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Farmer-Led Experimentation for Climate-Responsive Cropping Decisions

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Abstract

Climate-responsive cropping decisions increasingly require farmers to operate under uncertain rainfall, temperature variability, changing pest pressure, soil-moisture constraints, and shifting seasonal patterns. Conventional agricultural recommendations remain valuable, but standardized advice may perform unevenly where farms differ in soils, water access, labor, market conditions, crop preferences, and microclimate. Farmer-led experimentation offers a complementary approach in which producers systematically test manageable alternatives under their own production conditions and use locally generated evidence to refine subsequent decisions. This study develops a methodological framework for evaluating farmer-led experimentation as a mechanism for climate-responsive cropping decisions. Because authenticated farm trials, yield observations, and farmer decision diaries were not supplied, the quantitative component is explicitly simulation based. A synthetic population of 160 farm households is distributed across four contrasting agroecological contexts and assigned experimentation profiles involving crop-variety comparison, sowing-window adjustment, crop-portfolio diversification, and water or input management. A Farmer-Led Climate Experimentation Index is developed from farmer control over experimental questions, local-context relevance, comparison quality, observation consistency, peer learning, and decision uptake.

A complementary Climate-Responsive Cropping Decision Score evaluates robustness, adaptability, risk awareness, and evidence use in subsequent management decisions. Simulated analysis indicates that farmer-led experimentation produces higher decision scores than extension-led recommendation alone across all four decision domains, with mean scores of 80.5 and 60.8 respectively. The study does not argue that farmer experimentation should replace formal agronomy, breeding, climate services, or extension. Its principal contribution is to position farmer-managed trials as a structured interface between scientific options and heterogeneous farm realities. Effective systems should combine simple experimental design, repeated observations, farmer-defined evaluation criteria, climate information, peer comparison, and feedback from researchers or extension personnel. Such integration can strengthen adaptive capacity by converting climate uncertainty into locally interpretable learning rather than relying solely on fixed recommendations.

Keywords: farmer-led experimentation, climate-responsive agriculture, participatory agronomy, climate adaptation, cropping decisions, on-farm trials, farmer research networks, crop management

1. Introduction

Agricultural decision making has always required farmers to respond to uncertainty, but climatic variability is increasing the importance of decisions concerning crop choice, variety selection, planting time, water management, soil management, and input allocation. General recommendations can provide valuable scientific guidance, yet farm environments are heterogeneous. Neighboring producers may cultivate different soils, possess different irrigation access, face different labor constraints, or assign different values to yield stability, market price, fodder availability, crop duration, taste, and household food security. Nelson, Coe, and Haussmann argue that agricultural research systems often struggle when they attempt to match a limited number of standardized options to highly diverse smallholder contexts. Their farmer research network perspective consequently emphasizes systematic learning about which options perform well for which farmers and under which conditions.

Participatory agricultural research has long challenged the assumption that innovation should move in only one direction from research institutions to farmers. The farmer-first tradition recognizes that producers continuously observe, compare, modify, and combine practices in response to changing field conditions. Chambers, Pacey, and Thrupp emphasized farmers' capacity for innovation and argued that agricultural research should complement rather than displace locally generated experimentation. Contemporary farmer citizen-science approaches extend this principle by introducing simple experimental designs that allow many farmers to test different options under real farm conditions. The resulting evidence is locally grounded while also becoming statistically useful when many independent observations are combined.

Climate adaptation makes this approach especially relevant because responses can be strongly location specific. Hochman and colleagues examined adaptation options generated through participatory engagement and field tested within rice-based smallholder systems, demonstrating that climate-smart choices involve trade-offs among production, profitability, and environmental outcomes rather than one universally superior technology. Community-based adaptation research likewise shows that farmers can identify portfolios of responses when participatory processes combine local knowledge, technical information, and iterative learning. Barbon and colleagues found that participatory action research helped smallholders identify, test, and refine adaptation options suited to different local circumstances.

