Online ISSN Applied for

Review Article

Agro-Science Letters
Vol. 2, No. 1, January–March 2026

Digital and Participatory Extension Approaches in Vegetable Farming

Chandra Prakash Yadav*

[1] *Senior Project Associate IRRI Varansi*

* Corresponding author. E-mail: chandraprakashyadav0176@gmail.com

https://doi.org/10.48165/asl.2026.2.01.03

ARTICLE INFO

Keywords
traditions
shaped
vegetable
farmers
agronomic

ABSTRACT

Two distinct extension traditions have shaped how vegetable farmers gain agronomic knowledge: participatory approaches that treat farmers as co-designers of innovation, and digital approaches that use mobile phones, apps, and increasingly artificial intelligence to deliver advice at scale. This review examines both traditions and the growing literature on where they intersect. Evidence from the World Vegetable Center and related participatory-design frameworks shows that the appropriate level of farmer participation depends on how ready an innovation is for local use. Evidence from digital extension programmes shows real reach and adoption gains, but also a risk that farmer-centred design intentions erode as digital platforms scale. Machine-learning tools for vegetable pest and disease diagnosis show high technical accuracy in controlled studies, but limited evidence yet on real-world farmer uptake. Digital Farmer Field Schools, which combine both traditions directly, show some of the strongest documented knowledge gains of any approach reviewed here, though evidence on their cost-effectiveness and durability over time remains thin. The review argues that combining participatory design with digital delivery, rather than treating them as substitutes, offers the most promising path for reaching vegetable farmers at both scale and relevance.

INTRODUCTION

Extension research has traditionally treated "participatory" and "digital" approaches as separate literatures: one rooted in rural sociology and farmer empowerment, the other in information technology and scale economics. Vegetable farming sits at an interesting intersection of both. Vegetable production is judgment-intensive — diagnosing pest pressure, timing pesticide withdrawal, and adapting practices to fast-changing local conditions — which has traditionally favoured participatory, hands-on extension methods such as Farmer Field Schools [10]. At the same time, vegetable farmers are increasingly reachable through mobile phones and smartphone apps, and machine-learning tools capable of diagnosing plant disease from a photograph are now technically mature enough for field deployment [8].

This review examines four connected strands of evidence: (1) participatory extension principles and how they have been adapted specifically for vegetable innovation; (2) digital extension approaches reaching vegetable and other smallholder farmers; (3) machine-learning and image-recognition tools for vegetable pest and disease diagnosis; and (4) the emerging, more critical literature on what happens when digital and participatory approaches are combined — and where that combination succeeds or breaks down.

A fifth strand, addressed later in the review, is practical rather than conceptual: even where an extension approach demonstrably improves farmer knowledge, its viability depends on what it costs to deliver relative to the number of farmers reached. This cost dimension is often absent from studies that report only knowledge or adoption outcomes, yet it strongly shapes which approaches national extension systems and NGOs can realistically sustain at scale, and it recurs as a theme throughout the sections that follow.

PARTICIPATORY EXTENSION: PRINCIPLES AND METHODS

Participatory extension approaches position farmers as active co-creators of agricultural knowledge rather than passive recipients of expert advice [4]. The most widely used methods include Farmer Field Schools (season-long, hands-on group learning), Participatory Rural Appraisal (structured community diagnosis of needs and constraints), and Participatory Technology Development, in which farmers and researchers jointly test and adapt candidate innovations under local conditions [4]. A recent review found that participatory extension reliably increases farmer engagement and technology uptake, but also identified persistent institutional, financial, and socio-cultural barriers that limit how far these methods scale without sustained external support [4].

Co-design — a more intensive form of participation in which extension professionals and farmers jointly construct the research or intervention plan from the outset — has been formalized as a distinct step in Participatory Action Research for agriculture. Guidance on co-design emphasizes that the process must go beyond simple consultation: it needs to center local knowledge, negotiate shared goals explicitly, and remain flexible as understanding of the problem evolves [5].

These methods differ mainly in how much decision-making authority farmers hold at each stage of the innovation process. Participatory Rural Appraisal typically positions farmers as the primary source of diagnostic information — mapping local constraints, resources, and priorities — while researchers retain responsibility for designing the technical response. Participatory Technology Development shifts more authority to farmers by having them directly test and modify candidate technologies on their own fields under their own management conditions, generating feedback that reshapes the technology itself rather than just its delivery. Farmer Field Schools occupy a distinct position again: authority is shared within a structured, facilitator-guided curriculum, so farmers exercise judgment and experimentation within a bounded pedagogical framework rather than open-ended co-design. Understanding these gradations matters for vegetable extension specifically, because the reviewed evidence suggests that the appropriate gradation depends on how mature and locally validated a given practice or variety already is [1].

