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RESEARCH ARTICLE

SOCIAL INNOVATIONS AND COLLECTIVE MANAGEMENT OF FALL ARMYWORM (*SPODOPTERA FRUGIPERDA*) IN MAIZE PRODUCTION IN NORTHERN BENIN: FROM COLLECTIVE LEARNING TO COLLECTIVE ACTION

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Abstract

Background. Fall armyworm (*Spodoptera frugiperda*) is a mobile pest whose management extends beyond the farm scale. In northern Benin, development projects have fostered social innovations to organise pest management, but neither the nature of these innovations nor their ability to persist has been examined. This article analyses the social innovations used by maize farmers in N'Dali and their contribution to collective pest management.

Methods. A questionnaire survey and interviews were conducted in August-September 2026 with 76 maize farmers involved in at least one social innovation in the Digi CLA project area. The 111 reported instances of participation were classified into three dimensions (learning, relational and regulatory) and examined in light of Ostrom's principles of collective action and diffusion of innovations theory. Data were analysed using descriptive statistics, Fisher's exact tests, logistic regression and content analysis.

Results. Nine forms of social innovation were identified. Learning-oriented arrangements (farmer field schools, demonstration plots and communication campaigns)accounted for 64.0% of mentions, relational arrangements (farmer groups, village meetings and cooperatives) for 35.1%, while the regulatory dimension was represented by a single monitoring committee (0.9%). Only 10.5% of farmers reported formal collective rules, with sanctions limited to warnings. Learning-oriented arrangements, which were project-specific in 78.9% of cases, had been discontinued in 62.0% of cases, compared with 17.9% for relational arrangements ($p < 0.001$), mainly following the project's withdrawal.

After controlling for origin and village, the odds of discontinuation remained eight times higher for learning-oriented arrangements (OR = 8.0; 95% CI: 2.6-24.7), whereas project origin no longer had a significant effect. Membership in a farmer group was the main factor associated with access to information (OR = 8.5; 95% CI: 2.3-31.0).

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Conclusion. The social innovations examined support collective learning and the spread of practices, but have yet to establish collective pest regulation at the landscape level. Their sustainability appears to depend on embedding them in organisational arrangements that farmers take ownership of; project exit strategies should therefore build on these arrangements.

Introduction:-

Maize is Benin's leading cereal crop. It accounts for nearly 70% of the area planted to cereals and serves as a staple food, livestock feed and raw material for several industries (Pomalegni et al., 2019). Since its first detection in West and Central Africa in 2016 (Goergen et al., 2016), fall armyworm (FAW), *Spodoptera frugiperda*, has become one of the major pests affecting maize. In Benin, yield losses attributed to FAW can reach 53% (Sikirou et al., 2020). Its high dispersal and reproductive capacity, together with the seasonal dynamics of its populations, make it difficult to control at the scale of an individual field (Kenis et al., 2023; Laminou et al., 2022).

Farmers still rely heavily on synthetic insecticides to manage FAW, although their cost limits their use by smallholders (Zanzana et al., 2025). Integrated pest management, combining agroecological practices, botanical extracts, biological control and local knowledge, is recommended as an alternative (Harrison et al., 2019; Zanzana et al., 2024). Beninese farmers already draw on locally developed solutions based on their knowledge and experience (Houngbo et al., 2020; Tossou et al., 2026). These practices are still conceived and assessed at the level of individual farms. With a mobile pest such as FAW, however, what one farmer achieves in his or her field also depends on what the neighbours do. Several studies thus point to the lack of collective action among farmers as a major obstacle to managing invasive species and call for coordinated management at the landscape scale (Durocher-Granger et al., 2023, 2026; Toepfer et al., 2019).

The arrangements through which such coordination is organised fall within the scope of social innovation, understood as a change in ways of acting and cooperating that gives rise to new forms of collective action (Bock, 2012; Neumeier, 2012). Various arrangements, including farmer field schools (FFS), demonstration plots, village meetings and communication campaigns, have been introduced across Africa to disseminate knowledge about FAW and encourage experience-sharing among farmers (Cokola et al., 2023; Toepfer et al., 2019). Farmer organisations, particularly farmer groups, facilitate information flows and help monitor the implementation of practices (Sessou et al., 2022). Coordination among farmers can itself be seen as a social innovation (Gillerot, 2023): social innovation is defined less by a product or technique than by new forms of coordination among actors that address an unmet need while transforming social relations (Moulaert et al., 2005; Richez-Battesti et al., 2012).