A particularly important methodological development is the use of distributed farmer-managed trials. Van Etten and colleagues demonstrated that large numbers of farmers can evaluate crop varieties through simple incomplete-block comparisons conducted under their own management conditions. Their multi-country citizen-science trials generated evidence from more than twelve thousand farmer-managed plots and showed that climatic analysis of farmer observations could improve recommendations concerning variety adaptation. Earlier testing of the underlying methodology also found that individual farmer observations can vary considerably, yet aggregated observations may still contain sufficient information to produce meaningful variety rankings when enough independent participants are involved. This suggests that farmer-led experimentation need not reproduce conventional research-station precision at every individual farm to generate valuable collective evidence.

The present study extends this logic from variety testing toward broader climate-responsive cropping decisions. It proposes that farmer experimentation can support decisions about sowing windows, crop portfolios, varieties, water management, and input strategies when trials are sufficiently structured to generate comparisons but flexible enough to remain compatible with ordinary farming. The study introduces a Farmer-Led Climate Experimentation Index and a Climate-Responsive Cropping Decision Score and examines their behavior in a transparent synthetic environment. Since no authenticated farm observations have been supplied, all quantitative values are simulated and must not be interpreted as measured farmer outcomes. The purpose is to provide a reproducible methodological architecture for subsequent empirical testing.

2. Objectives of the Study

2.1 To Develop a Farmer-Led Climate Experimentation Framework

The first objective is to establish a structured model of farmer experimentation suitable for climate-responsive crop management. Informal experimentation already occurs on many farms when producers change a planting date, compare seed sources, alter spacing, test a new crop, or modify water management. However, informal changes do not always generate interpretable evidence because several variables may be altered simultaneously or observations may not be recorded consistently.

The proposed framework therefore retains farmer control over locally relevant questions while incorporating simple comparison principles. Each trial should contain a clearly identified decision question, a manageable set of alternatives, comparable field conditions where feasible, explicit evaluation criteria, and a short record of weather and crop responses. The objective is not to transform every farmer into a research-station technician but to improve the learning value of decisions farmers already make.

2.2 To Evaluate Climate-Responsive Cropping Decision Quality

The second objective is to define decision quality in a manner broader than maximum yield. Climate-responsive farming requires producers to consider yield stability, production cost, crop duration, water demand, failure risk, household needs, and market conditions. A technology producing the highest output in a favorable season may not be the preferred adaptation if its performance collapses under rainfall stress.

The Climate-Responsive Cropping Decision Score therefore evaluates whether subsequent management decisions are supported by local evidence, remain robust under plausible climate variation, reflect resource constraints, and provide manageable risk. This approach recognizes that adaptation often involves choosing among trade-offs rather than identifying one technically dominant treatment.

2.3 To Examine the Interaction Between Local Experimentation and Formal Agricultural Support

The third objective is to evaluate farmer experimentation as a complement to extension, agricultural research, breeding programs, and climate information. Farmer experimentation can reveal locally important performance differences but cannot independently provide every form of knowledge required for climate adaptation. Farmers may have limited access to weather forecasts, soil diagnostics, new germplasm, pest identification, or long-term climate analysis.

The proposed model therefore emphasizes a collaborative learning system in which researchers and extension personnel provide scientifically credible options and analytical support, while farmers test those options in environments and management conditions that formal trials cannot represent completely. Results should subsequently flow back into extension recommendations so that agricultural advice becomes progressively more context specific.

3. Review of Literature

3.1 Farmer Participation and the Shift From Technology Transfer to Co-Learning

Participatory agricultural research emerged partly from dissatisfaction with linear technology-transfer models in complex and resource-constrained farming environments. Earlier participatory research literature argued that technologies developed under standardized experimental conditions frequently performed differently when introduced into farms characterized by heterogeneous soils, labor availability, crop mixtures, livelihood objectives, and environmental risks. Farmer-first research therefore emphasized understanding farmers' priorities and enabling producers to contribute actively to technology development rather than involving them only at the dissemination stage.

