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Participatory Pest Surveillance Across Fragmented Small Farms

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Abstract

Pest surveillance becomes particularly difficult in agricultural landscapes composed of numerous small and spatially fragmented farms. Individual farmers may observe early symptoms or pest populations within their own fields, yet fragmented reporting, inconsistent scouting practices, diagnostic uncertainty, and weak communication among neighboring farms can delay recognition of wider outbreaks. This study develops a simulation-based framework for evaluating participatory pest surveillance as a community-scale early-warning strategy for fragmented small-farm landscapes. Five surveillance arrangements are compared: isolated farm scouting, informal neighbor reporting, cluster-based scout networks, standardized participatory surveillance, and participatory surveillance integrated with diagnostic verification. A Participatory Pest Surveillance Capacity Index is constructed using spatial coverage, reporting timeliness, diagnostic reliability, collective response coordination, and farmer inclusion. Simulated capacity increases from 43.4 under isolated scouting to 56.5 for informal reporting, 73.1 for organized cluster scouting, 85.2 for standardized participatory surveillance, and 90.0 when community reporting is linked with professional diagnostic verification.

A complementary response-lag simulation indicates that the median interval between initial field detection and coordinated response can decline from approximately 12 days under isolated scouting to 2.6 days in the most integrated model. The findings suggest that farmer participation can expand surveillance reach beyond what extension or regulatory personnel can inspect directly, but volunteered observations require standardized protocols, training, feedback, and quality-control mechanisms. Fragmented landscapes should therefore be monitored as connected epidemiological spaces rather than as collections of independent holdings. The study concludes that effective participatory pest surveillance combines local observation density with verified diagnosis, spatially coordinated reporting, transparent alert thresholds, and extension or plant-health institutional support. The proposed framework offers a practical basis for designing early-warning systems for smallholder landscapes without presenting hypothetical surveillance outcomes as empirical field evidence.

Keywords: participatory pest surveillance, small farms, integrated pest management, farmer monitoring, early warning, plant health, agricultural biosecurity, pest detection

1. Introduction

Crop pests and diseases remain a persistent source of production risk because biological threats can develop rapidly while their earliest signs are often spatially dispersed and difficult to detect. Surveillance is therefore a fundamental component of plant-health protection, integrated pest management, and outbreak preparedness. Formal plant-health authorities usually conduct structured surveys for priority organisms, yet surveillance capacity is constrained by personnel, time, travel costs, and the large geographical area that must be examined. Brown and colleagues emphasize that observations made by land users, farmers, professionals, and other nonregulatory participants can significantly extend formal surveillance by increasing the number of people capable of noticing and reporting unusual plant-health events.

The surveillance problem becomes more complex in landscapes dominated by numerous fragmented small farms. Small holdings may contain different crops, planting dates, varieties, management practices, pesticide histories, vegetation boundaries, and surrounding habitats. These differences can produce highly heterogeneous pest distributions, but farm boundaries do not necessarily correspond to biological movement boundaries. Research in fragmented coffee landscapes has shown that pest abundance can respond to land-cover patterns and crop connectivity at scales extending beyond individual fields. Consequently, a farmer who evaluates only one holding may receive an incomplete picture of an emerging population that is already developing across neighboring farms.

Participatory surveillance offers a potential response by converting farmers from recipients of pest warnings into contributors to the monitoring system. Farmer Field School approaches provide a well-established institutional foundation for this idea. FAO describes integrated pest-management field schools as learning systems in which neighboring farmers repeatedly observe crop conditions, pest populations, natural enemies, damage, and other agroecosystem indicators, discuss their observations collectively, and use field evidence to inform management decisions. Such participatory learning is particularly relevant to small farms because the number of farmers present throughout the landscape can provide observation density that professional surveillance teams alone may be unable to achieve.