Two questions, however, remain poorly documented: the nature of the social innovations fostered in this way, and their persistence beyond the setting in which they were introduced. The first question is whether these innovations primarily serve to transmit knowledge or whether they also establish the rules, monitoring arrangements and sanctions that underpin sustainable collective action in Ostrom's (1990) sense. In the case of invasive pests such as FAW, collective action is recognised as essential but has received little research attention in low- and middle-income countries (Durocher-Granger et al., 2023). The institutional arrangements capable of supporting it are poorly understood (Garcia-Figuera et al., 2021), and FAW management in Africa is still largely organised field by field (Kansiime et al., 2024). The second question concerns the persistence of these innovations. Participatory training arrangements improve knowledge and the adoption of practices, but require skilled facilitation, which is often difficult to sustain beyond externally funded interventions (Waddington et al., 2014); their effects after the intervention phase also remain poorly assessed (van den Berg et al., 2023). In the case of FAW, it is particularly unclear whether project-driven social innovations survive once external support is withdrawn.

This article examines these two questions through the case of maize farmers in N'Dali municipality, northern Benin. Maize, the country's main cereal crop, reached a production volume of 2,059,254 tonnes in 2023, accounting for more than 75% of national cereal production (Direction de la Statistique Agricole [DSA], 2024). It has been threatened by FAW since the pest's emergence in 2016: the Food and Agriculture Organization (FAO, 2020) reported that, in that first year, 40,000 ha of maize were affected, with losses estimated at around 41,500 tonnes. In N'Dali, maize production was estimated at more than 25,000 tonnes in 2023 (Ndoye et al., 2023). In this context, the project "AGriCef, a digital solution for more effective and efficient agroecological management of fall armyworm in northern Benin" (DigiCLA) was implemented from 2022 to 2024. It promoted agroecological control methods in N'Dali, disseminated through digital tools (AgriCef application and DigiKiosks), farmer field schools and farmer groups. This study aims to analyse the social innovations used by maize farmers in N'Dalifor FAW management

and their persistence.Unlike studies that assess the effects of farmer field schools or the feasibility of collective action, this article compares the persistence of these arrangements after external support has ended according to their function, and separates the effect of their function from that of their origin.

Analytical framework:-

Conceptually, social innovation refers to an action initiated by actors to meet a need or solve a problem while simultaneously transforming social relations and practices (Bouchard et al., 2015). It concerns less the development of a product than the coordination of actors (Richez-Battesti et al., 2012). Neumeier (2012) describes it as a process through which attitudes, behaviours or perceptions change within a group, leading to new forms of collaboration that improve the group's situation. For Bock (2012), social innovation in agriculture encompasses both the social mechanisms accompanying technical innovation and the transformation of relationships among actors. According to Ourrach and Touhami (2023) and Lahrour (2025), this process involves four phases: emergence, experimentation, appropriation and diffusion. Appropriation is the decisive phase: it turns an innovation from a proposed arrangement into a collective practice sustained by its beneficiaries. Depending on their origin, social innovations may be described as induced or endogenous: the former are designed and facilitated by an external actor, whereas the latter emerge from farmers themselves or involve the reconfiguration of existing organisational arrangements.

From a functional perspective, the sustainability of community-based collective action depends on the institutional conditions identified by Ostrom (1990) in her work on the governance of common-pool resources. Drawing on the study of systems that had operated successfully over time, Ostrom identified eight design principles: clearly defined boundaries; rules adapted to local conditions; collective-choice arrangements; monitoring of resources and users; graduated sanctions; conflict-resolution mechanisms; recognition of the right to organise; and nested levels of organisation.

Although originally developed for the management of common natural resources, this framework was adapted by Durocher-Granger et al. (2023, 2026) to the collective management of FAW in Zambia. The framework suits FAW because controlling a mobile pest has the characteristics of a public good: each farmer benefits from the efforts of neighbouring farmers and bears the consequences of their failures, exposing collective action to the risk of free-riding (Garcia-Figuera et al., 2021). It also allows three dimensions of social innovation to be distinguished: learning, relational and regulatory. In this article, collective pest management refers to coordination among neighbouring farms, through shared rules, joint field monitoring or common treatment schedules; participation in training or information-sharing alone does not meet this threshold.