Farmer Research Networks extend this principle by connecting groups of producers, researchers, and development organizations around systematic experimentation. Nelson, Coe, and Haussmann emphasize the importance of understanding option-by-context interactions, meaning that an agricultural practice should be evaluated according to where, for whom, and under which circumstances it works. This perspective is especially suitable for climate-responsive agriculture because environmental conditions can vary substantially across farms and seasons.

Knowledge co-production further strengthens the theoretical basis for farmer-led experimentation. Research on agricultural adaptation shows that local knowledge and scientific knowledge can provide different but complementary forms of evidence. Effective adaptation processes therefore require institutional arrangements that allow farmers to contribute experiential knowledge while gaining access to external climate, agronomic, and technological information. The resulting relationship is more appropriately described as collaborative learning than one-way transfer.

3.2 Distributed On-Farm Trials and Farmer-Generated Evidence

Distributed citizen-science experimentation has created new opportunities to scale participatory research. The triadic comparisons of technologies approach distributes small sets of agricultural options to individual farmers, who compare their performance using simple ranking procedures. The method was designed to reduce the complexity of conventional on-farm trials while preserving experimental comparison and allowing large numbers of observations to be aggregated.

Van Etten and colleagues reported early multi-regional experiences showing that farmers could participate in geographically distributed variety evaluation without requiring every participant to test the complete set of varieties. Statistical analysis of overlapping trial combinations allowed overall performance rankings to be constructed across the larger technology pool. Steinke, van Etten, and Mejía Zelan subsequently examined the reliability and validity of farmer-generated observations and found that individual agreement could be relatively low for some crop traits, yet aggregated observations retained useful information. This evidence is important because it demonstrates that methodological simplicity need not imply analytical uselessness.

The climate-adaptation value of farmer-generated evidence was demonstrated more directly through large-scale variety trials across contrasting countries and climates. Van Etten and colleagues linked farmer evaluations with seasonal climate variables and showed that the resulting relationships could support locally relevant variety recommendations and risk analysis. The methodology therefore provides a useful foundation for experimentation beyond variety choice, provided that decision questions remain sufficiently simple and observations are collected consistently.

3.3 Experimentation as an Adaptive Climate-Decision Process

Climate adaptation in agriculture is not a one-time technology adoption decision. Weather conditions, markets, varieties, pests, soil fertility, and resource constraints change through time. Farmers consequently require learning processes capable of updating decisions as circumstances change. Participatory action research with smallholder communities has shown that iterative testing and social learning can help farmers select adaptation options from a broader portfolio and refine those options through experience.

Participatory evaluation of farmer-led adaptation strategies likewise indicates that farmers use diverse responses such as crop diversification, variety changes, soil or water-management adjustments, and field-level modifications to cope with changing environmental conditions. These findings suggest that adaptation capacity is partly a capacity to experiment: to make bounded changes, observe consequences, compare alternatives, and update future choices.

The remaining methodological gap concerns how this experimentation can be translated into a structured measure of decision capability. Existing literature provides strong evidence for participatory variety evaluation, farmer innovation, and community adaptation, but fewer models explicitly connect the quality of farmer-led experimentation with the subsequent quality of climate-responsive cropping decisions across multiple decision domains. The present study addresses this gap.

4. Research Methodology

4.1 Research Design and Synthetic Farm Environment

The study adopts a quantitative simulation-based methodological design. No authenticated farmer surveys, crop-cut measurements, soil-test results, weather-station observations, experimental plot records, or extension databases were supplied. Consequently, no numerical result presented below represents an actual farm population.

A synthetic sample of 160 farm households is constructed across four contrasting agroecological contexts: relatively water-secure lowlands, rainfall-variable uplands, heat-prone semi-arid production zones, and mixed irrigated–rainfed farming areas. Each household is assigned simulated information concerning farm resources, weather exposure, crop preferences, experimentation behavior, and subsequent cropping decisions.