Digital reporting further expands this opportunity. The Fall Armyworm Monitoring and Early Warning System demonstrates how farmers, community focal persons, and extension personnel can record field observations through mobile tools and contribute data to larger surveillance platforms. FAO reports that these systems have been used to collect standardized field information, map pest occurrence, and support local and wider-scale early warning. Similarly, Plantwise demonstrates how trained plant-health intermediaries and plant clinics can connect farmer observations with diagnostic support and documented pest records. These initiatives demonstrate that participatory surveillance can combine local observation with organized technical validation.

Participation alone, however, does not guarantee reliable surveillance. Farmers differ in pest-identification skill, access to mobile technology, willingness to report, time available for scouting, and perception of economic risk. Opportunistic reporting can also become spatially biased because reports are generated more frequently where observers are active, confident, connected, or located near accessible areas. Brown and colleagues caution that passive and citizen-science surveillance data can be highly valuable while still requiring attention to observer bias, detection probability, training, and representativeness. The present study therefore develops a simulation-based framework for assessing how participatory pest surveillance might be structured across fragmented small farms. It compares increasingly coordinated surveillance models and examines how standardized scouting, farmer networks, diagnostic verification, and response protocols may reduce surveillance gaps without presenting simulated results as actual field observations.

2. Objectives of the Study

2.1 To Evaluate Surveillance Coverage Across Fragmented Small-Farm Landscapes

The first objective is to assess how different organizational models influence the geographical coverage of pest observation. Isolated scouting provides information at the level of individual holdings but may leave large gaps between farms whose owners do not scout consistently. Informal neighbor communication improves information exchange but remains dependent on personal relationships and variable reporting practices.

The study therefore evaluates whether organized clusters of neighboring farmers can create a denser surveillance network. Spatial coverage is treated not simply as the number of participating farmers but as the extent to which observations are distributed across different fields, crops, planting dates, landscape positions, and potential pest-entry points.

2.2 To Examine the Effect of Standardized Reporting and Diagnostic Verification

The second objective is to investigate how data quality changes when community observations are supported by standardized scouting procedures and professional diagnostic verification. Early warning becomes difficult when different farmers use different definitions of infestation or when visual symptoms are confused with nutrient deficiency, weather damage, natural enemies, or unrelated pest species.

The framework consequently distinguishes between farmer detection and confirmed diagnosis. Farmers can provide rapid local observations, while extension agents, plant doctors, laboratories, or other trained personnel can verify ambiguous or high-consequence reports. This layered design allows broad participation without assuming that every participant must possess specialist taxonomic expertise.

2.3 To Assess the Capacity for Coordinated Pest Response

The third objective is to evaluate whether participatory surveillance can shorten the interval between initial detection and collective action. Timely detection has limited practical value if neighboring farmers receive no warning, management thresholds remain unclear, or response recommendations differ across farms.

The study therefore considers communication, agreed alert thresholds, mapping, farmer-to-farmer notification, and links with extension and plant-health authorities as integral elements of the surveillance system. The central question is whether community-generated information can become actionable collective intelligence rather than a collection of disconnected observations.

3. Review of Literature

3.1 Farmer Participation in Integrated Pest Monitoring

Farmer Field Schools emerged from recognition that pest-management decisions require regular ecological observation rather than simple adoption of prescriptive pesticide schedules. FAO's Farmer Field School model brings neighboring farmers together throughout a cropping cycle to observe pests, beneficial organisms, crop development, weeds, disease symptoms, and other agroecosystem characteristics. Participants analyze observations collectively and use practical experimentation to strengthen their capacity for evidence-based pest management.

Van den Berg and Jiggins' evaluation of Farmer Field School experience emphasized that participatory learning can generate outcomes beyond immediate technical knowledge, including stronger group organization, decision capability, and local communication. The relevance to surveillance is significant because persistent monitoring requires farmer motivation and cooperation rather than one-time training. Surveillance networks are more likely to function when participants understand why observations matter and when information returns to the people who collected it.