VEGETABLE-SPECIFIC PARTICIPATORY DESIGN: EVIDENCE FROM THE WORLD VEGETABLE CENTER

The most directly relevant framework for vegetable extension comes from the World Vegetable Center (WorldVeg), which reviewed participatory design literature alongside its own vegetable innovation projects across Asia and Africa. The resulting guidance argues that the right level of farmer participation is not fixed — it should depend on how technically ready an innovation is for local use. Early-stage, less-proven innovations warrant deeper participatory design and co-experimentation with farmers, whereas mature, well-validated technologies can be introduced through lighter-touch demonstration and dissemination approaches, since the priority at that stage shifts to scaling rather than adapting the design itself [1].

This readiness-based framework is a useful corrective to extension programmes that apply the same participation model regardless of how proven a technology already is — over-consulting farmers on mature technologies wastes their time, while under-consulting them on unproven ones produces innovations that do not fit local conditions [1].

DIGITAL EXTENSION APPROACHES FOR VEGETABLE FARMERS

Digital extension has expanded rapidly on the promise of reaching far more farmers per extension worker than field-based methods allow. A scoping review of ICT applications in agricultural extension found that digital tools are now used across the full extension cycle — needs diagnosis, advice delivery, and feedback collection — with the clearest benefits for straightforward, timing-sensitive agronomic messages such as pest alerts and fertilizer application windows, which are highly relevant to vegetable production [6].

The Direct2Farm programme in India illustrates both the reach and the limits of mobile-based advisory services: at least 40% of 400,000 registered farmers became active users, and the service significantly influenced uptake of new practices, but smallholders, women, and elderly farmers — often the same groups vegetable extension most needs to reach — used the service less than better-resourced farmers [7]. A separate user-centred design study of a digital advisory service in Tanzania found that involving farmers directly in the design of message content and delivery format improved the perceived relevance and usability of the service compared to top-down message design [3].

Table 1: Participatory Approaches by Innovation Readiness (adapted from Pawera et al., 2024)

Innovation readiness	Recommended participation level	Example methods
Early-stage / unproven innovation	High — farmers as co-designers	Participatory Technology Development, on-farm co-experimentation, iterative prototyping with farmer feedback
Partially validated innovation	Moderate — farmers as active testers	Farmer-managed trials, comparative demonstration plots, structured feedback loops
Mature / well-validated innovation	Lower — farmers as adopters	Method demonstrations, field days, farmer-to-farmer dissemination, mass media

Source: Pawera et al. (2024), Agricultural Systems [1].

Table 2: Examples of Machine-Learning Performance in Vegetable Disease Detection

Crop / disease	Method	Reported accuracy
Radish — Fusarium wilt (UAV imagery)	Deep convolutional neural network (CNN)	93.3%, outperforming a standard random-forest baseline at 82.9% [9]
Radish — Fusarium wilt (RGB + near-infrared UAV imagery)	Customized deep-learning identification framework	Up to 96%, with NIR imagery outperforming RGB-only detection
Cauliflower — multi-disease classification	Random forest baseline	81.68%
Cauliflower — multi-disease classification	CNN transfer learning (InceptionV3)	90.08%, the best-performing single model among several CNN architectures tested
Cauliflower — multi-disease classification	Deep ensemble (CNN + CNN-SVM + DNN)	Up to 99.98% in controlled testing [10]

Sources: [8], [9], [10].

MACHINE-LEARNING TOOLS FOR VEGETABLE PEST AND DISEASE DIAGNOSIS

A newer and fast-growing strand of digital extension uses image recognition and machine learning to let farmers diagnose pests and diseases directly from a smartphone photograph. Reviews of this literature report that convolutional neural networks (CNNs) and related deep-learning architectures can classify vegetable disease symptoms with accuracy often exceeding 90% under research conditions, although performance varies substantially by crop, disease, and image-collection method [8].

These figures are encouraging but should be read cautiously: most of the underlying studies are conducted on curated image datasets under controlled conditions, and reviews of the broader plant-disease-detection literature note that accuracy achieved in research settings does not automatically transfer to messy, low-quality farmer-submitted photographs taken in variable lighting and field conditions [8]. Very little published evidence yet tracks whether farmers who receive an AI-generated diagnosis actually change their pest management practice as a result, which is the same knowledge-to-practice gap seen throughout the wider extension literature.

