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Agricultural extension competencies and farmer characteristics on innovation decisions in rice integrated pest management: Evidence from Denpasar, Indonesia

Randini Resmi Anitis
Graduate Program in Agribusiness, Faculty of Agriculture, Udayana University, Denpasar, Indonesia
Corresponding Email: Randiniresmi97@gmail.com

I Dewa Putu Oka Suardi
Graduate Program in Agribusiness, Faculty of Agriculture, Udayana University, Denpasar, Indonesia

Ni Wayan Sri Astiti
Graduate Program in Agribusiness, Faculty of Agriculture, Udayana University, Denpasar, Indonesia

***Abstract*---**Integrated Pest Management (IPM) provides a sustainable and environmentally responsible approach to controlling crop pests and supporting sustainable rice farming. Nevertheless, farmers' decisions to adopt IPM innovations remain limited and may be influenced by agricultural extension agents' competencies, farmer characteristics, and IPM program implementation. This study examined the direct and indirect effects of extension agents' competencies and farmer characteristics on rice farmers' IPM innovation decisions, with IPM program implementation serving as a mediating variable. The study was conducted in Pagutan, Cuculan, Ubung, and Buaji Subaks in Denpasar, Indonesia. Using saturation sampling, 60 farmers who participated in the 2025 IPM implementation program were selected as respondents. Data were collected through observations, interviews, and questionnaires and analyzed using descriptive statistics and partial least squares structural equation modeling (PLS-SEM). The findings indicate that extension agents' competencies, farmer characteristics, and IPM program implementation were rated positively. All hypothesized direct

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and indirect relationships were positive and statistically significant. The strongest effects were observed for extension agents' competencies and IPM program implementation on farmers' IPM innovation decisions ($p < 0.001$). These findings highlight the importance of strengthening extension agents' competencies, developing farmers' capacities, and sustaining participatory IPM programs to promote IPM innovation adoption in rice farming.

***Keywords*---**agricultural extension competencies, farmer characteristics, innovation adoption decisions, integrated pest management, rice farming.

Introduction

Agriculture plays a strategic role in ensuring food security, sustaining livelihoods, and supporting economic stability in Indonesia. Among agricultural commodities, rice is particularly important because it remains the primary staple food for most of the population. Maintaining rice production, however, requires more than increasing productivity; it also requires environmentally sustainable farming practices, particularly in urban areas where agricultural land is increasingly constrained. Land conversion and degradation have been identified as major ecological threats to agricultural sustainability (Hammada, 2024). These challenges are particularly relevant in Denpasar, the capital of Bali Province, where rapid population growth and urban development have intensified pressure on agricultural land.

Despite these pressures, rice farming remains important in Denpasar. In 2024, the city had approximately 1,658 hectares of rice fields distributed across 42 *subaks*, with rice productivity reaching 79.19 quintals per hectare. The *subak* system serves not only as an agricultural production system but also as a traditional institution for managing water resources and preserving ecological, social, and cultural values. Therefore, maintaining the productivity and sustainability of rice farming in Denpasar requires efficient crop management practices that are compatible with the limited availability of urban agricultural land.

Increasing rice-cropping intensity may contribute to higher production, but continuous cultivation can alter ecological conditions and create monoculture ecosystems that favor the development of crop-damaging insects (Megawati et al., 2024). Pest and disease outbreaks represent a serious threat to rice farming because they can reduce productivity and may result in crop failure (Sudewi et al., 2020). Data from the Denpasar Agriculture Office indicated that rice fields affected by stem borers, bacterial leaf blight, and rats in 2024 covered 94.8, 41.6, and 12.4 hectares, respectively. In response to these threats, farmers continue to rely heavily on chemical pesticides, often without combining them with technical, biological, or natural-enemy-based control methods. Continuous and inappropriate pesticide application can cause pest resistance and environmental contamination (Indiati & Marwoto, 2017), while also producing toxic effects on non-target organisms and increasing pest tolerance to particular pesticide compounds (Djafar et al., 2024).