Fall armyworm programs provide a practical example of this participatory logic. FAO's Farmer Field School guidance combines field scouting, pest identification, natural-enemy observation, experimentation, and locally adapted integrated pest-management decisions. Community monitoring is therefore not simply a mechanism for sending data upward to authorities. It can also help farmers distinguish between infestation and economically significant crop damage, understand biological control, and avoid unnecessary pesticide applications.

The literature consequently supports a surveillance model in which farmers serve both as observers and as local interpreters of agroecosystem change. However, the quality of participation depends on training, repeated practice, and feedback. Without these elements, farmer reporting may become inconsistent or may focus primarily on highly visible pests while missing less obvious symptoms.

3.2 Citizen Science, Passive Surveillance, and Diagnostic Quality

Plant-health surveillance literature increasingly recognizes that official surveys can be strengthened through wider networks of observers. Brown and colleagues describe passive surveillance as observations generated by land users and other members of the public who report pest or disease concerns outside formal regulatory inspection programs. Their review concludes that such reports can contribute valuable detections but that observer experience, reporting probability, spatial bias, and symptom distinctiveness influence data reliability.

Citizen-science approaches introduce greater structure by providing target species, reporting protocols, training, and predefined monitoring activities. Structured or semi-structured participation can reduce some of the uncertainty associated with purely opportunistic reports because participants are directed toward specific hosts, locations, times, or symptoms. Brown and colleagues further note that active and passive surveillance can be integrated, with professional survey teams used strategically to fill gaps or validate community-generated observations.

Plantwise offers another important model because farmers bring plant-health problems to trained plant doctors who diagnose symptoms, recommend management options, and record information. CABI characterizes accurate diagnosis as a foundational requirement because incorrect identification can lead to ineffective or inappropriate pest-management recommendations. Plant-clinic records can therefore function simultaneously as farmer advisory information and as surveillance intelligence.

Participatory surveillance should consequently incorporate diagnostic escalation. A farmer should be able to report a suspected problem quickly without waiting for perfect identification, but the system should differentiate among preliminary observation, probable identification, and confirmed diagnosis. This distinction is particularly important for invasive or regulated pests, where false alarms and delayed verification can both create substantial costs.

3.3 Fragmentation, Pest Movement, and Early-Warning Networks

Agricultural fragmentation creates both surveillance challenges and opportunities. Heterogeneous small farms can slow the spread of particular pests when host continuity is reduced, but fragmentation can also complicate monitoring because crop conditions and management practices vary sharply across short distances. Landscape research on insect pests demonstrates that pest abundance can be influenced by crop connectivity, elevation, adjacency, and surrounding land cover beyond the boundary of a single farm.

The implication is that surveillance scale should reflect pest ecology. Highly mobile insects may require monitoring across much wider areas than relatively sedentary pests. Pest movement may also be influenced by crop phenology, alternative hosts, wind, transport of plant material, or irrigation and drainage networks. A participatory network should therefore avoid assuming that administrative village boundaries or farm ownership lines define the relevant surveillance unit.

Digital early-warning systems offer one way to connect dispersed observations. FAO's monitoring platform for fall armyworm enabled standardized data to be recorded by farmers and agricultural workers and transmitted for mapping, validation, and risk assessment. The system illustrates how field-level observations can become more valuable when geographically aggregated rather than considered independently.

Early warning also depends on communication back to users. FAO's experience with fall armyworm emphasizes awareness, monitoring, real-time information, and stakeholder communication as interrelated components of pest management. A surveillance network that extracts reports without returning understandable alerts or management guidance risks participation fatigue and weak long-term engagement.

4. Research Methodology

4.1 Simulation-Based Comparative Design

The study adopts a simulation-based multicriteria design. No farm inspections, farmer surveys, trap counts, laboratory diagnoses, or actual outbreak data are presented as original observations. The analytical setting represents a hypothetical agricultural landscape containing numerous small and geographically fragmented holdings with variable crop calendars and management practices.