The learning dimension encompasses arrangements for transmitting and disseminating knowledge and practices, such as farmer field schools, demonstration plots, awareness-raising campaigns and digital information points. These arrangements improve farmers' knowledge and encourage the adoption of practices (Waddington et al., 2014), but primarily strengthen individual capacities.

The relational dimension brings together arrangements for exchange, deliberation and mutual assistance, such as farmer groups, cooperatives, village meetings and farmer-to-farmer exchange networks. It reflects the effect of social innovation on relationships among actors and the emergence of new forms of collaboration (Neumeier, 2012; Richez-Battesti et al., 2012). These spaces for dialogue provide a social setting in which externally introduced innovations can be discussed, adapted and appropriated (Darré, 1999). The relational dimension thus provides the foundation for social capital, understood in terms of trust, reciprocity and participation in networks (Pretty & Ward, 2001).

The regulatory dimension encompasses arrangements that establish common pest-management rules, field-monitoring procedures and sanctions, such as monitoring committees or collective rules adopted by farmer organisations. These three dimensions are not mutually exclusive. They can be understood as stages in the development of collective action, in which common rules become consolidated on the basis of relationships of trust established beforehand (Pretty & Ward, 2001).

Although these dimensions help characterise the nature of social innovations, they do not explain how the pest-management practices they support spread among farmers, or why some arrangements persist while others disappear. Rogers' (2003) diffusion of innovations theory, which views diffusion as the spread of an innovation over time, within a social system and through communication channels, offers a complementary reading. Exchanges among farmers and exposure to knowledge facilitate the adoption of agricultural technologies (Shikuku, 2019). In

northern Benin, interpersonal channels, such as farmer-group meetings and field visits, are the main route through which practices spread (Assogba et al., 2022).The article uses these three dimensions as the classification variable for the reported innovations. Ostrom's principles wereoperationalisedthrough questions on collective rules, field monitoring, sanctions and conflict-resolution mechanisms, while diffusion was captured through the communication channels used, the content of the information exchanged and the replication of practices.

Materials and Methods:-

Study area:-

The study was conducted in N'Dali, a municipality in Borgou Department, northeastern Benin. It covers an area of 3,748 km², is divided into five arrondissements (N'Dali, Bori, Gbégourou, Ouénou and Sirarou), and had a population of 113,604 at the 2013 census (Institut National de la Statistique et de l'AnalyseÉconomique [INSAE], 2016) (Figure 1). The climate is Sudano-Guinean, with a rainy season from April to October. Maize is a major crop alongside cotton and horticultural crops; Bori and Ouénou are the main maize-producing arrondissements. The municipality was selected because it is highly exposed to FAW and is covered by the DigiCLA project. The project, implemented by the Laboratory for Research on Innovation for Agricultural Development (LRIDA) at the University of Parakou in partnership with the NGO Éclosio and TIC Agro Business Center, and funded by the European Union, supports maize farmers through training, information-sharing and the organisation of farmer groups.

