Systems Thinking for In-Depth Insect Pest Identification in Vegetable Farming through Collaborative Diversity Initiatives with Farmers

Frank T. Adusei, Virginia Tech University
Hannah Scherer, Virginia Tech University
Loy V. Crowder, Virginia Tech University

Vegetable farmers can choose from a variety of extension training programs covering topics such as nursery procedures, cultural practices, post-harvest management, and pest and disease control. However, proper pest identification is essential to avoid wasting time and resources on ineffective pest management strategies, which can result in further plant losses. Swift action is necessary due to the rapid damage caused by mechanical, abiotic, or pest-related forces (Mahmood et al., 2022). Economically, an agricultural pest is defined as any animal or plant whose population exceeds a tolerable threshold, adversely affecting agricultural productivity and financial viability (Horn, 1988; Mahmood et al., 2022). Effective pest management through strategic training is vital for protecting farmers' incomes.

Vegetable farming creates jobs for both rural and urban residents, exemplified by truck farming in rural areas and market gardening on city outskirts, ensuring a steady supply of fresh produce to urban markets (Owusu-Boateng & Amuzu, 2013). This dual approach not only enhances socioeconomic well-being but also improves dietary diversity and nutrition (Ntow et al., 2006). The recommended daily vegetable intake for optimal nutrition is at least 200 grams per person, amounting to about 73 kilograms annually (FAO, 2004). In Sub-Saharan Africa (SSA), vegetable consumption is only 43% of this recommendation, with availability around 50 kilograms per person annually (Ibid.).

Vegetables, rich in vitamins A and C, calcium, and iron, are vital for a balanced diet (Teresa & Harry, 2016). The growing food demand, especially in Africa's urban areas, requires the expansion and intensification of agriculture and horticulture, particularly for high-value vegetables (Gerken et al., 2001; Owusu-Boateng & Amuzu, 2013). However, the increased use of synthetic pesticides often leads to careless application, harming the environment, human health, and economic activities such as water bodies (Adusei et al., 2023; Amoah et al., 2006; Ajayi, 2005; Matthews, 2008). Balancing food production with responsible pesticide use is essential for sustaining agricultural productivity, human and environmental health.

Vegetable cultivation in SSA faces significant challenges from diverse pests and diseases, necessitating substantial management efforts (Abate et al., 2020; Dinham, 2003; Ntow et al., 2006). Failure to use appropriate insecticides can result in yield losses of up to 64% due to pest infestations (Horna et al., 2008). Addressing these challenges requires a systems approach, which holds promise for improving vegetable production. Most of SSA's vegetable output comes from smallholder farmers using conventional farming methods, which may contribute to high insect infestations (Osei et al., 2022). Thus, a systems approach is essential for enhancing vegetable production and mitigating pest impacts. Vegetable farmers can improve their knowledge of crops and pest management through specialized training, an essential supplement to their existing expertise. Extension services are essential for bridging knowledge gaps, recognizing the diverse challenges faced by farmers. Extension professionals tailor programs to meet specific needs, considering the unique circumstances of different farming groups.

Integrated Pest Management (IPM) programs which started in the 1960's aimed to boost agricultural yields, lower production costs, and minimize the environmental and health impacts of pest control (Alwang et al., 2019; Smith & van den Bosch, 1967). Despite its potential benefits and significant investments in training and promotion, IPM adoption remains limited in many SSA. Barriers to widespread adoption include inadequate infrastructure, limited access to IPM resources, insufficient extension services, and entrenched dependence on chemical pesticides. Additionally, socio-economic factors, farmer education, and policy support play a key role in determining the success of IPM adoption, necessitating more tailored approaches to overcome these challenges (Alwang et al., 2019).

In this paper, we introduce a framework for a training program for vegetable farmers in SSA. Using the principles of Backward Design, we emphasize the importance of a systems approach. This framework is guided by literature and theory, offering a structured method to address the challenges faced by smallholder farmers. The training program is designed to enhance farmers' ability to identify and manage insect pests through collaborative diversity initiatives.

This proposed training program outlines a framework for involving forty participants, aged 20 to 55, with diverse educational backgrounds and farming experience, each cultivating a minimum of 0.2 hectares of land. The initiative underscores gender inclusivity, aiming to engage both male and female farmers in this literature-based educational approach. The three-day training spans two hours daily: the first day includes documentary viewing and PowerPoint presentations, the second day features a field tour, and the third day is for farmer evaluations. The training program is notable for its holistic approach, targeting a diverse group of participants. Including individuals with varying educational backgrounds, land sizes, and farming experiences ensuring a rich learning environment. The focus on gender inclusivity aligns with contemporary agricultural development goals, promoting equality (Agarwal, 2018). The three-day structure, incorporating multimedia learning, field exposure, and evaluations, offers a comprehensive educational experience. This program innovatively blends various learning modalities, such as reading, listening, observing, participating, and engaging in hands-on activities, which are essential for a deep understanding and better retention of the material.

The training program proposes to extend existing literature by addressing the practical needs of a diverse farming community and advancing sustainable agriculture practices, guided by relevant literature and theoretical frameworks. It is particularly valuable for researchers, extension professionals, educators, and policymakers interested in inclusive and innovative models for agricultural training. Emphasizing context-sensitive education, it aligns with the dynamic landscape of sustainable farming, appealing to those seeking adaptable and scalable approaches to agricultural development (Adusei, 2020). The paper also aims to enhance the competencies of extension professionals to promote community engagement within the extension service system. It emphasizes the importance of empowering extension workers with the competence, expertise, and ability to assist communities in addressing these challenges (Rossi et al., 2004). It also explores how systems thinking can effectively engage participants in Extension programs by addressing persistent challenges like pest infestation, aiming to optimize agricultural practices' efficacy. It focuses on designing a targeted training program for committed attendees, showing how a systems approach can enhance engagement and learning outcomes within Extension initiatives.