WHERE DIGITAL MEETS PARTICIPATORY: PROMISE AND TENSION

A growing critical literature examines what happens when digital extension platforms are explicitly designed to be farmer-centric. A 2026 study analysing two digital extension platforms built between 2014 and 2024 — one in the Global North, one in the Global South — found that in early development phases, digital extension was genuinely framed around supporting farmer sovereignty and decentralised, pluralistic design input. Over time, however, as the platforms scaled, farmer-centricity was increasingly instrumentalised: farmer participation became a mechanism for generating training data and driving peer-to-peer diffusion of the platform itself, rather than an end in its own right [2].

This finding matters directly for vegetable extension, where digital pest-diagnosis tools and advisory apps depend on farmer-submitted images and usage data to improve their underlying models. The Tanzania case study offers a more optimistic counter-example: by involving farmers directly in designing message content and delivery format from the start, the resulting digital advisory service was reported as more usable and relevant than services designed without that input, suggesting the erosion of farmer-centricity documented elsewhere is not inevitable but depends on how participation is structured into the platform's design process from the outset [3].

Taken together, the Tanzania and platform-evolution studies point to a practical design principle rather than a simple verdict for or against digital extension: farmer-centricity appears to survive scaling best when participation is embedded structurally in how a platform's content and governance evolve over time, not merely present as a one-time design consultation before launch. Extension programmes that treat participatory input as a continuous feedback loop — revisited as the platform grows and its user base diversifies — are, on the evidence reviewed here, better positioned to avoid the instrumentalization pattern documented in the broader platform-evolution literature [2], [3].

COMBINING DIGITAL AND PARTICIPATORY APPROACHES: A MARKET-LINKED EXAMPLE

Market-aggregation extension models offer a practical illustration of combining digital delivery with participatory, incentive-aligned design. In Jashore, Bangladesh, the "LOOP" aggregation scheme run by Digital Green combined structured market linkage with associated extension contact for vegetable farmers. Farmers participating in the scheme scored substantially higher on pesticide-safety knowledge and practice than non-participating farmers (knowledge: 67.8% vs. 55.0%; practice: 65.6% vs. 43.1%), although attitude scores remained low in both groups (17.4% vs. 4.2%), indicating that market-linked digital extension improved what farmers knew and did more than what they believed about pesticide safety [11].

Similarly, Farmer Field School evaluations for vegetable IPM in Benin found that group-based, hands-on training increased farmers' IPM knowledge and partially changed practice, even though the underlying pesticide-use behaviour did not fully shift — reinforcing that neither participatory nor digital approaches alone reliably close the knowledge-to-practice gap, and that the combination of the two, reinforced by market or institutional incentives, appears more promising than either in isolation [10].

DIGITAL FARMER FIELD SCHOOLS: COMBINING BOTH TRADITIONS DIRECTLY

Rather than treating participatory and digital extension as separate design choices, a small but growing set of programmes has combined them directly into a single delivery model: the Digital Farmer Field School (DFFS). A DFFS retains the core FFS principle of structured, expert-facilitated group learning but delivers it through video, tablets, or livestreamed sessions rather than requiring farmers and facilitators to be physically co-located in a demonstration plot.

Soybean DFFS in Maharashtra, India

The most directly measured example comes from the PAANI Foundation's "Digital Sheti Shaala" (Digital Farming School) initiative in Maharashtra, which runs weekly livestreamed sessions connecting soybean farmers with agricultural university experts at no cost to participants. A 2026 study surveyed 150 soybean growers (75 participants and 75 non-participants) across fifteen villages in Ahilyanagar district and assessed their knowledge of Standard Operating Procedures for soybean cultivation. The gap in outcomes was stark: 76% of DFFS participants demonstrated high knowledge of soybean SOPs, compared to just 6.67% of non-participants, with statistically significant differences confirmed across nine separate cultivation aspects [12].

The study's regression analysis found that education, scientific orientation, and "techno-savviness" were the strongest predictors of knowledge gain among participants, while traditional socio-economic factors such as landholding size and farming experience mattered comparatively little — suggesting that digital delivery reshapes who benefits most from extension contact, favouring farmers already comfortable with technology and formal learning over those whose advantage in conventional extension came from experience or social standing [12].