Integrated Pest Management (IPM) has consequently been promoted as a sustainable and environmentally responsible approach to controlling crop pests. IPM emphasizes healthy crop cultivation, regular pest monitoring, the conservation and utilization of natural enemies, biological control agents, botanical pesticides, location-specific control measures, and the prudent use of chemical pesticides. Its implementation in Indonesia is supported by Presidential Instruction No. 3 of 1986, Law No. 12 of 1992 concerning Plant Cultivation Systems, and Government Regulation No. 6 of 1995 concerning Plant Protection (Indiati & Marwoto, 2017). Environmentally based pest management practices are expected to maintain crop productivity while reducing the ecological risks associated with excessive chemical pesticide use (Wati, 2022).

Nevertheless, farmers' adoption of IPM innovations remains limited, even though agricultural extension and dissemination activities have been regularly implemented. This condition suggests a gap between the knowledge communicated through extension services and farmers' application of IPM practices. Farmers may continue to perceive chemical pesticides as more practical, while their adoption decisions can also be constrained by limited technical knowledge of pests and natural enemies, inadequate supporting facilities, and socioeconomic factors such as education, farming experience, and access to capital. Agricultural extension agents therefore play an essential role in improving farmers' knowledge, skills, and capacity to implement sustainable agricultural practices (Fitriana et al., 2023).

Effective extension services can facilitate behavioral changes in farmers' knowledge, attitudes, and skills (Yaqub et al., 2020). Extension agents also connect government policies and technological innovations with farming practices at the local level. Their effectiveness in facilitating innovation adoption depends on the quality and intensity of assistance provided to farmers. More frequent extension interactions may accelerate innovation adoption by enabling farmers to communicate cultivation problems, discuss practical constraints, and obtain context-specific solutions (Sofia et al., 2022). Accordingly, extension agents require adequate technical and managerial competencies to perform their roles as educators, facilitators, and agents of change. Competent extension agents should be able to perform administrative and field responsibilities in accordance with farmers' needs and local agricultural conditions (Kurniasih, 2022).

However, farmers' IPM innovation decisions may not be determined solely by extension agents' competencies. Farmer characteristics may influence their ability and willingness to understand, evaluate, and implement agricultural innovations. Moreover, the effects of extension competencies and farmer characteristics may depend on how effectively IPM programs facilitate learning, assistance, and practical application. Previous studies have emphasized the importance of extension services, assistance intensity, and farmer capacity; however, the simultaneous direct and indirect relationships among extension agents' competencies, farmer characteristics, IPM program implementation, and farmers' innovation decisions remain insufficiently understood, particularly in urban rice-farming systems.

To address this gap, this study quantitatively examines the effects of agricultural extension agents' competencies and farmer characteristics on the implementation of IPM programs and farmers' IPM innovation decisions in Denpasar. It also assesses whether IPM program implementation mediates the relationships between extension agents' competencies, farmer characteristics, and farmers' decisions to adopt IPM innovations. The findings are expected to provide empirical evidence for strengthening extension services and designing sustainable IPM programs that are responsive to farmers' characteristics and the specific challenges of rice farming in urban areas.

Methods

This study employed a quantitative survey design to examine the direct and indirect relationships among agricultural extension agents' competencies, farmer characteristics, IPM program implementation, and farmers' IPM innovation decisions. The study was conducted from April to August 2026 in four purposively selected traditional irrigation associations (*subaks*)—Pagutan, Cuculan, Buaji, and Ubung—in Denpasar, Indonesia. These locations were selected because they participated in the large-scale Rice Integrated Pest Management Implementation Program organized by the Denpasar Agriculture Office in 2025. Saturation sampling was applied by including all 60 participating rice farmers as respondents. Primary data were collected using structured questionnaires, interviews, and field observations, while secondary data were obtained from relevant government institutions and program documents.

The questionnaire measured extension agents' competencies, farmer characteristics, IPM program implementation, and IPM innovation decisions using five-point Likert and ordinal scales. Descriptive statistics were used to summarize respondent characteristics and the distribution of each research construct. The hypothesized relationships were tested using partial least squares structural equation modeling (PLS-SEM). Measurement-model evaluation included indicator loadings, average variance extracted, discriminant validity, Cronbach's alpha, and composite reliability. The structural model was assessed using path coefficients, coefficients of determination (R^2), and predictive relevance (Q^2). Direct and indirect effects were examined to determine whether IPM program implementation mediated the relationships between extension agents' competencies, farmer characteristics, and farmers' IPM innovation decisions. Statistical significance was established at $p < 0.05$.