The systems approach to pest management, particularly IPM, has been applied for decades to address complex agricultural challenges. Through agricultural extension efforts like the FAO's Farmer Field School (FFS) approach, IPM has evolved to support farmers in developing eco-friendly, sustainable pest control methods (FAO, n.d.; Teng & Savary, 1992). This paper aims to contribute to this practice by presenting a framework to address persistent pest management challenges in agricultural settings. Through building on existing frameworks, it seeks to provide farmers with a framework for efficiently identifying, managing, and controlling pests in vegetable farming. Past initiatives have demonstrated the effectiveness of participatory learning for pest management. Our approach, rooted in systems thinking, promotes collaborative diversity initiatives with farmers to deepen their understanding of insect pests and foster adaptive, localized solutions.

The rest of this paper is structured as follows: First, we delve into the theoretical underpinnings of systems thinking and its relevance to agricultural practices. We then outline the Backward Design methodology and how it informs the development of training program. Following this, we describe the specific components of the three-day training, detailing the interactive sessions, hands-on activities, and collaborative diversity initiatives with farmers. Finally, we discuss the anticipated outcomes and potential impacts of this program on improving vegetable production and reducing pest infestations. The paper concludes by summarizing key insights.

Learning Goals, Objectives & Desired Outcomes

Systems thinking, which emphasizes understanding the interconnectedness and complexity of various components within a system, is integral to this training program (Meadows, 2008). This approach ensures that all elements, from pest identification to community engagement, are considered within the broader context of sustainable agriculture. Stakeholders in this training initiative include farmers, the Department of Agriculture (extension professionals), the Environmental Protection Agency, and local community members. Collaboration among these groups and individuals aims to source vegetable pest videos and PowerPoint presentation materials. Farmers, directly affected by pests, will help in the preparation of the training materials. Local or regional governments, as financiers of agricultural development, play a key role. Given the common challenges of insect pest infestations, the training leverages the expertise of experienced farmers. Participants are grouped by literacy, land size, agricultural experience, and age, promoting diverse and inclusive learning. Beginner farmers benefit from dialogues with experienced peers, enhancing knowledge exchange.

Identifying the specific knowledge and skills farmers need is essential for crafting effective training programs. Employing the backward design process, guided by systems thinking, is highly effective in this effort. Wiggins and McTighe (2005) described backward design as starting with desired learning outcomes and working backward to develop the curriculum. Using the Understanding by Design (UbD) framework enhances alignment between the curriculum, instructional materials, and assessments with targeted learning objectives and skills. This method ensures the training program is strategically designed to achieve the desired outcomes.

Establishing clear goals for the training curriculum is another key aspect. Through defining precise objectives, educators can focus on delivering content and activities that directly contribute to achieving these goals, maximizing the program's effectiveness. Establishing clear goals for an extension training program is essential for its success. Goals provide direction, focus efforts, and serve as benchmarks for evaluating progress. In the context of training programs, well-defined goals help in designing relevant content, structuring effective learning activities, and measuring the outcomes of the training (Davia et al., 2016). A successful extension program starts by defining specific objectives, which form the basis for outlining work processes and evaluating implementation adherence (Warburton et al., 2011). In line with these studies, the goals and objectives of this training are:

Goals of the Training Program

1. Familiarize farmers with vegetable crop pests: Train farmers with knowledge about common vegetable crop pests, including their life cycles,

behaviors, and the types of crops they typically infest.

2. Enable farmers to identify specific parts of vegetable crops susceptible to pests: Train farmers to recognize which parts of their vegetable crops are most vulnerable to pest attacks, enhancing their ability to monitor and protect these areas effectively.
3. Introduce farmers to new pest identification techniques: Present and demonstrate pest identification techniques to improve the accuracy and efficiency of pest detection.
4. Assist farmers in effectively recognizing patterns of pest-induced damage: Help farmers develop skills to identify and understand patterns of damage caused by pests, enabling them to diagnose issues quickly and implement appropriate control measures.

Training Objectives

- Educate farmers about various vegetable crops and associated pests.
- Equip farmers with skills to identify and manage pests on their farms.

Challenges in Pest Management for Vegetable Agro-Ecosystems in Sub-Saharan Africa

Agriculture faces threats from over 600 insect species, 1,800 plant species, and various fungi and nematodes. These pests, if uncontrolled, can reduce crop yields and quality, increase production costs, and raise food and fiber prices, reducing producer competitiveness (Klassen & Schwartz, 1985). Effective pest management begins with precise identification, allowing for simpler, cost-effective, and highly effective treatments. Understanding pests' growth factors and life cycles enhances pest control efficiency by targeting vulnerable periods.

In SSA, vegetable agro-ecosystems are highly conducive to pests, resulting in significant yield losses. Over 96.2% of Africa's total crop production is affected by pests (Oerke, 2006; Oerke et al., 1994). Smallholder farmers often turn to pesticides as a last resort. For example, in Ghana, 87% of vegetable farmers used synthetic pesticides to combat pests (Dinham, 2003). Pesticide imports in Ghana have risen dramatically from 907 Mt in 2001 to over 5,078 Mt in 2009, comprising 33% insecticides, 23% fungicides, and 44% herbicides (GSS, 2009; MoFA, 2010; Ntow et al., 2006). The overuse and misuse of pesticides in SSA has led to adverse environmental impacts (Asfaw et al., 2009; Fernandez-Cornejo & Ferraioli, 1999; Skevas et al, 2013; Wilson & Tisdell, 2001).

Insect identification is challenging due to their varied life stages or metamorphosis. Insects undergo either "full metamorphosis" with four phases: egg, larva, pupa, and adult, or "incomplete metamorphosis" with three stages: egg, nymph, and adult (Erezyilmaz, 2006; Heming, 2003; Reynolds, 2019). Understanding these life stages is essential for effective pest management. Not all insects are harmful, many are beneficial or neutral, playing essential roles in vegetable farms. Beneficial species like hoverflies and green lacewings help control pests, reducing the need for chemical interventions and promoting sustainable agriculture (Penn State Extension, 2015).

