a culture of continuous improvement and competitiveness.

Extension Services in Developing Countries

India: India has a diverse and extensive extension network, including public, private, and non-governmental organizations (NGOs). The National Agricultural Extension System, under the Indian Council of Agricultural Research (ICAR), has implemented numerous programs to enhance food security. One notable example is the Green Revolution, where extension services played a critical role in disseminating high-yielding varieties of wheat and rice. More recently, ICT initiatives like the mKisan portal and Kisan Call Centers have improved farmers' access to information and advisory services.

Kenya: In Kenya, extension services have been pivotal in addressing food security challenges, particularly in rural areas. The introduction of participatory extension approaches, such as the Farmer Field Schools, has empowered smallholder farmers with knowledge and skills to improve their productivity. Extension services have also promoted the adoption of drought-resistant crop varieties and conservation agriculture techniques, enhancing resilience to climate variability.

Impact of Extension Services on Food Production and Security

Empirical studies provide quantitative evidence of the impact of extension services on food production and security.

Increased Crop Yields: Numerous studies have demonstrated that farmers who participate in extension programs achieve higher crop yields compared to those who do not. For example, a study by Muyanga and Jayne (2008) found that extension services in Kenya significantly increased maize yields. Farmers who received extension advice reported a 9% higher yield compared to those who did not.

Adoption of Climate-Smart Agriculture: In Ethiopia, the Agricultural Transformation Agency (ATA) promoted climate-smart practices, resulting in increased crop yields and resilience to climate variability (Louhichi., et al., 2020).

Improved Income and Livelihoods: Extension services not only enhance food production but also improve farmers' incomes and livelihoods**.** Extension services in Uganda improved farmers' access to high-value markets, leading to increased household income and better food security (Benin et al., 2011).

Enhanced Nutritional Outcomes: Beyond food production, extension services contribute to better nutritional outcomes. In Malawi, extension programs that integrated nutrition education with agricultural training led to increased dietary diversity and improved nutritional status among participating households.

Empowerment of Women in Agriculture: Women play a crucial role in agriculture, and their empowerment through extension services is vital for food security. Extension services that target women farmers can lead to increased productivity and improved household food security.

Challenges and Barriers in Agricultural Extension

While agricultural extension services have demonstrated significant contributions to food security, they also face numerous challenges and barriers that limit their effectiveness.

Financial Constraints

Insufficient Funding: Many extension services, especially in developing countries, suffer from inadequate funding. This leads to understaffing, lack of resources for training and dissemination activities, and limited reach. Ensuring sustainable financing mechanisms is critical for the continuity and effectiveness of extension services.

Dependency on Donor Funding: The reliance on donor funding can lead to programmatic instability and misalignment with local priorities. Extension services need to develop strategies for financial independence and sustainability to ensure long-term impact.

Technological Barriers

Limited Access to Technology: In many rural areas, farmers have limited access to modern agricultural technologies and inputs. Extension services need to address the affordability and availability of these technologies to ensure broader adoption.

Digital Divide: The digital divide remains a significant barrier, particularly in remote and underserved regions. While ICT-based extension models have great potential, they require investments in digital infrastructure and literacy to be effective.

Policy and Institutional Barriers

Weak Institutional Frameworks: In some countries, the institutional frameworks governing extension services are weak or fragmented, leading to inefficiencies and duplication of efforts. Strengthening these frameworks and enhancing coordination among stakeholders is essential.

Inconsistent Policies: The inconsistent and poorly implemented agricultural policies can undermine the effectiveness of extension services. Policy coherence and stability are necessary to provide a conducive environment for agricultural development.

Social and Cultural Barriers

Gender Inequality: Gender inequality is a significant barrier to effective extension services. Women farmers often have limited access to extension programs and resources, despite their critical role in agriculture. Extension services need to adopt gender-sensitive approaches to ensure inclusivity.

Cultural Resistance: Cultural resistance to new technologies and practices can hinder the adoption of innovations promoted by extension services. Building trust and understanding within communities is essential for overcoming this resistance.

Addressing the challenges faced by agricultural extension services requires innovative approaches and the adoption of best practices.