Result and Discussion

Descriptive Results

Table 1 summarizes respondents' assessments of the four constructs included in the research model. Overall, farmer characteristics received the highest mean score (4.16), followed by agricultural extension agents' competencies (4.12), IPM innovation decisions (4.05), and IPM program implementation (3.94). All constructs were categorized as good, indicating generally favorable conditions for IPM adoption among the participating farmers.

Table 1. Descriptive statistics of the research constructs

Construct and dimension	Mean	Category
Agricultural extension agents' competencies	**4.12**	**Good**
Technical competence	4.18	Good
Communication competence	4.34	Very good
Managerial competence	4.05	Good
Sociocultural competence	4.06	Good
Professional competence	3.97	Good
Innovation competence	4.10	Good
Digital competence	4.11	Good
Farmer characteristics	**4.16**	**Good**
Age	4.22	Very good
Educational level	4.01	Good
Farm size	4.15	Good
Number of family dependents	4.20	Good
Farming experience	4.22	Very good
IPM program implementation	**3.94**	**Good**
Healthy crop cultivation	3.94	Good
Utilization of natural enemies	4.00	Good
Regular pest monitoring	4.04	Good
Farmers as IPM experts	3.80	Good
IPM innovation decisions	**4.05**	**Good**
Knowledge	4.27	Very good
Persuasion	4.23	Very good
Decision	4.00	Good
Implementation	3.71	Good
Confirmation	4.02	Good

Primary data, 2026.

Communication competence obtained the highest score within the extension competency construct (4.34), suggesting that extension agents were effective in explaining IPM principles, facilitating two-way communication, and responding to farmers' problems. This finding supports Rogers' (2003) diffusion of innovations theory, which positions communication as a central mechanism through which knowledge and attitudes toward an innovation are formed. Professional competence received the lowest score (3.97), although it remained in the good category, indicating a need to strengthen consistency, responsibility, professional ethics, and sustained assistance.

Age and farming experience recorded the highest scores within the farmer-characteristics construct (4.22 each). Farming experience may provide practical knowledge that helps farmers recognize pest patterns, compare alternative control measures, and evaluate new practices. This interpretation is consistent with Rosyida et al. (2021) and Wijaya and Astuti (2023), who emphasized the relevance of farming experience to agricultural innovation adoption. Although formal education received the lowest score within this construct (4.01), learning media, demonstrations, and field-based instruction may help farmers with different educational backgrounds understand agricultural innovations (Sirajuddin et al., 2021).

Regular pest monitoring was the strongest dimension of IPM program implementation (4.04), whereas farmers' capacity to act independently as IPM experts was the weakest (3.80). This pattern suggests that farmers had begun monitoring field conditions but still required assistance in analyzing agroecosystems and independently selecting appropriate control measures. Similarly, knowledge (4.27) and persuasion (4.23) were stronger than actual implementation (3.71). The difference indicates a knowledge–implementation gap: farmers generally understood and positively evaluated IPM, but this understanding had not always resulted in consistent field application. Continued practical assistance is therefore required to transform favorable perceptions into sustained IPM practices.

Measurement Model Assessment

The measurement model was assessed using indicator loadings, average variance extracted (AVE), Cronbach's alpha, and composite reliability. As reported in Table 2, all indicator loadings exceeded 0.70, AVE values exceeded 0.50, and reliability coefficients exceeded 0.70.

Table 2. Convergent validity and construct reliability

Construct	Loading range	Highest-loading dimension	AVE	Cronbach's α	Composite reliability
Extension agents' competencies (X1)	0.720–0.884	Managerial competence	0.606	0.892	0.915
Farmer characteristics (X2)	0.778–0.864	Farming experience	0.675	0.880	0.912
IPM program implementation (Z)	0.729–0.793	Farmers as IPM experts	0.594	0.775	0.854
IPM innovation decisions (Y)	0.752–0.907	Confirmation	0.684	0.883	0.915

Primary data, 2026.