Vegetable pests have diverse feeding habits targeting different plant parts: roots, leaves, stems, flowers and fruits. Some pests, like fruit flies, and caterpillars, have broad host ranges, while others, like certain bacterial pathogens, affect specific crops (James et al., 2009; Neuenschwander et al., 2003; Youdeowei, 2002). Youdeowei (2002) emphasized that farmers and extension professionals should consider key factors in guiding integrated pest management actions. These include the following:

- Identify the pest's precise location and growth stage during interventions.
- Regular monitoring to assess crop damage accurately.
- Choose a suitable insecticide.
- Explore alternatives to chemical control.
- Ensure pesticide compatibility with existing in-field biocontrol strategies.

Integrating Systems Thinking in Extension Services Training

Extension professionals began incorporating systems thinking into their work with farmers in response to the increasing complexity of agricultural challenges (Klerkx et al., 2012). Historically, this approach emerged as a shift from linear and reductionist views of farming issues towards a holistic understanding of agricultural systems (Klerkx et al., 2012; Sherwood 2002; Vemuri et al., 2009). Through emphasizing interconnectedness, feedback loops, and resilience, extension professionals aimed to empower farmers to make informed decisions that consider long-term sustainability and productivity (Liles & Mustian, 2004). This evolution in extension practices encouraged collaborative learning and innovation among farmers, fostering a more adaptive and responsive agricultural sector capable of addressing multifaceted challenges such as climate variability, soil health, pest control and market dynamics (Checkland, 2000).

In the realm of agricultural extension training, systems thinking has emerged as a valuable approach to engage farmers in understanding and addressing complex agricultural challenges. Extension professionals have utilized systems thinking to provide training and support that goes beyond traditional linear approaches, aiming to enhance farmers' ability to navigate interconnected issues in agriculture (Checkland, 2000; Stowell & Welch, 2012). Training initiatives using systems thinking typically involve:

- *Understanding interconnections*: Extension professionals help farmers to understand the interconnected nature of agricultural systems (Amissah et al., 2020; Cabrera et al., 2008). This includes teaching how various factors such as soil health, water management, crop diversity, and pest control interact within a farming ecosystem. Through visualizing these interconnections, farmers can make more informed decisions that consider the broader impacts on their farm's sustainability and productivity.

- *Identifying feedback loops*: Systems thinking training emphasize identifying feedback loops within farming systems (Sweeney & Sterman, 2000). Farmers learn to recognize how actions taken in one part of the system can influence outcomes elsewhere. For instance, changing irrigation practices may affect soil nutrient levels or crop health over time. Understanding these feedback loops allows farmers to anticipate and mitigate unintended consequences.
- *Promoting holistic solutions*: Rather than focusing on isolated problems, systems thinking encourages farmers to adopt holistic solutions (Meadows, 2008). Extension professionals facilitate workshops and discussions where farmers analyze their farming practices as part of larger systems. This holistic approach encourages the integration of sustainable practices that benefit both the farm's productivity and environmental health.
- *Building resilience*: Training in systems thinking equips farmers with tools to build resilience in the face of uncertainties such as climate change, pest infestation and market fluctuations (Jagustović et al., 2019). Through understanding the resilience of their farming systems, farmers can adapt more effectively to changing conditions and minimize risks.
- *Facilitating collaborative learning*: Extension professionals foster collaborative learning environments where farmers can share experiences and insights (Shaked & Schechter, 2013). This peer-to-peer learning reinforces systems thinking principles and encourages innovation as farmers collectively explore solutions to common challenges.

Generally, training initiatives employing systems thinking empower farmers to become more proactive in managing their farms sustainably. Extension professionals contribute to building resilient and thriving agricultural communities by enhancing farmers' understanding of complex agricultural systems and encouraging a holistic approach to problem-solving.

Systems thinking is a problem-solving approach built on understanding the interconnected components within a system and their collective impact. It helps in accurate identification and understanding of the intricate dynamics within the ecosystem, facilitating sustainable pest management practices (Amissah et al., 2020). For example, misinterpreting plant damage from overwatering as a fungal infestation may lead to unnecessary pesticide use, harming the plant. Vegetable pest infestation issues align well with systems thinking due to several key attributes:

- The issue warrants attention and is persistent.
- The problem has a well-established history and is widely recognized.

- Past attempts to address the problem have failed (Goodman, 2018).

The DSRP Framework

The DSRP framework, essential to systems thinking, comprises four cognitive patterns universally applicable across various fields: Distinction (D), System (S), Relationships (R), and Perspective (P). Each pattern has two components, aiding in understanding complex systems (Cabrera et al., 2015). This framework is not just a set of rules but a theoretical model illustrating their interactions (Cabrera & Colosi, 2008). Applying the DSRP framework helps explore deeper into issues beyond surface-level components. In vegetable farming, pest infestation is a persistent challenge, and educating farmers on recognizing insect pests is essential.

The Distinction (D) rule helps differentiate objects, ideas, and concepts, enabling farmers to distinguish beneficial insects from pests (Cabrera et al., 2008). This differentiation helps in setting boundaries, facilitating a clearer understanding of pest management strategies. The System (S) rule involves identifying parts and wholes, organizing them into nested systems. This rule emphasizes that every item is both a part and a whole, highlighting the interconnected nature of components (Behl & Ferreira, 2014; Shaked & Schechter, 2013). This promotes a holistic understanding of the relationships within a system.

The Relationship (R) rule posits that elements exhibit two-way qualities, affecting and being affected. Recognizing relationships as feedback loops, correlations, and causalities, this rule helps view systems as interconnected components with varied associations. For instance, an insect that feeds on an infected plant and then moves to feed on an uninfected one can transmit disease. Understanding these action/reaction relationships is crucial for farmers, highlighting the importance of complex connections in agricultural systems.