Innovations and successful strategies that have improved the effectiveness of extension services:

Use of Information and Communication Technology (ICT)

Mobile-Based Extension Services: Mobile phones have become a powerful tool for agricultural extension. Services like SMS-based advisories, mobile apps, and helplines provide farmers with timely information on weather forecasts, market prices, and agronomic advice. Examples include the mKisan platform in India and the Esoko service in Ghana.

Digital Learning Platforms: Digital learning platforms, such as e-learning courses and webinars, offer farmers access to a wealth of knowledge and training materials. These platforms can reach a large audience and provide interactive and engaging learning experiences.

Community-Based Approaches

Farmer Field Schools (FFS): As previously mentioned, FFS are an effective participatory approach that fosters experiential learning and problem-solving among farmers. This model has been successfully implemented in various countries, including Indonesia, Kenya, and Uganda.

Community Extension Agents: Training community members as extension agents can enhance the reach and impact of extension services. Community extension agents are often

more trusted and accessible to farmers, facilitating better communication and knowledge transfer.

Public-Private Partnerships

Collaboration with Agribusinesses: Public-private partnerships can leverage the expertise and resources of the private sector to enhance extension services. For example, partnerships with seed companies, agrochemical firms, and technology providers can facilitate the dissemination of high-quality inputs and innovative technologies.

Market Linkages: Establishing market linkages through partnerships with agribusinesses and cooperatives helps farmers access markets and improve their incomes. Extension services can play a crucial role in facilitating these linkages and providing market information.

Capacity Building and Skill Development

Training of Trainers (ToT): The ToT approach focuses on building the capacity of extension agents, who in turn train farmers. This cascading model ensures the multiplication of knowledge and skills across a wide range of beneficiaries. ToT programs cover a variety of topics, including modern farming techniques, climate-smart agriculture, and effective communication skills.

Vocational Training Centers: Establishing vocational training centers dedicated to agriculture provides farmers with practical, hands-on training in various agricultural disciplines. These centers offer courses on crop production, livestock management, agro-processing, and agribusiness management, enabling farmers to acquire specialized skills.

Farmer-to-Farmer Extension: The farmer-to-farmer extension approach leverages the knowledge and experience of progressive farmers to train their peers. This method builds on the trust and credibility existing within communities and encourages the rapid dissemination of best practices.

Conclusion

Agricultural extension services are indispensable for achieving global food security. They play a critical role in enhancing agricultural productivity, promoting sustainable practices, and improving the livelihoods of farmers. By providing education, technical assistance, and policy support, extension services bridge the gap between research and practical application, ensuring that farmers have access to the latest knowledge and innovations.

This review paper has highlighted the historical evolution of extension services, their key components, and the theoretical framework linking them to food security. Empirical evidence and case studies from both developed and developing countries demonstrate the positive impact of extension services on food production, income, and nutritional outcomes. However, several

challenges and barriers need to be addressed to maximize the effectiveness of extension services.

Innovations such as ICT integration, community-based approaches, public-private partnerships, and capacity building have shown promise in overcoming these challenges. Policy recommendations emphasize the need for strengthened institutional frameworks, enhanced funding mechanisms, promotion of sustainable agricultural practices, and gender-sensitive approaches.

Moving forward, it is crucial to continue research on the impact of extension services, adapt to emerging challenges, and implement best practices to ensure that agricultural extension remains a powerful tool in the quest for global food security. The collaborative efforts of governments, private sector actors, NGOs, and farmer organizations will be essential in realizing the full potential of agricultural extension services in achieving a world free from hunger and malnutrition.

References

1. Adekunle, A. A., Fatunbi, A. O., & Jones, M. P. (2010). How to set up an innovation platform.
2. Ahmed, A. U., Rabbani, M., Sulaiman, M., & Das, N. C. (2009). The impact of asset transfer on livelihoods of the ultra poor in Bangladesh. *Research Monograph Series*, *39*, 1-62.
3. Anderson, J. R. (2006). *The rise and fall of training and visit extension: an Asian mini-drama with an African epilogue* (Vol. 3928). World Bank Publications.
4. Anderson, J. R., & Feder, G. (2004). Agricultural extension: Good intentions and hard realities. The World Bank Research Observer, 19(1), 41-60.
5. Aker, J. C. (2011). Dial "A" for agriculture: a review of information and communication technologies for agricultural extension in developing countries. *Agricultural economics*, *42*(6), 631-647.
6. Axinn, G. H. (1985). Systems of agricultural extension. In *IRRI, Education for Agriculture Proceedings of the Symposium on Education for Agriculture, IRRI, Manila, Philippines* (pp. 161-171).
7. Baxter, M. (2019). Investments in Agricultural Extension. In Technology Systems For Small/spec Sale O Issues And Options (pp. 153-166). CRC Press.
8. Ban, A. V. D., & Hawkins, H. S. (1996). *Agricultural extension* (pp. ix+-294).