Five surveillance arrangements are compared. Isolated farm scouting represents independent farmer observation with minimal information exchange. Informal neighbor reporting allows farmers to exchange pest information through existing social relationships. Cluster scout networks organize representative farmers or community scouts across defined groups of neighboring farms. Standardized participatory surveillance introduces common scouting frequency, field forms or digital reporting, severity categories, and shared alert rules. Participatory surveillance with diagnostic verification adds trained extension personnel, plant doctors, or laboratory confirmation for uncertain and priority reports.

The model assumes that pest-management recommendations follow integrated pest-management principles and that surveillance itself does not automatically trigger pesticide application. Reports are interpreted alongside pest identity, crop stage, damage levels, natural enemies, and applicable economic or ecological thresholds.

4.2 Participatory Pest Surveillance Capacity Index

A Participatory Pest Surveillance Capacity Index (PPSCI) was developed using five criteria. Each criterion receives a standardized score between 0 and 100, where higher values represent stronger surveillance performance.

Table 1: Criteria and weighting structure of the Participatory Pest Surveillance Capacity Index

Criterion	Operational interpretation	Weight
Spatial surveillance coverage	Distribution of observations across farms, crops, landscape positions, and potential outbreak locations	0.25
Reporting timeliness	Speed with which suspicious pest observations enter the shared surveillance system	0.20
Diagnostic reliability	Accuracy and confidence associated with pest identification and severity assessment	0.20
Coordinated response capacity	Ability to convert reports into alerts, neighboring-farm action, extension follow-up, or verified management response	0.20
Farmer inclusion and continuity	Accessibility of participation and likelihood that farmers remain engaged across the production season	0.15

The index is expressed as:

$$PPSCI = 0.25C + 0.20T + 0.20D + 0.20R + 0.15I$$

where C represents coverage, T reporting timeliness, D diagnostic reliability, R coordinated response, and I farmer inclusion and continuity.

Spatial coverage receives the highest individual weight because fragmented landscapes require distributed observation. Timeliness, diagnosis, and coordinated response receive equal weights because early detection is ineffective if reports arrive late, identification is unreliable, or no coordinated decision follows.

4.3 Surveillance Workflow and Data-Quality Safeguards

The proposed surveillance workflow begins with routine field observation using a standardized scouting protocol. Participating farmers or local scouts record the crop, location, crop stage, suspected pest or symptom, severity category, affected area, relevant photographs where feasible, and any visible natural enemies or associated crop stress.

Reports meeting predefined concern criteria are transmitted to the local surveillance network. Neighboring farmers receive an alert indicating what to look for, while uncertain or high-risk cases are escalated for verification. A trained diagnostician may review photographs, visit the farm, collect specimens, or refer material to a laboratory depending on the pest and regulatory significance.

The framework deliberately separates reporting quality from reporting volume. A surveillance system should not be evaluated as successful merely because it receives many records. Duplicate observations, incorrect pest identification, unequal participation, missing location data, and overrepresentation of easily accessible farms can create misleading surveillance maps.

5. Analysis

5.1 Comparative Surveillance Capacity

The simulated results demonstrate a progressive increase in surveillance capability as the model moves from isolated observation toward standardized community monitoring and diagnostic integration. Isolated farm scouting achieves a PPSCI of 43.4. Farmers may recognize problems within their own holdings, but geographic gaps, delayed information exchange, and limited collective response substantially reduce system-level effectiveness.

Informal neighbor reporting increases the simulated index to 56.5. Local communication provides an important improvement because farmers can warn one another about visible pest activity. Nevertheless, participation remains uneven and diagnostic terminology may differ among individuals.

Cluster scout networks achieve a PPSCI of 73.1. Their principal advantage is deliberate spatial organization. Selected scouts or actively participating farmers provide more systematic coverage across groups of holdings and can serve as communication nodes between local farmers and extension services.