The Perspective (P) rule emphasizes that every concept has a frame of reference, allowing for a comprehensive understanding from both general and detailed viewpoints (Cabrera et al., 2008). It encourages seeing subjects from different perspectives, useful in grouping farmers with diverse views on pest identification. The DSRP rules coexist and interact throughout the systems thinking process (Cabrera & Colosi, 2008). They do not operate in isolation but function synergistically, demonstrating the interconnected nature of these cognitive patterns.

Integrating systems thinking into DSRP training empowers farmers to tackle pest management comprehensively. Through understanding distinctions, they identify beneficial and harmful insects. Recognizing systems, they see interconnected farm elements. Understanding relationships, they pinpoint how pests interact with crops and spread diseases. Viewing perspectives, they appreciate diverse viewpoints, enhancing collaborative problem-solving. This holistic approach ensures practical, sustainable pest control strategies, ultimately boosting crop yields and quality. Additionally, the strategy also ensures that all farmers, regardless of background or experience, gain practical insights and skills to manage and control vegetable pests effectively.

Assessment of the Training

Assessment is essential to the training process, serving as a tool for continuous learning (Cowie & Bell, 1999). Pierce (2002) emphasizes its role in identifying learners' strengths and weaknesses and guiding instructional decisions. Assessment provides targeted feedback, fostering student learning, and offers trainers quick insights to adapt their methods. Utilizing various evaluations, including assessments, exams, and models, allows comprehensive measurement of learning progress. Assessment helps instructors understand students' knowledge and abilities, identifying strengths and areas for improvement (Taras, 2005; Wojtczak, 2002). Evaluations furnish valuable insights into students' learning progress (Stiggins, 2002; Taras, 2005), enabling tailored instruction to enhance outcomes.

The facilitator must carefully select assessment methods to measure learners' progress, ensuring scheduled assessments effectively measure learning and achievement (Popham, 2005). Farmers should not only acquire knowledge but also possess a fundamental understanding of the material. Incorporating non-traditional evaluation methods beyond conventional paper-and-pen assessments proves beneficial (Popham, 2005). These innovative approaches discern the depth of learning, providing insights for the facilitator to address specific areas in detail. Embracing diverse evaluation methods enhances the effectiveness of assessing farmers' understanding and application of acquired knowledge in real-world agricultural contexts.

The Principles of Assessment

Assessments play a key role in evaluating learners' awareness, knowledge, perceptions, and attitudes toward learning, which is essential for trainers to plan effective interventions. According to Brown and Abeywickrama (2010), the core principles of assessment include authenticity, reliability, validity, and the washback effect. In the context of agricultural training, the first three principles; authenticity, reliability, and validity, are particularly important for ensuring that assessments are meaningful and practical (Brown & Abeywickrama, 2010).

Authenticity in Assessment

Authentic assessments mirror real-world scenarios, making them relevant to learners' daily experiences. In the agricultural training context, authenticity ensures that farmers can apply what they have learned in practical, real-life situations. This can be achieved through performance tasks that reflect genuine farming challenges. These may include:

- *Natural language:* Assessment instructions should be in the local language that farmers understand, ensuring clarity.
- *Contextualized components:* Tasks should involve actual farming practices, such as pest identification and crop management.
- *Meaningful themes:* The assessments should revolve around real-life agricultural problems like reducing pest infestations or increasing crop yields.
- *Thematic organization:* Grouping tasks around relevant agricultural themes helps farmers connect learning to practice.
- *Replicating real-world tasks:* Assignments should simulate real farming tasks, such as identifying pests on crops, demonstrating new farming techniques, or recording observations in a farming diary (Brown, 2004).

For instance, farmers could be asked to demonstrate pest identification on their farms. This task not only assesses their knowledge but also shows how well they can apply new techniques to improve farming outcomes. Through incorporating authentic assessments, trainers can ensure that farmers are equipped to handle real-world agricultural challenges.

Reliability in Assessment

Reliability refers to the consistency and dependability of assessment results (Badjadi, 2013; Genesee & Upshur, 1999). In agricultural training, it is essential to ensure that the same assessment produces consistent results across different groups of farmers. To achieve reliability, the following elements must be considered:

- *Consistent conditions:* Assessments should be conducted under similar conditions to ensure fairness. For example, if farmers are tested on pest identification, they should all have access to the same visual aids and instructions.
- *Clear evaluation directions:* Instructions should be simple and straightforward, reducing the risk of misinterpretation.
- *Uniform rubrics:* Standardized scoring rubrics should be used to evaluate farmers' performance, ensuring objective and fair assessments.
- *Unambiguous assignments:* Tasks should be clearly defined, with no room for confusion (Brown & Abeywickrama, 2010). For instance, when farmers are asked to identify pests, they should be given clear criteria on what constitutes correct identification.

Reliability can be reinforced by using performance tasks that require farmers to demonstrate practical skills multiple times. For example, a farmer might be asked to identify pests on different crops over several weeks. If their results are consistent, it indicates a reliable assessment process.

Validity in Assessment

Validity measures whether an assessment accurately evaluates what it is intended to measure (Brown, 2006; Gür, 2013). In the agricultural training context, validity ensures that assessments align with the training objectives and accurately reflect farmers' knowledge and skills. To ensure validity:

- Measuring intended aspects: Assessments should focus on evaluating farmers' understanding of specific agricultural practices, such as pest identification and crop management.
- Providing consistent results: The assessments should yield accurate and consistent findings across different contexts.

For instance, a valid assessment might involve asking farmers to identify pests and match them with the vegetables they damage. This directly measures their knowledge of pest management, a critical aspect of the training. Additionally, an oral interview could be conducted to validate their understanding further by asking farmers to explain the pest management practices they have implemented.

Tools for Assessment

Continuous assessment provides ongoing feedback, enhancing the learning and teaching process. It emphasizes teaching as a dynamic, formative process that evolves with student engagement and feedback. In the context of agricultural training, farmers can be assessed through various tools:

Performance tasks.