9. Barney, J. (1991). Firm resources and sustained competitive advantage. *Journal of management*, *17*(1), 99-120.
10. Benin, S., Nkonya, E., Okecho, G., Randriamamonjy, J., Kato, E., Lubade, G., & Kyotalimye, M. (2011). Returns to spending on agricultural extension: the case of the National Agricultural Advisory Services (NAADS) program of Uganda. *Agricultural economics*, *42*(2), 249-267.
11. Birner, R., Davis, K., Pender, J., Nkonya, E., Anandajayasekeram, P., Ekboir, J., ... & Cohen, M. (2009). From best practice to best fit: A framework for designing and analyzing pluralistic agricultural advisory services worldwide. Journal of agricultural education and extension, 15(4), 341-355.
12. Braun, A., Jiggins, J., Röling, N., Van Den Berg, H., & Snijders, P. (2006). A global survey and review of farmer field school experiences. *A Report for the International Livestock Research Institute, Wageningen*.
13. Chambers, R. (1994). The origins and practice of participatory rural appraisal. *World development*, *22*(7), 953-969.
14. Chambers, R. (1997). *Whose reality counts* (Vol. 25). London: Intermediate technology publications.
15. Chambers, R., Conway, G., & Brighton Institute of Development Studies. (1992). *Sustainable rural livelihoods: practical concepts for the 21st century* (Vol. 296, pp. 1-29). Brighton: Institute of development studies.
16. Chambers, R., & Thrupp, L. A. (Eds.). (1994). *Farmer first: Farmer innovation and agricultural research*. Karthala Editions.
17. Christoplos, I. (2010). Mobilizing the potential of rural and agricultural extension.
18. Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS quarterly*, 319-340.
19. Davis, K. (2006). Farmer field schools: a boon or bust for extension in Africa?.
20. Davis, K., Ekboir, J., Mekasha, W., Ochieng, C. M., Spielman, D. J., & Zerfu, E. (2007). Strengthening agricultural education and training in sub-Saharan Africa from an innovation systems perspective: Case studies of Ethiopia and Mozambique. IFPRI Discussion Paper, 733.
21. Davis, K. E. (2008). Extension in Sub-Saharan Africa: Overview and assessment of past and current models, and future prospects. *Journal of International Agricultural and Extension Education*.

22. Evenson, R. E., & Gollin, D. (2003). Assessing the impact of the Green Revolution, 1960 to 2000. *science*, *300*(5620), 758-762.
23. FAO. (2003). Trade Reforms and Food Security: Conceptualizing the Linkages. Food and Agriculture Organization of the United Nations.
24. FAO, I. (2016). E agriculture Strategy Guide, Piloted in Asia-Pacific Countries. *Bangkok, Thailand*.
25. Faure, G., Davis, K., Ragasa, C., Franzel, S., & Babu, S. C. (2016). Framework to assess performance and impact of pluralistic agricultural extension systems. *Report for International Food Policy Research Institute*.
26. Feder, G., Just, R. E., & Zilberman, D. (1985). Adoption of agricultural innovations in developing countries: A survey. *Economic development and cultural change*, *33*(2), 255-298.
27. Feder, G., Willett, A., & Zijp, W. (2001). *Agricultural extension: Generic challenges and the ingredients for solutions* (pp. 313-353). Springer uS.
28. Franzel, S., & Wambugu, C. (2007). The uptake of fodder shrubs among smallholders in East Africa: Key elements that facilitate widespread adoption. Agricultural Systems, 94(2), 360-372.
29. Freebairn, D. K. (1995). Did the Green Revolution concentrate incomes? A quantitative study of research reports. *World Development*, *23*(2), 265-279.
30. Godtland, E. M., Sadoulet, E., Janvry, A. D., Murgai, R., & Ortiz, O. (2004). The impact of farmer field schools on knowledge and productivity: A study of potato farmers in the Peruvian Andes. *Economic development and cultural change*, *53*(1), 63-92.
31. Griliches, Z. (1957). *Hybrid corn: An exploration in economics of technological change* (Doctoral dissertation, The University of Chicago).
32. Haug, R. (1999). Some leading issues in international agricultural extension, a literature review. Journal of Agricultural Education and Extension, 5(4), 263-274.
33. Hawkins, R., Heemskerk, W., Booth, R., Daane, J., Maatman, A., & Adekunle, A. A. (2009). Integrated agricultural research for development (IAR4D). In *A Concept Paper for the Forum for Agricultural Research in Africa (FARA) Sub-Saharan Africa Challenge Programme (SSA CP). FARA, Accra, Ghana*.
34. Hazell, P. B. (2010). An assessment of the impact of agricultural research in South Asia since the green revolution. *Handbook of agricultural economics*, *4*, 3469-3530.