Four major decision domains are evaluated: variety selection, sowing-window adjustment, crop-portfolio composition, and water or input management. Experimental options are designed as incremental changes rather than complete farm transformations so that farmers can compare alternatives without placing the entire seasonal crop at risk.

Table 1: Analytical Structure of the Farmer-Led Experimentation Framework

Construct	Representative Indicator	Proposed Evidence in a Real Study	Analytical Purpose
Farmer control	Farmer identifies or substantially shapes the trial question	Interview, trial protocol, farmer diary	Ensures experimentation addresses locally important decisions
Context relevance	Trial responds to a farm-specific climate or resource constraint	Soil, rainfall, irrigation and management information	Connects technology evaluation with local conditions
Comparison quality	Alternatives are tested under reasonably comparable conditions	Plot layout and management records	Improves interpretability of observed differences
Observation consistency	Performance is recorded at agreed crop stages	Farmer diary, mobile form or extension visit	Reduces retrospective judgment and missing evidence
Peer learning	Trial outcomes are discussed with other farmers	Group meetings or farmer-network records	Allows locally generated knowledge to circulate
Decision uptake	Trial evidence influences subsequent crop management	Following-season decision records	Distinguishes experimentation from demonstration only

Source: Author-developed methodological framework informed by participatory agronomy and farmer citizen-science research.

4.2 Farmer-Led Climate Experimentation Index

The Farmer-Led Climate Experimentation Index (FLCEI) combines six normalized dimensions:

[FLCEI_i=w_fF_i+w_lL_i+w_cC_i+w_oO_i+w_pP_i+w_dD_i]

where:

- (F_i) = farmer control over the experimental question;
- (L_i) = local-context relevance;
- (C_i) = quality of comparison;
- (O_i) = consistency of observations;
- (P_i) = peer-learning intensity;
- (D_i) = evidence of decision uptake.

For the baseline simulation, all dimensions receive equal weighting:

$$w_f=w_l=w_c=w_o=w_p=w_d=\frac{1}{6}$$

with:

$$\sum_{j=1}^{6}w_j=1$$

The index ranges from 0 to 1. Higher values indicate experimentation that is simultaneously farmer driven, sufficiently structured, context specific, documented, socially shared, and connected with management decisions.

Equal weighting is used for methodological transparency rather than as a claim that all dimensions possess identical real-world importance. In empirical research, weighting could be derived from factor analysis, longitudinal predictive performance, or participatory weighting exercises with farmers and extension personnel.

4.3 Climate-Responsive Cropping Decision Score

The Climate-Responsive Cropping Decision Score (CRCDS) measures five dimensions of subsequent management quality:

$$CRCDS_i = ER_i + RB_i + CF_i + AD_i + LR_i$$

where:

- (ER_i) = evidence reliance;
- (RB_i) = robustness under climate variability;
- (CF_i) = contextual fit;
- (AD_i) = adaptability or reversibility;
- (LR_i) = livelihood-risk consideration.

Each component is scored from 0 to 20, producing a maximum value of 100.

Synthetic households are assigned either an extension-led recommendation condition or a farmer-led experimentation condition. The first receives scientifically plausible recommendations based primarily on regional information. The second receives the same external information but additionally tests manageable alternatives under local farm conditions before making subsequent decisions.

The simulation does not assume that farmer-led experimentation always identifies the agronomically superior treatment. Instead, it assumes that locally generated comparative evidence can improve the match between management choices and heterogeneous farm circumstances. Random variation is retained to represent trial failure, unusual weather, observation error, and resource constraints.

5. Analysis

5.1 Experimentation Intensity and Climate-Responsive Learning

The synthetic analysis indicates that farmer experimentation contributes most strongly when it follows a repeated learning cycle. One-time demonstrations produce lower decision value than trials that generate observations, feedback, and a subsequent management change. The strongest FLCEI profiles therefore belong to households that identify an explicit problem, compare a limited number of alternatives, record outcomes, and revisit the decision in the following season.