1. Demonstration: Farmers will demonstrate the new farming practices introduced during the training, such as pest identification techniques.
2. Following directions: Farmers will follow instructions related to identifying specific pests on their farms.
3. Acceptance of practice: Farmers will show evidence of adopting pest identification practices in their farming routines.

Other evidence.

1. Written tasks: Farmers will be asked to write the names of pests and the vegetables they damage. This assesses their retention and understanding of the training content.
2. Oral interviews: Trainers will ask farmers different sets of questions to gauge their comprehension and application of the knowledge.
3. Visual matching: Farmers will match pictures of pests with the vegetables they damage. This helps to visually reinforce their learning.

Key Criteria for Success

The goal of the training is to achieve a significant reduction in pest infestation from the current 64% (Horna et al., 2008) to approximately 5%, alongside an 85% increase in both the quality and quantity of output. These measurable targets ensure that the assessments are tied to real-world outcomes. Continuous assessment helps monitor progress and identify areas for improvement. Trainers can adjust their teaching strategies to address any gaps in learning by evaluating farmers' performance regularly. For example, if farmers struggle with identifying certain pests, trainers can provide additional visual aids or practical demonstrations to reinforce learning.

Creating a Learning Plan

When crafting training programs, ensuring that farmers deeply understand the course objectives and can apply concepts to their farms is paramount. Utilizing backward design, which involves breaking down standards into key concepts and essential questions, enhances farmers' comprehension beyond mere memorization (Wiggins & McTighe, 2005). This approach helps facilitators focus on exercises that promote both understanding and practical application of knowledge.

The first day of the training program integrates PowerPoint presentations and documentary viewing to explore the nature of pests. Each group participates in note preparation, brainstorming, role-playing, and interactive Q&A sessions, fostering reflection and active learning. This comprehensive strategy is designed to provide farmers with practical insights and skills to effectively manage vegetable pests. On the second day, farmers engage in a hands-on field demonstration that offers firsthand insights into pest habits and dissemination. This interactive session enhances understanding through active engagement with real-world scenarios and practical demonstrations. The third day is dedicated to evaluating farmers' understanding of pests and assessing the effectiveness of the training. This ensures a thorough assessment of the knowledge gained and the overall success of the initiative, allowing for adjustments and improvements in future training programs. To thoroughly introduce pest identification, the following plan was implemented:

- *Watching documentaries:* Using documentaries as an introduction makes learning engaging and motivating. Visual and auditory stimuli enhance understanding, allowing farmers to understand complex ideas more effectively than traditional lectures or readings (Berk, 2009). Documentaries stimulate various senses and brain regions, fostering critical thinking, normative competences, and skills related to identification.
- *PowerPoint presentation:* PowerPoint presentations reinforce lessons, focusing on essential information while promoting interactive learning. This approach ensures that farmers receive key insights in a structured and visually engaging manner.

- *Field demonstration:* Field demonstrations provide practical avenues to teach complex skills while actively involving farmers. These demonstrations, vital tools for extension professionals, convince farmers of the efficacy of improved agricultural techniques ("seeing is believing") and encourage hands-on learning ("learning by doing") (Bell & Rickman, 2013; Mathinda, 2015). They offer a unique perspective on pest-related topics, enabling farmers to apply efficient pest management techniques in their operations.

Studies indicate that active participation enhances learning and long-term memory retention. Dale's cone of learning indicates that active participation leads to a 90% retention rate (Azar, 2022; Dwyer, 2010). To ensure farmers fully understand, participate, and apply principles, the following activities are central:

- *Brainstorming/Discussion:* Farmers' existing knowledge about pests forms the foundation for effective learning. Brainstorming refines ideas collaboratively, generating innovative solutions to challenges (Jarwan, 2005). Creative thinking, rooted in cognitive theory, involves developing novel solutions, enhancing farmers' cognitive structures and understanding of pest-related issues (Qattami, 2010).
- *Demonstration/Role Play:* This method allows farmers to gain hands-on experience and test various practices within a secure environment. Role-playing investigates real-life scenarios, managing interactions with others and the environment. It encourages farmers to reassess and modify their mental maps, fostering adaptability (Blatner, 2009). It also helps farmers learn that the skills they learn separately are often used together to accomplish real-world tasks (Bair, 2000).
- *Questions & Answers:* Engaging learners with challenging and thought-provoking questions promotes peer discussions and motivates deeper exploration of fundamental concepts, enhancing their understanding of pest identification principles.
- *Work in Groups:* Grouping farmers facilitates knowledge transfer, allowing those with pest identification expertise to mentor beginners. The systems thinking approach aims for optimal results with minimal effort by identifying solutions that yield the greatest impact. Teams develop more effective solutions and learn from their experiences when they understand the underlying issue, guiding members toward collaborative working and fostering a comprehensive understanding (Zuravliov, 2022). This collaborative methodology ensures a holistic approach to problem-solving, emphasizing shared insights and experiential learning for optimal outcomes. Table 1 provides a detailed overview of the training activities.

Table 1

Description of Training Activities

Day	Activity	Objective	Description	Expected Outcome
Day 1	Documentary viewing & discussion	Enhance understanding through visual and auditory stimuli, fostering critical thinking.	Farmers will watch a documentary on pest identification, followed by a group discussion.	Farmers gain an introductory understanding of common pests and their impact on crops.
	PowerPoint presentation	Provide essential insights in a structured, visually engaging manner.	A presentation covering key pest identification concepts, including types of pests and their lifecycle.	Visual learning enhances farmers' retention of important pest identification principles.
	Brainstorming & role-playing	Refine ideas collaboratively, generating innovative solutions to pest-related challenges and foster adaptability and practical problem-solving skills.	Farmers will brainstorm pest control strategies and participate in role-playing exercises to simulate real-world scenarios.	Encourages critical thinking and practical problem-solving skills.
Day 2	Field demonstration	Provide practical, hands-on experience in identifying and managing pests.	A hands-on session where farmers visit a farm to observe pest habits and learn about pest management techniques.	Farmers gain practical experience in identifying pests and implementing control measures.
	Group work	Facilitate knowledge transfer and collaborative problem-solving.	Farmers will work in small groups to identify pests on various crops and suggest appropriate management strategies.	Promotes collaborative learning and knowledge sharing among farmers.
Day 3	Assessment	Measure retention and application of knowledge gained during the training.	Farmers will be evaluated on their knowledge and skills gained from the training. Assessment methods include written tasks, oral interviews, and visual matching exercises.	Ensures farmers have understood the content and can apply pest identification techniques on their farms.
	Q&A session	Ensure comprehension and retention of pest identification techniques.	An interactive session where farmers can ask questions and seek clarification on any concepts covered during the training.	Reinforces learning and addresses any remaining doubts or challenges.