Cocoa DFFS Design Lessons from Sierra Leone

An earlier and more design-focused DFFS example comes from Sierra Leone, where a tablet-based digital learning environment was developed and tested as a substitute for face-to-face certification training in cocoa production. The prototype deliberately applied FFS pedagogical principles — collective learning, practical orientation, farmer-facilitator interaction — within a user-experience design process intended to keep the platform genuinely responsive to farmer needs rather than simply digitizing a training manual. Field testing found the offline, periodically-updated tablet platform to be both socio-culturally and technologically appropriate for cocoa farmers and value-chain stakeholders in the study area [13].

Later assessments of similar DFFS deployments have also surfaced practical friction points that pure

Table 3: Approximate Cost and Reach Trade-offs Across Extension Approaches

Approach	Approximate cost profile	Reach characteristics
Classical in-person FFS	~US$47.60–US$62 per farmer trained (Philippines/Indonesia estimates) [14]	Deep, hands-on learning; limited geographic reach per facilitator; weak informal diffusion to non-participants [14]
Digital Farmer Field School (DFFS)	High fixed cost to design and pilot the platform; lower marginal cost per additional participant once built [12], [13]	Can extend FFS-style structured learning across a wider area than in-person sessions allow, but still requires connectivity and device access
Mobile/SMS advisory (e.g., Direct2Farm)	Low marginal cost per farmer reached at scale	Very large potential reach (hundreds of thousands of registered users), but lower depth of engagement and lower uptake among smallholder, women, and elderly farmers [7]
Market-linked digital extension (e.g., LOOP)	Cost partly offset by market/aggregation business model rather than pure extension budget	Reach limited to farmers within the aggregation scheme's commercial catchment, but stronger incentive alignment for sustained practice change [11]

Sources: [7], [11], [12], [13], [14].

knowledge-outcome studies tend to miss: farmers cited unsuitable session timings and inadequate practical, hands-on orientation as barriers, and proposed flexible scheduling, more frequent in-person expert interaction, stronger rural digital infrastructure, and subsidized devices as the improvements they most wanted — a reminder that even a well-designed DFFS does not fully substitute for the tacit, hands-on learning that in-person Farmer Field Schools provide.

COST-EFFECTIVENESS CONSIDERATIONS

Knowledge and adoption outcomes are only half of the picture facing extension planners; the other half is what an approach costs to deliver relative to how many farmers it reaches. This question has a long history in the Farmer Field School literature specifically, because FFS's intensive, season-long, small-group format is inherently expensive per farmer trained. Early World Bank analysis of FFS programmes in the Philippines and Indonesia estimated a conservative per-farmer training cost of around US$47.60–US$62, and concluded that the approach's fiscal sustainability at national scale was a genuine risk: available extension budgets could fund only a modest number of trained farmers under the classical FFS model, even before accounting for the finding that FFS graduates rarely diffused their knowledge informally to non-participant neighbours in the volumes originally hoped for [14].

Read together, these cost profiles suggest a genuine trade-off rather than a clear winner: in-person FFS produces the deepest knowledge gains (as seen throughout this review) but at a cost per farmer that is difficult to sustain at national scale; pure mobile advisory reaches the most farmers most cheaply but with the shallowest engagement and the weakest reach into exactly the smallholder and women farmer populations most in need of support; and DFFS and market-linked models occupy a middle ground, trading some depth or reach for a more sustainable cost structure, provided the fixed costs of platform design and connectivity infrastructure can be met [7], [11], [12], [13], [14].

BARRIERS AND LIMITATIONS

- **The digital divide persists inside participation:** the smallholder, women, and elderly farmers who most need participatory design attention are also the least likely to be active users of the digital tools meant to reach them at scale [7].
- **Participation can be tokenistic:** without a readiness-based framework or a structured co-design process, "farmer participation" risks becoming a checkbox exercise rather than a genuine influence on design decisions [1], [5].
- **Digital platforms can drift from their founding intent:** farmer-centric design commitments made early in a platform's life are not automatically preserved as the platform scales and commercializes [2].
- **Lab-to-field performance gaps in AI tools:** high classification accuracy in controlled studies does not guarantee equivalent performance, or farmer behaviour change, when deployed with real farmer-submitted images in the field [8].
- **Cost–depth trade-offs:** the extension approaches that build the deepest knowledge, in-person FFS and DFFS, cost more per farmer than approaches that reach the most people, such as mass mobile advisory, forcing planners to choose between depth and scale rather than achieving both at once [14].