Table 2: Simulated performance of participatory pest-surveillance arrangements

Surveillance arrangement	Spatial coverage	Reporting timeliness	Diagnostic reliability	Coordinated response	Farmer inclusion	PPSCI
Isolated farm scouting	45	40	55	28	50	43.4
Informal neighbor reporting	60	58	52	50	63	56.5
Cluster scout network	76	72	70	73	74	73.1
Standardized participatory surveillance	88	86	82	85	84	85.2
Surveillance + diagnostic verification	90	90	95	88	86	90.0

Note: All numerical values are simulated for methodological demonstration and do not represent actual farm-surveillance measurements.

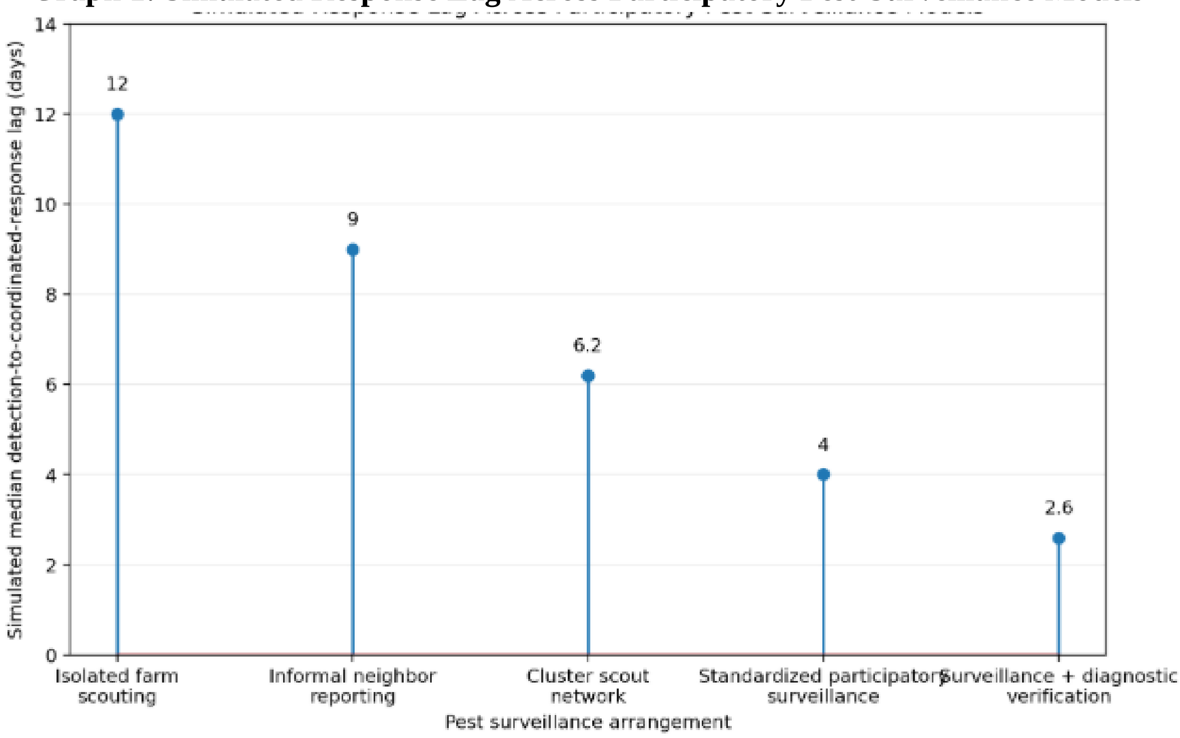
Standardized participatory surveillance reaches 85.2 because common scouting rules improve comparability across farms. The highest score of 90.0 occurs when participatory surveillance is linked with diagnostic verification. The result illustrates that farmer participation and professional plant-health expertise are complementary rather than competing surveillance models.

5.2 Detection-to-Response Lag

The second simulation examines the interval between the first meaningful field observation and a coordinated local response. Under isolated scouting, the simulated median lag is approximately 12 days because farmers may initially manage the problem independently or wait until damage becomes more obvious before seeking external advice.