35. Hazell, P. B., & Ramasamy, C. (1991). *The Green Revolution reconsidered: the impact of high-yielding rice varieties in south India* (pp. xiv+-286pp).
36. Heeks, R. (2017). *Information and communication technology for development (ICT4D)*. Routledge.
37. Holling, C. S. (1973). Resilience and stability of ecological systems.
38. Jones, G. E., & Garforth, C. (1997). The history, development, and future of agricultural extension.
39. Kaplinsky, R., & Morris, M. (2000). *A handbook for value chain research* (Vol. 113). Brighton: University of Sussex, Institute of Development Studies.
40. Klerkx, L. (2020). Advisory services and transformation, plurality and disruption of agriculture and food systems: towards a new research agenda for agricultural education and extension studies. *The Journal of Agricultural Education and Extension*, *26*(2), 131-140.
41. Klerkx, L., & Jansen, J. (2010). Building knowledge systems for sustainable agriculture: supporting private advisors to adequately address sustainable farm management in regular service contacts. *International Journal of Agricultural Sustainability*, *8*(3), 148-163.
42. Klerkx, L., Van Mierlo, B., & Leeuwis, C. (2012). Evolution of systems approaches to agricultural innovation: concepts, analysis and interventions. *Farming Systems Research into the 21st century: The new dynamic*, 457-483.
43. Knight, F. H. (1921). *Risk, uncertainty and profit* (Vol. 31). Houghton Mifflin.
44. Lambrecht, I., Vanlauwe, B., Merckx, R., & Maertens, M. (2014). Understanding the process of agricultural technology adoption: mineral fertilizer in eastern DR Congo. *World development*, *59*, 132-146.
45. Louhichi, K., Temursho, U., Colen, L., & y Paloma, S. G. (2019). Upscaling the productivity performance of the Agricultural Commercialization Cluster Initiative in Ethiopia. *JRC Science for Policy Report, Publications office of the European Union, Luxembourg*.
46. Meinzen-Dick, R., DiGregorio, M., & McCarthy, N. (2004). Methods for studying collective action in rural development. *Agricultural systems*, *82*(3), 197-214.
47. Mittal, S., Gandhi, S., & Tripathi, G. (2010). *Socio-economic impact of mobile phones on Indian agriculture* (No. 246). Working paper.
48. Mudege, N. N., Chevo, T., Nyekanyeka, T., Kapalasa, E., & Demo, P. (2016). Gender norms and access to extension services and training among potato farmers in Dedza and

Ntcheu in Malawi. *The Journal of Agricultural Education and Extension*, *22*(3), 291-305.