DOI: https://doi.org/10.48165/asl.2026.2.01.03

DISCUSSION AND RESEARCH GAPS

The evidence reviewed here suggests that participatory and digital extension approaches are most powerful in combination rather than in isolation, but the literature that studies this combination directly — rather than each tradition separately — remains thin and recent. Several gaps stand out.

First, very few studies track whether AI-based vegetable disease diagnosis tools change farmer practice in the field, as distinct from their technical classification accuracy [8]. Second, the critical literature on digital platform evolution is based on only a small number of in-depth case studies, and more comparative work is needed to understand which design and governance choices help farmer-centricity survive scaling [2]. Third, the readiness-based participation framework developed for vegetable innovations has not yet been widely tested outside the World Vegetable Center's own projects, leaving open how generalizable it is to other institutional settings [1].

Fourth, the Digital Farmer Field School literature, while promising, remains dominated by single-site, short-term studies; the Maharashtra soybean study and the Sierra Leone cocoa prototype are illustrative rather than representative, and neither tracks whether knowledge gains persist over multiple growing seasons or diffuse to non-participants, which the classical FFS literature identifies as a recurring weak point [12], [13], [14]. Fifth, cost data is reported inconsistently across the literature — some studies report per-farmer training cost, others report only aggregate programme budgets or platform development cost — making it difficult to construct a rigorous, standardized cost-per-outcome comparison across approaches; the figures compiled in Table 3 should therefore be read as indicative order-of-magnitude comparisons rather than precise benchmarks [7], [11], [12], [13], [14]. Finally, almost none of the reviewed studies disaggregate outcomes by gender in vegetable-specific contexts specifically, even though the wider digital and participatory extension literature consistently flags women farmers as under-reached by both traditions; vegetable-specific gender-disaggregated evidence would strengthen future reviews considerably.

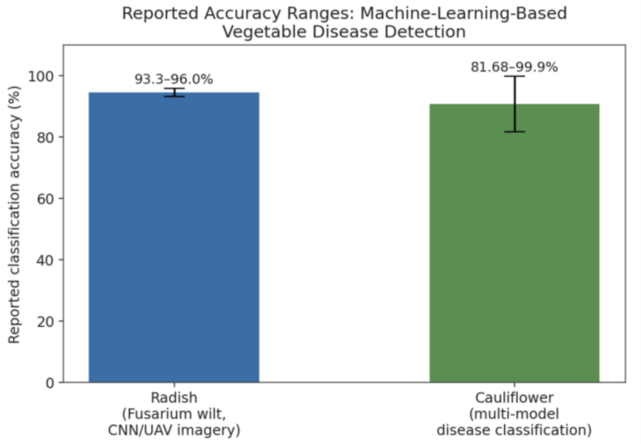

Figure 1: Reported accuracy ranges for machine-learning-based detection of two common vegetable diseases across multiple studies.

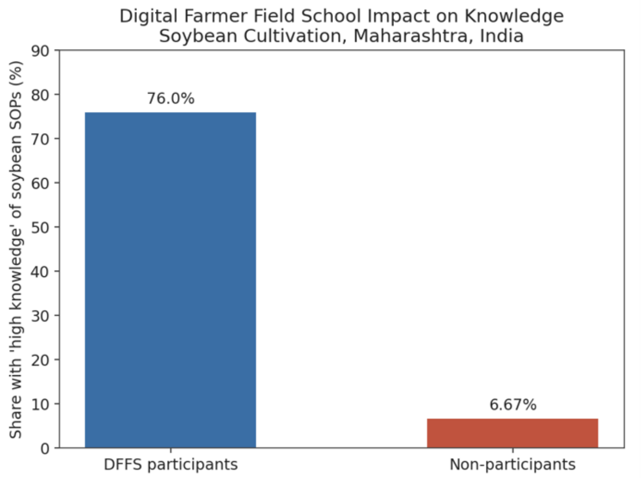

Figure 2: Knowledge outcomes for soybean cultivation SOPs among Digital Farmer Field School participants versus non-participants, Maharashtra, India [12].

CONCLUSION

Vegetable farmers sit at the meeting point of two extension traditions that are often discussed separately: participatory approaches that build relevance and trust through farmer co-design, and digital approaches that offer scale and immediacy through mobile phones and AI-based tools. Neither tradition alone reliably solves the persistent knowledge-to-practice gap documented throughout the vegetable extension literature. The most promising evidence reviewed here comes from approaches that deliberately combine the two — participatory design embedded into digital platforms from the outset, digital delivery reinforced by market or institutional incentives, and Digital Farmer Field Schools that preserve FFS pedagogy while extending its reach — while remaining alert to the risk that farmer-centred intentions can quietly erode as digital tools scale, and to the hard cost-versus-depth trade-off that still shapes what any extension system can realistically sustain.