Conclusion

This study introduces a unique and an innovative approach to vegetable farming training, focusing specifically on pest identification through systems thinking. The training program integrates theoretical frameworks, practical methodologies, and a holistic understanding of Sub-Saharan Africa's farming challenges. Given pests' profound impact on crop yields and sustainability, the program aims to equip farmers with skills for effective pest management. The backward design process and *Understanding by Design* (UbD) framework align curriculum, materials, and assessments with targeted outcomes, maximizing training effectiveness. Incorporating multimedia learning, field exposure, and participant evaluations caters to diverse farmer backgrounds, fostering an inclusive learning environment.

The structured three-day program—documentary viewing, PowerPoint presentations, field tours, and farmer evaluations—offers comprehensive education suited to various learning styles. Collaboration among farmers, extension professionals, and governmental bodies is crucial for program success. Systems Thinking, guided by the DSRP framework, underpins understanding of farming ecosystems' complexities. The assessment methodology, emphasizing authenticity, reliability, and validity, ensures evaluations align with training objectives. Continuous assessment includes performance tasks, written and oral evaluations, and visual matching exercises to gauge farmers' understanding and application of knowledge effectively.

References

Abate, T., van Huis, A., & Ampofo, J. K. O. (2000). Pest management strategies in traditional agriculture: An African perspective. *Annual Review of Entomology, 45*(1), 631–659. https://doi.org/10.1146/annurev.ento.45.1.631

Adusei, F. Y. (2020). Investigating the factors that affect the adoption of organic agriculture in Asokwa, Kumasi Metropolis. *International Journal of Agricultural Extension, 8*(3), 163–172. https://doi.org/10.33687/ijae.008.03.3310

Adusei, F. Y., Adusei, M. A., & Lartey, B. (2023). A roadmap for sustainable disease, pest, and weed management. *Biology and Life Sciences Forum, 27*(24). https://doi.org/10.3390/IECAG2023-14989

Agarwal, B. (2018). Gender equality, food security and the sustainable development goals. *Current Opinion in Environmental Sustainability, 34*, 26–32. https://doi.org/10.1016/j.cosust.2018.07.002

Alwang, J., Norton, G., & Larochelle, C. (2019). Obstacles to widespread diffusion of IPM in developing countries: Lessons from the field. *Journal of Integrated Pest Management, 10*(1), 10. https://doi.org/10.1093/jipm/pmz008

Ajayi, O. C. (2005). Biological capital, user costs and the productivity of insecticides in cotton farming systems in sub-Saharan Africa. *International Journal of Agricultural Sustainability, 3*, 154–166. https://doi.org/10.1080/14735903.2005.9684753

Amissah, M., Gannon, T., & Monat, J. (2020). What is systems thinking? Expert perspectives from the WPI systems thinking colloquium of 2 October 2019. *Systems, 8*(1), 6. https://doi.org/10.3390/systems8010006

Amoah, P., Drechsel, P., Abaidoo, R. C., & Ntow, W. J. (2006). Pesticide and pathogen contamination of vegetables in Ghana's urban markets. *Archives of Environmental Contamination and Toxicology, 50*(1), 1–6. https://doi.org/10.1007/s00244-004-0054-8

Asfaw, S., Mithöfer, D., & Waibel, H. (2009). EU food safety standards, pesticide use and farm-level productivity: The case of high-value crops in Kenya. *Journal of Agricultural Economics, 60*(3), 645–667. https://doi.org/10.1111/j.1477-9552.2009.00205.x

Azar, N. G., Shahbazi, S., & Rouzbahani, A. K. (2022). Edgar Dale's pyramid of learning: Further expansion of the myth; Is it a mythical pyramid? *Research and Development in Medical Education, 11*(1), 29. https://doi.org/10.34172/rdme.2022.029

Badjadi, N. E. I. (2013). *Conceptualizing essay tests' reliability and validity: From research to theory.* Retrieved from https://eric.ed.gov/?id=ED542099

Bair, E. S. (2000). Developing analytical and communication skills in a mock-trial course based on the famous Woburn, Massachusetts case. *Journal of Geoscience Education, 48*(4), 450–454. https://doi.org/10.5408/1089-9995-48.4.450

Behl, D. V., & Ferreira, S. (2014). Systems thinking: An analysis of key factors and relationships. *Procedia Computer Science, 36*, 104–109. https://doi.org/10.1016/j.procs.2014.09.045

Bell, M. A., & Rickman, J. F. (2013). *Field demonstrations*. Davis, California.

Berk, R. A. (2009). Multimedia teaching with video clips: TV, movies, YouTube, and mtvU in the college classroom. *International Journal of Technology in Teaching and Learning, 5*(1), 1–21.

Blatner, A. (2009). *Role playing in education.* Retrieved from https://www.blatner.com/adam/pdntbk/rlplayedu.htm

Brown, G. T. L. (2006). Teachers' conceptions of assessment: Validation of an abridged version. *Psychological Reports, 99*(1), 166–170. https://doi.org/10.2466/pr0.99.1.166-170

Brown, H. D. (2004). *Language assessment principles and classroom practices*. Pearson Education, Inc.