Informal neighbor communication reduces this interval to approximately nine days. Cluster-based monitoring lowers the simulated lag to 6.2 days, while standardized participatory surveillance produces a four-day interval. The most integrated configuration reaches approximately 2.6 days because standardized reporting and diagnostic pathways are already defined.

Graph 1: Simulated Response Lag Across Participatory Pest-Surveillance Models



The graph should not be interpreted as an empirical estimate of actual outbreak-response speed. Real delays would depend on pest biology, farmer availability, extension capacity, communication infrastructure, travel distances, diagnostic difficulty, laboratory turnaround, weather, and institutional procedures.

The underlying principle is nevertheless important. Early warning requires not merely early observation but a predefined path connecting observation with verification and action. FAO's fall-armyworm monitoring experience illustrates the value of systems in which farmer-level observations are standardized, aggregated, validated, and used to inform pest-management decisions.

5.3 Spatial Coordination Across Farm Boundaries

The analysis indicates that surveillance units should be defined according to ecological risk rather than individual ownership alone. Farmers growing the same host crop within a connected area may require synchronized monitoring even if their fields are separated by property boundaries. Conversely, pest movement may be slower across landscapes where host plants are discontinuous.

Cluster design should therefore consider host distribution, planting dates, prevailing wind direction where relevant, irrigation pathways, local topography, market or seed movement, and known pest dispersal behavior. Landscape research demonstrates that different pests may respond to different spatial scales and habitat-connectivity patterns. Uniform surveillance radii are therefore unlikely to be appropriate for every pest.

Participatory mapping can help identify high-priority monitoring zones. Farmers can contribute knowledge of recurring infestation hotspots, volunteer host plants, abandoned fields, seed-exchange routes, storage facilities, irrigation edges, and locations where pest pressure commonly appears first. Professional plant-health staff can then combine this local information with biological and epidemiological evidence.

The resulting network should retain some structured sampling rather than depending entirely on reports from visible outbreaks. Brown and colleagues emphasize that volunteered surveillance data are valuable but can be geographically biased. A robust system can therefore combine farmer reports with periodic structured inspections designed specifically to cover farms or landscape zones that otherwise receive little observation.

6. Discussion

6.1 Farmers as Distributed Sensors, Not Substitute Inspectors

The central implication of this study is that farmer participation can greatly expand the observation capacity of pest-surveillance systems. Small farmers are physically present within agricultural landscapes every day and can recognize changes in crop condition long before occasional institutional inspections occur. This distribution of observers creates a substantial surveillance resource.

However, describing farmers as distributed sensors should not imply that public plant-health authorities can withdraw from surveillance responsibilities. Participatory reporting requires training, diagnostic support, data management, risk communication, and feedback. Brown and colleagues show that volunteer-based surveillance becomes more useful when observer behavior, reporting bias, training, and data validation are explicitly considered.

A layered model is therefore more appropriate. Farmers provide broad spatial observation and rapid local reporting. Community scouts or trained farmer facilitators provide additional standardization. Extension specialists and plant doctors support diagnosis and management interpretation. Laboratories and plant-protection organizations address cases requiring authoritative confirmation.

This division of responsibility can improve both scalability and credibility. Requiring specialists to inspect every field is unrealistic, while expecting every farmer to diagnose every pest accurately is equally unrealistic. Participatory surveillance performs best when each actor contributes according to comparative capability.

6.2 Standardization Without Eliminating Local Knowledge

A second implication concerns the tension between standardization and farmer knowledge. Surveillance systems require comparable data, but overly complicated forms can reduce participation. Farmers should not need to complete lengthy technical questionnaires before reporting a suspicious pest.A practical protocol could therefore use a small set of standardized fields: crop, location, date, crop stage, suspected problem, approximate severity, photograph where feasible, and whether the problem is spreading. More detailed information can be added during diagnostic follow-up.

Farmer Field School experience demonstrates why local ecological interpretation should remain part of this process. Farmers can observe pest-natural enemy relationships, crop condition, damage patterns, and management histories that a remote reporting platform cannot capture fully. The surveillance system should consequently standardize the minimum information needed for comparison while preserving qualitative local observations that may explain unusual patterns.