REFERENCES

Pawera, L., Manickam, R., Wangungu, C., Bonnarith, U., Schreinemachers, P., & Ramasamy, S. (2024). Guidance on farmer participation in the design, testing and scaling of agricultural innovations. *Agricultural Systems, 218*, 104006. https://doi.org/10.1016/j.agsy.2024.104006

Jones-Garcia, E., Legun, K., & Klerkx, L. (2026). From farmer-centred design to algorithmic participation: Navigating technical demands and normative discourses in digital extension. *Agriculture and Human Values, 43*(3), 127. https://doi.org/10.1007/s10460-026-10928-z

Ortiz-Crespo, B., Steinke, J., Quirós, C. F., van de Gevel, J., Daudi, H., Mgimiloko, M. G., & van Etten, J. (2021). User-centred design of a digital advisory service: Enhancing public agricultural extension for sustainable intensification in Tanzania. *International Journal of Agricultural Sustainability, 19*(5–6), 566–582. https://doi.org/10.1080/14735903.2020.1720474

Vidyawati, Singh, S. P., & Jadoun, R. S. (2025). Participatory agricultural extension: A catalyst for sustainability and farmer empowerment. https://doi.org/10.33545/26180723.2025.v8.i4e.1790

Diaz, J., & Polanco, Y. (2025). *Co-design for participatory action research in agriculture: A practical guide for extension* (EDIS, AEC832). https://doi.org/10.32473/EDIS-WC494-2025

Xu, Z., Adeyemi, A. E., Catalan, E., Ma, S., Kogut, A., Guzman, C., & Kordrostami, M. (2023). A scoping review on technology applications in agricultural extension. *PLOS ONE*. https://doi.org/10.1371/journal.pone.0292877

Kansiime, M. K., Alawy, A., Allen, C., Subharwal, M., Jadhav, A., & Parr, M. (2019). Effectiveness of mobile agri-advisory service extension model: Evidence from Direct2Farm program in India. *World Development Perspectives, 13*, 25–33. https://doi.org/10.1016/j.wdp.2019.02.007

Image-based crop disease detection using machine learning. (2024). *Plant Pathology*. https://doi.org/10.1111/ppa.14006

Ha, J. G., Moon, H., Kwak, J. T., et al. (2017). Deep convolutional neural network for classifying Fusarium wilt of radish from unmanned aerial vehicles. *Journal of Applied Remote Sensing, 11*(4), 042621. https://doi.org/10.1117/1.JRS.11.042621

Advanced deep learning techniques for early disease prediction in cauliflower plants. (2023). *Scientific Reports*. https://doi.org/10.1038/s41598-023-45403-w

Begum, I. A., Alam, M. J., Shankar, B., Cooper, G., Rich, K., Mastura, T., Parikh, P., Ratna, N. N., & Kadiyala, S. (2025). Pesticide safety behavior among vegetable farmers in Bangladesh: Evaluating the role of market aggregation services. *Heliyon, 11*(1), e41013. https://doi.org/10.1016/j.heliyon.2024.e41013

Kadam, K. R., Ahire, M. C., Dhadwad, M. B., & Dahatonde, A. S. (2026). Effect of soybean digital farmer field school on knowledge levels of respondents in Maharashtra. *Indian Journal of Extension Education*. https://doi.org/10.48165/IJEE.2026.62105

Witteveen, L., Lie, R., Goris, M., & Ingram, V. (2017). Design and development of a digital farmer field school: Experiences with a digital learning environment for cocoa production and certification in Sierra Leone. *Telematics and Informatics, 34*(8), 1673–1684. https://doi.org/10.1016/j.tele.2017.07.013

Quizon, J., Feder, G., & Murgai, R. (2001). Fiscal sustainability of agricultural extension: The case of the farmer field school approach. *Journal of International Agricultural and Extension Education, 8*(1), 13–24. https://doi.org/10.5191/jiaee.2001.08102

How to Cite this Article: Yadav C.P.. (2026). Digital and Participatory Extension Approaches in Vegetable Farming. *Agro-Science Letters*, ***2***(1), 12-19. https://doi.org/10.48165/asl.2026.2.01.03