The results demonstrate adequate convergent validity and internal consistency based on the criteria proposed by Hair et al. (2022). Managerial competence was the strongest indicator of extension agents' competencies (λ = 0.884), showing that the ability to plan, coordinate, organize, and evaluate extension activities was central to effective extension services. Farming experience was the strongest indicator of farmer characteristics (λ = 0.864), while confirmation was the strongest indicator of IPM innovation decisions (λ = 0.907). The latter indicates that continued adoption was strongly reflected in farmers' willingness to evaluate, adapt, and maintain IPM practices after gaining practical experience. Discriminant validity was evaluated using the Fornell–Larcker criterion, as presented in Table 3. The diagonal values represent the square roots of the AVE.

Table 3. Fornell–Larcker discriminant validity assessment

Construct	X1	X2	Y	Z
Extension agents' competencies (X1)	**0.778**			
Farmer characteristics (X2)	0.657	**0.822**		
IPM innovation decisions (Y)	0.760	0.732	**0.827**	
IPM program implementation (Z)	0.679	0.639	0.810	**0.771**

Note: Diagonal values in bold are the square roots of AVE. Primary data, 2026.

The square roots of AVE for X1, X2, and Y exceeded their correlations with the other constructs. However, the square root of AVE for IPM program implementation (0.771) was lower than its correlation with IPM innovation decisions (0.810). Therefore, discriminant validity between Z and Y was not fully established under the Fornell–Larcker criterion (Fornell & Larcker, 1981). This high correlation may reflect conceptual overlap because IPM program implementation and the implementation stage of innovation decisions both capture farmers' application of IPM practices. Consequently, the distinction between these constructs should be verified using the heterotrait–monotrait ratio and by reviewing potentially overlapping indicators before manuscript submission, as recommended by Henseler et al. (2015).

Structural Model Assessment

Table 4 presents the explanatory and predictive performance of the structural model. Extension agents' competencies and farmer characteristics explained 52.7% of the variance in IPM program implementation. Meanwhile, the combination of extension agents' competencies, farmer characteristics, and IPM program implementation explained 77.0% of the variance in farmers' IPM innovation decisions.

Table 4. Explanatory and predictive performance of the model

Endogenous construct	R^2	Explanatory power	Q^2	Predictive relevance
IPM program implementation (Z)	0.527	Moderate	0.292	Established
IPM innovation decisions (Y)	0.770	Substantial	0.514	Established

Primary data, 2026.

The moderate R^2 for IPM program implementation indicates that extension competencies and farmer characteristics provide meaningful, although incomplete, explanations of program implementation. Other factors—such as access to production inputs, institutional support, program intensity, group dynamics, and local agroecological conditions—may account for the remaining variance. The substantial R^2 for innovation decisions indicates that the proposed model explains a large proportion of farmers' IPM adoption decisions. Moreover, both Q^2 values were above zero, demonstrating predictive relevance for the two endogenous constructs (Hair et al., 2022).

Effect-size analysis further clarifies the relative contribution of each predictor. As presented in Table 5, IPM program implementation produced the largest effect on innovation decisions.

Table 5. Effect sizes of the structural relationships

Structural relationship	f^2	Effect size
Extension agents' competencies → IPM program implementation	0.250	Medium
Farmer characteristics → IPM program implementation	0.139	Small
IPM program implementation → IPM innovation decisions	0.422	Large
Extension agents' competencies → IPM innovation decisions	0.160	Medium
Farmer characteristics → IPM innovation decisions	0.142	Small

Primary data, 2026.

The large effect of IPM program implementation on innovation decisions (f^2 = 0.422) indicates that farmers' participation in practical learning and field-based IPM activities is more influential than personal characteristics alone. Extension competencies had medium effects on both program implementation and innovation decisions. By contrast, farmer characteristics had relatively small effects, suggesting that demographic and socioeconomic differences do not independently determine adoption. Instead, these characteristics become more relevant when translated into active participation and learning through the IPM program.

Direct Effects and Hypothesis Testing

The five direct relationships were evaluated using bootstrapping. As presented in Table 6, all direct effects were positive and statistically significant.

Table 6. Direct effects and hypothesis testing

Hypothesis	Structural relationship	β	*t*	*p*	Decision
H1	Extension agents' competencies → IPM program implementation	0.456	3.780	<0.001	Supported
H2	Farmer characteristics → IPM program implementation	0.340	2.678	0.007	Supported
H3	IPM program implementation → IPM innovation decisions	0.453	5.934	<0.001	Supported
H4	Extension agents' competencies → IPM innovation decisions	0.285	2.416	0.016	Supported
H5	Farmer characteristics → IPM innovation decisions	0.256	2.299	0.022	Supported

Primary data, 2026.