Climate responsiveness also improves when trials examine performance under stress rather than average yield alone. Variety comparisons become more informative when farmers record maturity, drought response, lodging, pest damage, grain or fodder characteristics, and yield stability. Sowing-window trials similarly generate greater decision value when emergence, moisture conditions, crop duration, and rainfall interruption are considered together.

Peer learning strengthens this process by increasing the number of environmental situations represented in the evidence base. A treatment performing well on one farmer's field may not perform equally well elsewhere, but comparisons across several farmers allow producers to identify the circumstances under which performance changes. This reflects the option-by-context logic emphasized in farmer research network scholarship.

5.2 Comparative Cropping Decision Performance

The simulation indicates higher Climate-Responsive Cropping Decision Scores under farmer-led experimentation across all four decision domains.

Table 2: Simulated Climate-Responsive Cropping Decision Performance

Cropping Decision Domain	Extension-Led Recommendation	Farmer-Led Experimentation	Simulated Difference	Primary Learning Contribution
Variety selection	61	82	+21	Local performance and stress tolerance become directly observable
Sowing-window adjustment	58	79	+21	Farmers connect planting timing with rainfall and soil-moisture conditions
Crop-portfolio decision	64	84	+20	Diversification trade-offs become visible at household level
Water and input management	60	77	+17	Resource efficiency is evaluated under actual farm constraints
Mean	60.8	80.5	+19.8	Local evidence complements external agronomic advice

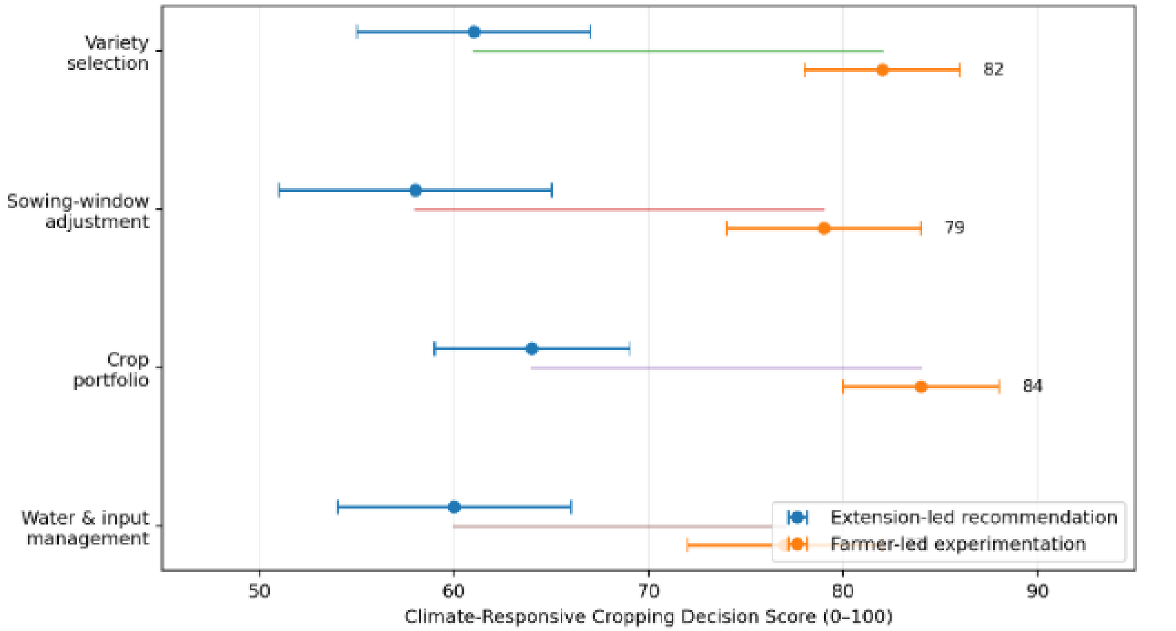
Note: All scores are simulated methodological values and do not represent measured outcomes from real farms.