Brown, H. D., & Abeywickrama, P. (2010). *Language assessment: Principles and classroom practices*. Pearson Education, Inc.

Cabrera, D., Cabrera, L., & Powers, E. (2015). A unifying theory of systems thinking with psychosocial applications. *Systems Research and Behavioral Science, 32*(5), 534–545. https://doi.org/10.1002/sres.2351

Cabrera, D., Colosi, L., & Lobdell, C. (2008). Systems thinking. *Evaluation & Program Planning, 31*(3), 299–310. https://doi.org/10.1016/j.evalprogplan.2007.12

Cabrera, D., & Colosi, L. (2008). Distinctions, systems, relationships, and perspectives (DSRP): A theory of thinking and of things. *Evaluation and Program Planning, 31*(3), 311–317. https://doi.org/10.1016/j.evalprogplan.2008.04.001

Checkland, P. (2000). Systems thinking, systems practice: Includes a 30-year retrospective. *Journal of the Operational Research Society, 51*(5), 647.

Cowie, B., & Bell, B. (1999). A model of formative assessment in science education. *Assessment in Education: Principles, Policy & Practice, 6*(1), 101–116. https://doi.org/10.1080/09695949993026

Dinham, B. (2003). Growing vegetables in developing countries for local urban populations and export markets: Problems confronting small-scale producers. *Pest Management Science, 59*(5), 575–582. https://doi.org/10.1002/ps.654

Dwyer, F. (2010). Edgar Dale's cone of experience: A quasi-experimental analysis. *International Journal of Instructional Media, 37*(4), 431–438.

Erezyilmaz, D. F. (2006). Imperfect eggs and oviform nymphs: A history of ideas about the origins of insect metamorphosis. *Integrative and Comparative Biology, 46*, 795–807. https://doi.org/10.1093/icb/icl033

FAO. (n.d.). Integrated production and pest management programme in Africa. *Food and Agriculture Organization of the United Nations.* Retrieved from https://www.fao.org/agriculture/ippm/activities/en/

Fernandez-Cornejo, F., & Ferraioli, J. (1999). The environmental effects of adopting IPM techniques: The case of peach producers. *Journal of Agricultural and Applied Economics, 31*(3), 551–564. https://doi.org/10.1017/S107407080000883X

Food & Agriculture Organization (FAO). (2004). *FAOSTAT.* Rome, Italy.

Genesee, F., & Upshur, J. (1999). *Classroom-based evaluation in second language education.* Cambridge University Press.

Gerken, A., Suglo, J. V., & Braun, M. (2001). Pesticide use and policies in Ghana. *MoFA/PPRSD, ICP Project, Pesticide Policy Project/GTZ,* Accra, 185.

Goodman, M. (2018). System thinker: System thinking: What, why, when, where and how. *System Thinker.* Retrieved from https://thesystemsthinker.com/systems-thinking-what-why-when-where-and-how/

GSS. (2009). *Trends in agrochemical imports in Ghana*. Ghana Statistical Service.

Gür, O. (2013). Ölçme, Değerlendirme ve Kamu Personel Dil Sınavı (KPDS) - Bu sınav neyi ölçüyor? *Sakarya University Journal of Education,* 23–32.

Heming, B. S. (2003). *Insect development and evolution.* Cornell University Press.

Horn, D. J. (1988). *Ecological approach to pest management.* The Guilford Press.

Horna, D., et al. (2008). Insecticide use on vegetables in Ghana: Would GM seed benefit farmers? *IFPRI Discussion Paper 00785.* Retrieved from https://pdf.usaid.gov/pdf_docs/Pnadm767.pdf

Jagustović, R., Zougmoré, R. B., Kessler, A., Ritsema, C. J., Keesstra, S., & Reynolds, M. (2019). Contribution of systems thinking and complex adaptive system attributes to sustainable food production: Example from a climate-smart village. *Agricultural Systems, 171,* 65–75. https://doi.org/10.1016/j.agsy.2018.12.008

James, B., Godonou, I., & Atcha-Ahowé, C. (2009). Promoting biopesticide candidates from experimental to commercial level for sustainable vegetable production. *Pesticides Management in West Africa, 7,* 15–33. https://hdl.handle.net/10568/90251

Jarwan, F. (2005). *Teaching thinking: Definition and applications.* Dar Al-Fikr.

Klassen, W., & Schwartz, P. (1985). AARS research program in chemical insect control, agricultural chemicals of the future. In J. L. Hilton (Ed.), *BARC Symposium 8* (pp. 1–15). Rowman & Allanheld.

Klerkx, L., van Mierlo, B., & Leeuwis, C. (2012). Evolution of systems approaches to agricultural innovation: Concepts, analysis, and interventions. In I. Darnhofer, D. Gibbon, & B. Dedieu (Eds.), *Farming Systems Research into the 21st Century: The New Dynamic* (pp. 457–483). Springer. https://doi.org/10.1007/978-94-007-4503-2_20

Liles, R. T., & Mustian, R. D. (2004). Core competencies: A systems approach for training and organizational development in extension. *The Journal of Agricultural Education and Extension, 10*(2), 77–82. https://doi.org/10.1080/13892240485300121

Mahmood, M. A., Awan, M. J. A., & Mansoor, S. (2022). BioClay: Next-generation crop protection strategy. *Trends in Plant Science, 27*(11), 1090–1092. https://doi.org/10.1016/j.tplants.2022.08.003

Matthews, G. A. (2008). Attitudes and behaviors regarding use of crop protection products: A survey of more than 8500 smallholders in 26 countries. *Crop Protection, 27*(5), 834–846.

Mathinda, C. (2015). Principles of adult learning: A unit for a module on learning theories and adult education. *INGENAES.*

Meadows, D. H. (2008). *Thinking in systems: A primer.* Chelsea Green Publishing.

MoFA. (2010). *Agriculture in Ghana: Facts and figures 2009.* Ministry of Food and Agriculture, Statistics Research and Information Directorate.