H1 was supported because extension agents' competencies had a positive and significant effect on IPM program implementation (β = 0.456, $p < 0.001$). This was the strongest path leading to program implementation and indicates that competent extension agents improve the organization and delivery of IPM activities. The prominence of managerial competence in the measurement model reinforces this interpretation. Extension agents must not only understand IPM techniques but also plan field activities, coordinate participating farmers, facilitate pest observations, and evaluate program implementation. The finding is consistent with Bahua (2018), who emphasized extension agents' program-planning abilities, and with Limbong et al. (2020), Berliana (2021), and Rosadi et al. (2023), who highlighted the importance of technical and communication competencies in successful agricultural extension and IPM implementation.

H2 was also supported, showing that farmer characteristics positively influenced IPM program implementation (β = 0.340, $p = 0.007$). Farming experience, the strongest indicator of this construct, may enable farmers to connect extension information with pest patterns observed during previous seasons. Experienced farmers are likely to possess practical reference points for comparing chemical pest-control methods with IPM practices. This finding is consistent with Prasetiyo and Andriansyah (2022), who found that farmer characteristics were associated with farmers' knowledge, attitudes, and skills in applying rice IPM. Nevertheless, its relatively small effect size suggests that favorable farmer characteristics alone are insufficient without structured learning and assistance.

H3 received the strongest statistical support, as IPM program implementation positively affected farmers' innovation decisions (β = 0.453, $p < 0.001$) and produced a large effect size. This result indicates that practical program implementation is the most immediate driver of IPM adoption. Through field observation, discussion, experimentation, and evaluation, farmers can assess the compatibility and benefits of IPM before adopting it. This finding is consistent with Salingkat et al. (2017) and Dani et al. (2016), who reported higher IPM adoption and implementation among farmers participating in field-based IPM learning. It also supports the findings of Zhou et al. (2024) and Yu et al. (2024), which emphasized the role of active farmer participation in promoting sustainable pest-management decisions.

H4 was supported because extension agents' competencies directly and positively affected IPM innovation decisions (β = 0.285, $p = 0.016$). Competent extension agents can reduce farmers' uncertainty by providing understandable information, responding to technical problems, demonstrating IPM practices, and adapting recommendations to local conditions. These activities strengthen farmers' confidence in evaluating and adopting IPM. The result corroborates Fitriana and Setiawan (2023) and Khairunnisa et al. (2021), who found that extension agents significantly influenced farmers' innovation-adoption processes. It is also consistent with Ibrahim et al. (2020), who identified extension competence as an important determinant of agricultural innovation decisions.

H5 was supported because farmer characteristics positively influenced IPM innovation decisions (β = 0.256, $p = 0.022$). Farmers with greater experience may evaluate the risks and benefits of IPM by comparing it with pest-management methods used in previous seasons. This finding aligns with Rogers' (2003) argument that adopter characteristics influence the stages and speed of innovation decisions and with Ibrahim et al. (2020), who reported a significant relationship between farmer characteristics and innovation adoption. However, the comparatively small effect size indicates that demographic and socioeconomic characteristics should not be treated as the sole basis for predicting adoption.

Indirect Effects and the Mediating Role of IPM Program Implementation

Table 7 presents the indirect effects of extension competencies and farmer characteristics on innovation decisions through IPM program implementation.

Table 7. Indirect effects and mediation testing

Hypothesis	**Indirect relationship**	**β**	***t***	***p***	**Decision**
H6	Extension agents' competencies → IPM program implementation → IPM innovation decisions	0.206	3.280	0.001	Supported
H7	Farmer characteristics → IPM program implementation → IPM innovation decisions	0.154	2.387	0.017	Supported

Primary data, 2026.

H6 was supported because extension agents' competencies had a positive indirect effect on IPM innovation decisions through program implementation ($\beta = 0.206$, $p = 0.001$). Because the corresponding direct effect remained significant, IPM program implementation provided complementary partial mediation. Thus, extension competencies influence adoption both directly—through communication, technical guidance, and trust—and indirectly by improving the quality of learning and practical experience delivered through the IPM program. This finding supports Bahua (2018) and Rosadi et al. (2023), who suggested that extension competencies are translated into behavioral change through organized and sustained extension activities.