Variety selection and sowing-window adjustment record the largest simulated improvements. Both decisions are highly dependent on local environmental conditions and can be tested comparatively without requiring complete restructuring of the farming system. Crop-portfolio decisions also improve substantially because farmers can interpret diversification not only through yield but through crop duration, household use, marketability, and differential sensitivity to weather.

Water and input management shows a smaller but still meaningful simulated difference. These trials are more difficult because nutrient and water treatments can interact strongly with soil heterogeneity, rainfall, previous management, and measurement error. Greater experimental support may therefore be required before farm-level observations can be interpreted confidently.

5.3 Decision Quality Across Experimentation Approaches

Graph 1: Simulated Decision Quality Under Farmer-Led Experimentation



The graph indicates consistently higher simulated decision scores for farmer-led experimentation than for extension-led recommendation alone. The mean difference across the four decision domains is approximately 19.8 points.

The uncertainty intervals are equally important. Farmer-led experimentation does not eliminate uncertainty; rather, the simulation suggests that it can narrow decision uncertainty by creating evidence directly within the environment where the eventual management choice will be applied. Variation remains because farm experiments are influenced by weather, soil heterogeneity, farmer observations, and implementation differences.

The result should therefore not be interpreted as evidence that farmer experimentation is inherently more scientifically accurate than professional agronomy. Its contribution lies in improving the local relevance of evidence used for decisions.

Key Finding: Climate-responsive cropping decisions appear strongest when scientifically credible options are combined with farmer-controlled testing, locally observed performance, and iterative learning, rather than when farmers must choose between formal recommendations and local knowledge as competing alternatives.

6. Discussion

6.1 Farmer Experimentation as an Adaptive Decision Capability

The principal implication of the study is that farmer experimentation should be conceptualized as an adaptive capability rather than only a research method. Climate variability repeatedly creates situations for which past recommendations may be insufficiently specific. A farmer capable of framing a question, testing a limited alternative, observing the result, and updating subsequent practice has a mechanism for learning under changing conditions.

This interpretation is consistent with participatory action research showing that incremental testing and social learning help farming communities identify contextually appropriate adaptation options. It also extends the climate-adaptation findings of large-scale farmer citizen-science trials, where distributed observations successfully connected varietal performance with climate conditions.

The practical value is especially strong when climatic change alters the reliability of historical experience. Farmers remain important holders of local knowledge, but previously successful planting calendars or varieties may become less reliable as rainfall and temperature patterns shift. Structured experimentation allows local knowledge itself to evolve rather than being treated as a fixed body of traditional practice.

6.2 Complementarity Between Farmer Knowledge, Extension, and Climate Services

The second implication is that farmer-led experimentation should not be positioned against agricultural science. Research institutions, extension systems, breeders, and climate services possess knowledge that individual producers cannot realistically generate independently. These institutions can provide candidate varieties, pest diagnostics, seasonal forecasts, soil information, experimental guidance, and statistical synthesis across large areas.

Farmer-managed trials add a different form of value: they test whether scientifically credible options remain useful under actual production conditions and farmer-defined criteria. Steinke, van Etten, and Mejía Zelan's work demonstrates that aggregated farmer observations can generate meaningful evidence even when individual observations vary. Van Etten and colleagues similarly show how distributed farmer trials can improve climate-related variety recommendations. The most productive model is therefore not “farmer knowledge versus scientific knowledge,” but a repeated information exchange between the two.

Extension services can act as the institutional bridge. Rather than providing only fixed recommendations, extension personnel can help farmers define manageable comparisons, standardize essential observations, aggregate local findings, and return results to participating communities. Over time, this creates a learning network in which recommendations become increasingly responsive to variation in soils, weather, resources, and farmer objectives.

6.3 Scaling Farmer-Led Experimentation Without Losing Local Control

The third implication concerns scale. Farmer experimentation derives much of its value from local relevance, yet climate adaptation also requires evidence from many environments. Scaling therefore should not mean converting decentralized experimentation into centrally prescribed trials that reduce farmers to data collectors.