49. Muyanga, M., & Jayne, T. S. (2008). Private agricultural extension system in Kenya: Practice and policy lessons. *Journal of agricultural education and extension*, *14*(2), 111-124.
50. Pingali, P. L. (2012). Green revolution: impacts, limits, and the path ahead. *Proceedings of the national academy of sciences*, *109*(31), 12302-12308.
51. Pontius, J., Dilts, R., & Bartlett, A. (2002). From farmer field school to Community IPM (Integrated Pest Management): ten years of IPM training in Asia. *RAP Publication (FAO)*, (2002).
52. Pound, B., & Conroy, C. (2017). The innovation systems approach to agricultural research and development. In *Agricultural systems* (pp. 371-405). Academic Press.
53. Pretty, J. N. (1995). Regenerating Agriculture: Policiees and Pratice Sustainability adn self Reliance. Earth Scan.
54. Pretty, J. (2008). Agricultural sustainability: concepts, principles and evidence. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *363*(1491), 447-465.
55. Qiang, C. Z., Kuek, S. C., Dymond, A., Esselaar, S., & Unit, I. S. (2012). *Mobile applications for agriculture and rural development*. Washington, DC: World Bank.
56. Rajalahti, R., Janssen, W., & Pehu, E. (2008). *Agricultural innovation systems: From diagnostics toward operational practices*. Washington, DC: Agriculture & Rural Development Department, World Bank.
57. Ramussen, W. D. (2002). *Taking the university to the people: Seventy-five years of cooperative extension*. Purdue University Press.
58. Reijntjes, C., Haverkort, B., & Waters-Bayer, A. (1992). *Farming for the Future*. Macmillan Educ..
59. Rivera, W. M. (1988). Developing agricultural extension systems nationwide: a structural approach.
60. Rivera, W. M., & Sulaiman, V. R. (2009). Extension: object of reform, engine for innovation. *Outlook on agriculture*, *38*(3), 267-273.
61. Rivera, W. M. (2019). An overview of Agricultural Extension systems. *Technology Systems For Small/spec Sale O Issues And Options*, 93-118.
62. Rogers, E. M., Singhal, A., & Quinlan, M. M. (2014). Diffusion of innovations. In *An integrated approach to communication theory and research* (pp. 432-448). Routledge.

63. Rola, A. C., Jamias, S. B., & Quizon, J. B. (2002). Do farmer field school graduates retain and share what they learn? An investigation in Iloilo, Philippines.
64. Ruttan, V. W. (2002). Productivity growth in world agriculture: sources and constraints. *Journal of Economic perspectives*, *16*(4), 161-184.
65. Scarborough, V., Killough, S., Johnson, D. A., & Farrington, J. (Eds.). (1997). *Farmer-led extension: concepts and practices* (pp. x+-214).
66. Schultz, T. W. (1961). Investment in human capital. *The American economic review*, *51*(1), 1-17.
67. Selener, D., Chenier, J., Zelaya, R., Endara, N., Fadherbe, P., & Jacques, A. (1997). Farmer-to-farmer extension. *Lessons from the field. IIRR, New York*.
68. Simpson, B. M., & Owens, M. (2002). Farmer field schools and the future of agricultural extension in Africa. *Journal of International Agricultural and Extension Education*, *9*(2), 29-36.
69. Spielman, D. J., & Birner, R. (2008). *How innovative is your agriculture?: Using innovation indicators and benchmarks to strengthen national agricultural innovation systems*. Washington, DC, USA: World Bank.
70. Swanson, B. E., & Rajalahti, R. (2010). Strengthening agricultural extension and advisory systems: Procedures for assessing, transforming, and evaluating extension systems. *Agriculture and rural development discussion paper*, *45*, 1-187.
71. Swanson, B. E., & Samy, M. M. (2002). Developing an extension partnership among public, private, and nongovernmental organizations. *Journal of International Agricultural and Extension Education*, *9*(1), 5-10.
72. Tilman, D., Cassman, K. G., Matson, P. A., Naylor, R., & Polasky, S. (2002). Agricultural sustainability and intensive production practices. *Nature*, *418*(6898), 671-677.
73. Trendov, N. M., Varas, S., & Zeng, M. (2019). Digital technologies in agriculture and rural areas.
74. Van den Berg, H., & Jiggins, J. (2007). Investing in farmers—the impacts of farmer field schools in relation to integrated pest management. *World development*, *35*(4), 663-686.
75. Vasilaky, K., & Leonard, K. L. (2015). As Good as the Networks They Keep?: Improving Farmers Social Networks via Randomized Information Exchange in Rural Uganda. *Africa Gender Innovation Lab*.

76. Wang, S. L., Heisey, P., Schimmelpfennig, D., & Ball, V. E. (2015). Agricultural productivity growth in the United States: Measurement, trends, and drivers. *Economic Research Service, Paper No. Err-189*.
77. World Bank. (2012). *Agricultural innovation systems: An investment sourcebook*. The World Bank.
78. Zhang, C., & Kovacs, J. M. (2012). The application of small unmanned aerial systems for precision agriculture: a review. *Precision agriculture*, *13*, 693-712.