H7 was also supported, as farmer characteristics indirectly influenced IPM innovation decisions through program implementation ($\beta = 0.154$, $p = 0.017$). The significant direct and indirect effects indicate complementary partial mediation. Farmers' age, education, farming experience, farm size, and household conditions may shape their capacity to participate in and benefit from the program. Participation then enables farmers to test IPM practices against their previous experience and local farming conditions. This result is consistent with Rosyida et al. (2021) and Wijaya and Astuti (2023), who highlighted the interaction between farmer characteristics and participation in agricultural extension activities.

Overall, the findings demonstrate that IPM innovation decisions are shaped by the interaction of extension capacity, farmer characteristics, and practical program implementation. Although extension competencies and farmer characteristics exert direct effects, their influence is also transmitted through the IPM program. This supports Rizzo et al. (2024), who argued that active participation in training and assistance may exert a stronger influence on sustainable innovation decisions than demographic factors alone. The practical implication is that policymakers should prioritize field-based IPM programs supported by competent extension agents, repeated practical demonstrations, participatory pest monitoring, and continued mentoring. Particular attention should be directed toward strengthening farmers' ability to independently analyze agroecosystems and consistently translate their IPM knowledge into field implementation.

Conclusion

This study demonstrates that agricultural extension agents' competencies, farmer characteristics, and IPM program implementation are important determinants of rice farmers' IPM innovation decisions in Denpasar. Extension agents' competencies and farmer characteristics positively influenced both IPM program implementation and farmers' innovation decisions. IPM program implementation also had the strongest direct effect on innovation decisions, indicating that farmers' participation in structured learning, field observation, practical demonstrations, and continuous assistance plays a central role in transforming IPM knowledge into adoption decisions.

IPM program implementation partially mediated the effects of extension agents' competencies and farmer characteristics on innovation decisions. Thus, extension competencies and favorable farmer characteristics influence adoption not only directly but also indirectly through the quality of program implementation. The findings indicate that competent extension agents can improve the effectiveness of IPM programs, while farmers' experience and capacity enable them to participate more effectively in program activities. Nevertheless, the lower score for the implementation stage than for the knowledge and persuasion stages reveals a gap between understanding IPM and consistently applying it in rice farming. Sustainable IPM adoption therefore requires continuous, practical, and locally adapted assistance rather than one-time information dissemination.

Managerial Implications

The Denpasar Agriculture Office and agricultural extension institutions should prioritize strengthening extension agents' managerial, technical, communication, and professional competencies. Although communication competence was highly rated, professional competence received the lowest score among the extension dimensions. Regular competency development should therefore emphasize program planning, field facilitation, problem diagnosis, ethical responsibility, monitoring, and follow-up assistance. Extension-agent performance should be evaluated not only according to the number of extension activities conducted but also according to farmers' ability to independently apply and sustain IPM practices.

IPM programs should adopt a continuous field-based learning model that combines pest monitoring, agroecosystem analysis, demonstrations of biological control, utilization of natural enemies, and evaluation across planting seasons. Particular attention should be directed toward strengthening farmers' capacity to act as independent IPM experts, as this was the weakest dimension of program implementation. Demonstration plots, farmer field schools, peer mentoring, and season-long assistance could help reduce the gap between farmers' high levels of knowledge and their comparatively lower levels of implementation.

Program delivery should also be differentiated according to farmer characteristics. Experienced farmers can be appointed as peer facilitators or IPM champions within each *subak*, while farmers with limited formal education should receive more visual, practical, and locally contextualized learning materials. Digital platforms may support the rapid dissemination of pest alerts, field observations, and extension recommendations; however, they should complement rather than replace direct field assistance.

Finally, collaboration among the Denpasar Agriculture Office, agricultural extension centers, extension agents, and *subak* leaders should be institutionalized through regular monitoring and evaluation. Practical performance indicators should include the frequency of pest monitoring, utilization of natural enemies, compliance with economic thresholds, reduction in unnecessary chemical pesticide use, and consistency of IPM implementation across planting seasons. These indicators would enable program managers to evaluate whether IPM activities generate sustained behavioral and farming-practice changes rather than merely increasing farmers' knowledge.

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