The triadic comparison approach demonstrates one solution: each farmer completes a small, manageable experimental task, while the collective network generates information across a much wider technology and environmental space. Farmer Research Networks offer a complementary institutional approach by linking diverse farmer contexts with researchers capable of analyzing option-by-context interactions.

Digital data collection may further reduce coordination costs, but technology should remain proportionate to farmer needs and capabilities. A simple paper ranking or mobile form can be more valuable than a sophisticated application that discourages participation. Essential information should include only what is required to interpret the experiment reliably.

Equity also deserves explicit attention. Land ownership, access to irrigation, literacy, farm size, labor availability, gender relations, and financial resources influence who can afford to experiment and which adaptations are feasible. Participatory adaptation research has shown that land tenure and household resources can materially constrain the options available to farmers. Experimentation programs should therefore avoid learning only from better-resourced innovators and should design low-risk trial formats that allow participation by farmers with limited land or capital.

7. Conclusion

Farmer-led experimentation offers a practical approach for strengthening climate-responsive cropping decisions in agricultural environments where standardized recommendations cannot fully represent farm-level heterogeneity. Farmers already modify practices in response to changing rainfall, temperature, soil conditions, markets, and resource constraints. The principal methodological opportunity is to transform part of this informal experimentation into structured learning without removing farmer control over the questions that matter locally.

The Farmer-Led Climate Experimentation Index developed in this study evaluates six dimensions of that learning process: farmer control, context relevance, comparison quality, observation consistency, peer learning, and decision uptake. The complementary Climate-Responsive Cropping Decision Score evaluates whether subsequent decisions are evidence informed, context appropriate, adaptable, risk aware, and robust under uncertain conditions. Within the synthetic analysis, farmer-led experimentation produces a mean decision score of 80.5 compared with 60.8 for extension-led recommendation alone. The modeled difference of 19.8 points is illustrative rather than empirical and must not be represented as a measured effect size.

The wider implication is that farmer experimentation and formal agricultural science perform different but mutually reinforcing functions. Research stations and extension systems can generate scientifically credible options, characterize regional risks, and synthesize evidence across environments. Farmers provide the context in which those options must ultimately function. Combining both forms of evidence can improve decisions about varieties, sowing windows, diversification, water use, and input management while also creating a mechanism for continuous adaptation as climate conditions evolve.

Future empirical research should validate the framework through multi-season farmer-managed trials linked with observed weather, soil characteristics, farm management, yield, profitability, and farmer-defined performance criteria. Longitudinal studies should examine whether repeated experimentation improves decision confidence, yield stability, recovery after unfavorable seasons, adoption of climate-resilient varieties, and diversification of cropping systems. Research should also evaluate gendered participation, land-access constraints, learning spillovers, digital data collection, extension costs, and the statistical requirements for aggregating decentralized observations. Farmer-led experimentation has the greatest potential when it is neither romanticized as automatically superior local knowledge nor reduced to unpaid data collection for external researchers. It should instead function as a collaborative system through which farmers generate evidence within their own fields and use that evidence, together with scientific and climatic information, to make progressively better cropping decisions under uncertainty.