Training should also emphasize differentiation between pest presence and the need for intervention. Surveillance can unintentionally encourage pesticide overuse if every reported insect becomes interpreted as a control emergency. Integrated pest-management principles require identification of beneficial organisms, pest abundance, crop growth stage, damage, and threshold conditions before intervention decisions are made.

This distinction is particularly important for invasive pests, where fear and unfamiliarity may cause excessive pesticide use. FAO's fall-armyworm initiatives combined monitoring with Farmer Field School education specifically to strengthen ecological understanding and reduce inappropriate management responses.

6.3 Participation, Trust, and Long-Term Network Sustainability

Participatory surveillance systems frequently face a challenge after the initial training or outbreak emergency ends. Reporting can decline when farmers do not receive feedback, when alerts appear to produce no response, or when participation becomes an additional unpaid burden with little local value.
Feedback should therefore be treated as an operational requirement. Farmers who submit reports should receive confirmation that the observation was received, an indication of diagnostic status, relevant management guidance, and information about whether similar observations have been reported nearby.

Aggregated surveillance maps can further strengthen participation when they are understandable and locally useful. A farmer who sees how individual reports contribute to a community risk map is more likely to understand the collective value of surveillance. FAO's FAMEWS model illustrates how farm-level reports can support maps and broader risk assessment.

Inclusion also requires non-digital reporting options. Smartphone applications can improve speed and geolocation, but systems that depend entirely on advanced devices or continuous connectivity may exclude older farmers, poorer households, remote communities, or participants with limited digital literacy. Local extension workers, farmer facilitators, telephone reporting, plant clinics, and group meetings can provide complementary channels.

Trust is especially important where reports could potentially influence quarantine, crop destruction, market access, or regulatory intervention. Farmers may avoid reporting suspicious pests if they fear economic penalties or loss of control over farm information. Data-governance rules should therefore explain how farm-level information will be used and distinguish advisory surveillance from regulatory procedures where applicable.

7. Conclusion

Participatory pest surveillance offers a strong institutional approach for improving early warning across agricultural landscapes dominated by fragmented small farms. Pest populations move through ecological space rather than according to farm ownership boundaries, making isolated field observation insufficient for many emerging threats. By linking neighboring farmers through common scouting methods and communication channels, surveillance can become spatially broader and temporally faster.

The simulation developed in this study demonstrates a progressive improvement in surveillance capacity as coordination increases. The Participatory Pest Surveillance Capacity Index rises from approximately 43.4 under isolated scouting to 90.0 when standardized farmer participation is combined with diagnostic verification. The corresponding simulated detection-to-response lag declines from approximately 12 days to 2.6 days. These values are illustrative rather than empirical, but they clarify how surveillance performance can depend simultaneously on coverage, timeliness, diagnosis, coordination, and inclusion.

The analysis also demonstrates that participation should complement rather than replace professional plant-health systems. Farmers can provide high-density observation, while trained diagnosticians, extension personnel, laboratories, and regulatory authorities provide confirmation, interpretation, and institutional response. Integrating these capacities allows surveillance to expand without sacrificing data quality. Structured sampling should also remain part of the system because opportunistic reports can overrepresent locations containing more active or better-connected observers.

Future empirical research should test the framework in real small-farm landscapes using georeferenced scouting records, trap data, farmer-reported observations, laboratory diagnoses, extension-response times, participation rates, and actual pest-spread outcomes. Comparative trials could examine whether cluster surveillance detects outbreaks earlier than conventional extension inspection, whether diagnostic verification reduces false reports, and whether shared alerts improve integrated pest-management decisions among neighboring farms. Longitudinal assessment would also reveal whether community participation can be sustained after the initial outbreak or project period. The broader goal should be the development of plant-health systems in which farmer knowledge, professional diagnostics, digital tools, and landscape-scale epidemiological reasoning operate as an integrated early-warning network.

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