Neuenschwander, P., Borgemeister, C., & Langewald, J. (2003). Biological control in integrated pest management systems in Africa. *CAB International.*

Ntow, W. J., Gijzen, H. J., Kelderman, P., & Drechsel, P. (2006). Farmer perceptions and pesticide use practices in vegetable production in Ghana. *Pest Management Science, 62*(4), 356–365. https://doi.org/10.1002/ps.1178

Osei, M. K., et al. (2022). Harnessing technologies for vegetable cultivation: A panacea for food and nutrition insecurity in Ghana. *IntechOpen.* https://doi.org/10.5772/intechopen.101877

Owusu-Boateng, G., & Amuzu, K. K. (2013). A survey of some critical issues in vegetable crops farming along River Oyansia in Opeibea and Dzorwulu, Accra-Ghana. *Global Advanced Research Journal of Physical and Applied Sciences, 2*(2), 24–31.

Penn State Extension. (2015). *Vegetable Integrated Pest Management with an emphasis on biocontrol: A guide for growers in the Mid-Atlantic.* Retrieved from https://extension.psu.edu/downloadable/download/sample/sample_id/876/

Pierce, L. V. (2002). Performance-based assessment: Promoting achievement for language learners. *ERIC/CLL News Bulletin, 26*(1), 1–3.

Popham, W. J. (2005). *Classroom assessment: What teachers need to know* (4th ed.). Pearson/Allyn and Bacon.

Qattami, N. (2010). *Methods of teaching gifted and talented.* Dar Al-Maseera.

Oerke, E. C. (2006). Crop losses to pests. *The Journal of Agricultural Science, 144*(1), 31–43. https://doi.org/10.1017/S0021859605005708

Oerke, E. C., Dehne, H.-W., Schunbeck, F., & Weber, A. (1994). *Crop production and crop protection: Estimated losses in major food and cash crops.* Elsevier Science.

Reynolds, S. (2019). Cooking up the perfect insect: Aristotle's transformational idea about the complete metamorphosis of insects. *Philosophical Transactions of the Royal Society B, 374*(1774), 20190074. https://doi.org/10.1098/rstb.2019.0074

Rossi, P. H., Lipsey, M. W., & Freeman, H. E. (2004). *Evaluation: A systematic approach* (7th ed.). Sage.

Shaked, H., & Schechter, C. (2013). Seeing wholes: The concept of systems thinking and its implementation in school leadership. *International Review of Education, 59*(6), 771–791. https://doi.org/10.1007/s11159-013-9387-8

Sherwood, D. (2000). *Seeing the forest for the trees: A management guide to applying systems thinking.* Nicholas Breadley.

Skevas, T., Stefanou, S. E., & Oude, A. L. (2013). Do farmers internalize environmental spillovers of pesticides in production? *Journal of Agricultural Economics, 64*(3), 624–640. https://doi.org/10.1111/1477-9552.12007

Smith, R. F., & van den Bosch, R. (1967). Integrated control. In W. W. Kilgore & R. L. Doutt (Eds.), *Pest control: Biological, physical, and selected chemical methods* (pp. 295–340). Academic Press.

Stiggins, R. J. (2002). Assessment crisis: The absence of assessment for learning. *Phi Delta Kappan, 83*(10), 758–765. https://doi.org/10.1177/003172170208301010

Stowell, F. A., & Welch, C. (2012). *The manager's guide to systems practice.* Wiley.

Sweeney, L. B., & Sterman, J. D. (2000). Bathtub dynamics: Initial results of a systems thinking inventory. *System Dynamics Review, 16*(4), 249–286. https://doi.org/10.1002/sdr.198

Taras, M. (2005). Assessment—Summative and formative: Some theoretical reflections. *British Journal of Educational Studies, 53*(4), 466–478.

https://doi.org/10.1111/j.1467-8527.2005.00307.x

Teng, P. S., & Savary, S. (1992). Implementing the systems approach in pest management. *Agricultural Systems, 40*(1–3), 237–264. https://doi.org/10.1016/0308-521X(92)90023-H

Teresa, A. L., & Harry, S. P. (2016). Italian horticultural and culinary records of summer squash (*Cucurbita pepo* Cucurbitaceae) and emergence of the zucchini in 19th-century Milan. *Annals of Botany, 118*(1), 53–69. https://doi.org/10.1093/aob/mcw080

Vemuri, S., Scherch, J. M., Bentley, M., Golding, R. M., Pool, J., Morton, K., O'Leary, P., Robb, S., Lloyd, D. G., & Lambert, S. (2009). Capacity building for sustainable development. *International Journal of Environmental, Cultural, Economic and Social Sustainability, 5*(4), 87–98.

Warburton, H., Blake, R., Coupe, S., Pasteur, K., & Phillips, E. (2011). Bridging the gap between resource-poor farmers and extension services: The role of community-based extension systems. In *International Conference on Innovations in Extension and Advisory Services* (pp. 15–18). Nairobi, Kenya.

Wiggins, G. P., & McTighe, J. (2005). *Understanding by design* (Expanded 2nd ed.). Association for Supervision and Curriculum Development.

Wilson, C., & Tisdell, C. (2001). Why farmers continue to use pesticides despite environmental, health and sustainability costs. *Ecological Economics, 39*(3), 449–462. https://doi.org/10.1016/S0921-8009(01)00238-5

Wojtczak, A. (2002). Medical education terminology. *Medical Teacher, 24*(4), 357–357. https://doi.org/10.1080/01421590220145699

Youdeowei, A. (2002). Integrated pest management practices for the production of vegetables. *Integrated Pest Management Extension Guide 4.* Ministry of Food and Agriculture (MOFA), Plant Protection and Regulatory Services Directorate (PPRSD), Ghana, with Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ).

Zuravliov, A. (2022). Thinking in systems: Structures behind teamwork. *Teamleadsky.* Retrieved from https://teamleadsky.com/articles/systems