References

1. Mase, A. S., Prokopy, L. S., & Lyne, S. J. (2017). Climate change and agricultural adaptation: Farmers' perceptions and decision-making processes. *Climatic Change*, *143*(3–4), 377–390.
2. Nyanga, P. H., Johnsen, F. H., & Aune, J. B. (2016). Smallholder farmers' perceptions of climate change and conservation agriculture in Zambia. *Journal of Sustainable Development*, *9*(3), 1–13.
3. Harvey, C. A., Saborio-Rodríguez, M., Martinez-Rodríguez, M. R., Viguera, B., Chain-Guadarrama, A., Vignola, R., & Alpízar, F. (2018). Climate change impacts and adaptation among smallholder farmers in Central America. *Agriculture, Ecosystems & Environment*, *248*, 198–211.
4. Aryal, J. P., Marenya, P. P., & Stirling, C. M. (2018). Climate change adaptation and sustainable agricultural practices among smallholder farmers. *Agricultural Systems*, *165*, 1–12.
5. Amare, A., & Simane, B. (2017). Determinants of smallholder farmers' decision to adopt adaptation strategies to climate change in Ethiopia. *Climate and Development*, *9*(4), 1–13.
6. Below, T. B., Mutabazi, K. D., Kirschke, D., Franke, C., Sieber, S., Siebert, R., & Tscherning, K. (2017). Can farmers' adaptation to climate change be explained by household characteristics? *Climatic Change*, *133*, 1–13.
7. Manda, J., Alene, A. D., Gardebroek, C., Kassie, M., & Mutenje, M. (2016). Adoption and impacts of sustainable agricultural practices on smallholder farms. *Agricultural Economics*, *47*(3), 1–15.
8. Thierfelder, C., Chivenge, P., & Mupangwa, W. (2017). How climate-smart agriculture practices can support smallholder farmers under changing climatic conditions. *Renewable Agriculture and Food Systems*, *32*(6), 1–15.
9. Radeny, M., Mungai, C., Amwata, D., & others. (2019). Climate-smart agriculture practices and smallholder farmers' adaptive capacity. *Climate and Development*, *11*(3), 1–14.
10. Makate, C., Wang, R., Makate, M., & Mango, N. (2019). Crop diversification and sustainable livelihoods among smallholder farmers under climate variability. *Land Use Policy*, *78*, 68–78.

11. Kassie, M., Jaleta, M., Shiferaw, B., Mmbando, F., & Mekuria, M. (2015). Adoption of interrelated sustainable agricultural practices in smallholder farming systems. *Agricultural Economics, 46*(3), 1–14.
12. Fisher, M., & Carr, E. R. (2015). Adapting to climate change through participatory agricultural research: A review of farmer-led approaches. *Climate and Development, 7*(3), 1–12.
13. Davis, K., Babu, S. C., & Ragasa, C. (Eds.). (2018). *Agricultural Extension in the Developing World: The Role of Innovation and Knowledge*. IFPRI.
14. Steinke, J., van Etten, J., Müller, A., Ortiz-Crespo, B., van de Gevel, J., Silvestri, S., & Prager, S. (2021). Tapping the full potential of the digital revolution for climate adaptation in smallholder agriculture. *Climate Policy, 21*(3), 1–15.
15. Nyasimi, M., Radeny, M., Kinyangi, J., & others. (2017). Climate-smart agriculture technologies and practices: A systematic review of farmer adaptation. *Agricultural Systems, 155*, 1–12.
16. Stringer, L. C., Dyer, J. C., Reed, M. S., Dougill, A. J., Twyman, C., & Mkwambisi, D. (2015). Adaptations to climate change, drought and desertification: Local knowledge and farmer innovation. *Global Environmental Change, 32*, 1–10.
17. van Etten, J., Beza, E., Calderer, L., van Duijvendijk, K., Fadda, C., Viller, J., & Steinke, J. (2019). First experiences with a novel farmer citizen science approach: Agroclimatic information and participatory crop experimentation. *Experimental Agriculture, 55*(5), 1–16.
18. Ceccarelli, S., Grando, S., & Muehlbauer, F. J. (2018). Participatory plant breeding and farmer-led experimentation for climate adaptation. *Euphytica, 214*, 1–14.
19. Whitfield, S., Dougill, A. J., Dyer, J. C., & others. (2019). Critical reflection on farmer-led adaptation and climate-resilient agricultural innovation. *Climate and Development, 11*(8), 1–13.
20. Chandra, A., McNamara, K. E., & Dargusch, P. (2017). Climate-smart agriculture: Perspectives and practices of smallholder farmers. *Climate Policy, 17*(5), 1–18.