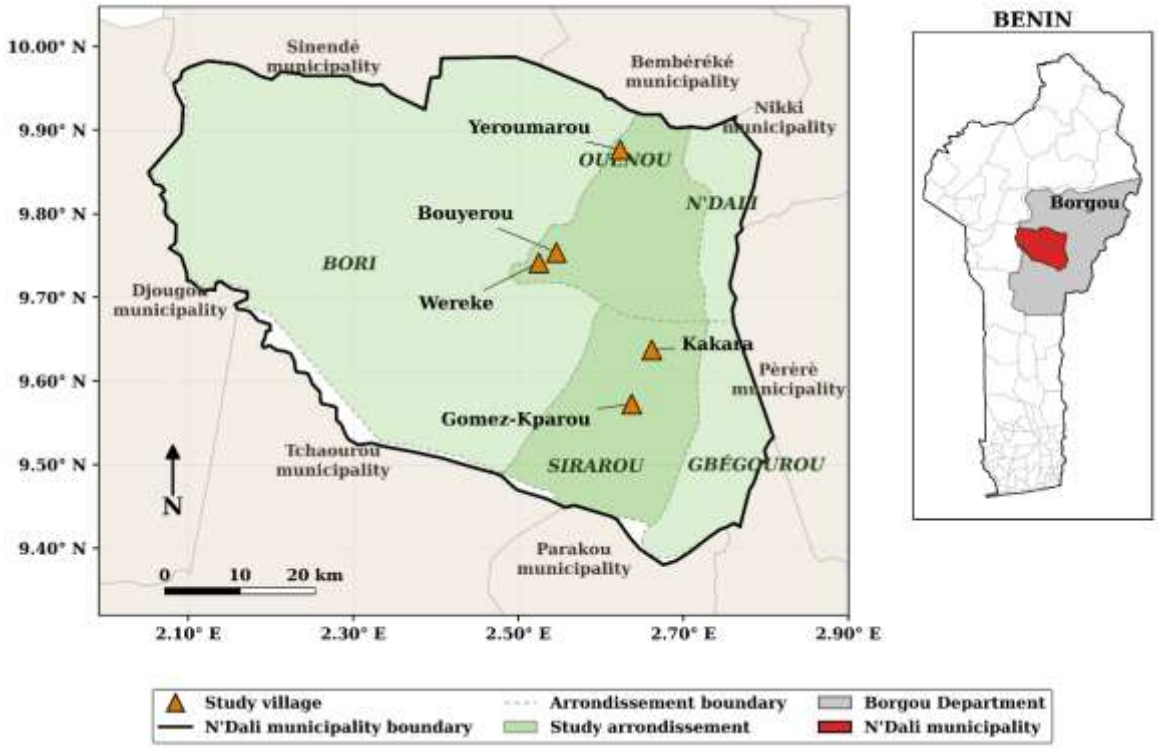

Figure 1. Location of the study villages in N'Dali municipality (Borgou, Benin)
Source: Survey data, August-September 2026.

Sampling:-

Farmers were selected through purposive sampling. The inclusion criterion was participation in at least one social innovation for FAW management: membership in a farmer group or cooperative that had established information-sharing mechanisms or collective rules, or participation in training activities organised under the DigiCLA project or another initiative. Of the 94 maize farmers monitored by the DigiCLA project, the 76 who had participated in at least one social innovation were included. They were distributed across five project intervention villages: Wereke (18), Kakara (16), Gomez-Kparou (15), Bouyerou (14) and Yeroumarou (13), located in the arrondissements of Ouénou and Sirarou (Figure 1). Because the study focuses on the nature and persistence of social innovations, farmers' participation in at least one of them was used as the inclusion criterion. All 76 eligible farmers were

interviewed. As farmers who had never taken part in a social innovation were excluded, the findings cannot begeneralised to all maize farmers in N'Dali, and the levels of information access, practice adoption and perceived effectiveness reported here are likely to be higher than in the wider farming population.

Data collection:-

Data were collected in August and September 2026 using a structured questionnaire administered through KoboToolbox and pre-tested with 10 maize farmers from the same agroecological zone, outside the study villages, supplemented by individual semi-structured interviews with key informants (farmer-group leaders, DigiCLA project technicians and staff of the Agricultural Territorial Development Agency [ATDA]). The data covered farmers' and farm characteristics, as well as an inventory and characterisation of the social innovations in which each farmer was or had been involved. For each innovation reported, the questionnaire recorded its type, year of establishment, origin (project-specific, farmer-led or mixed), nature (entirely new, improved or adapted), actors involved, resources mobilised, whether it had been discontinued and why, and how it had evolved. Data were also collected on the existence of collective rules (their content, sanctions and conflict-resolution procedures), receipt of information and communication channels, pest-management practices, and perceived effectiveness measured on five-point Likert scales.Changes in FAW damage were assessed by asking farmers to compare the current situation with previous cropping seasons since joining collective management, using ordinal response categories. Crop losses were estimated using the pebble method. Farmers received 20 pebbles representing their total harvest and removed those corresponding to the share lost to FAW. The proportion of losses was calculated from the number of pebbles removed. To reduce socially desirable responses, interviews were conducted by an enumerator independent of the DigiCLA project.

Farmers were informed about the study's objectives and assured that their responses would remain confidential. Oral consent was obtained before each interview, and all data were anonymised prior to analysis.

Data analysis:-

Each reported innovation was assigned to one of the three dimensions of the analytical framework (learning, relational or regulatory) according to its primary function.The primary function of each arrangement was identified through farmers' descriptions and interview accounts. Arrangements mainly involving the transmission of techniques by technicians were classified as learning-oriented, while those based on peer exchange, deliberation and mutual support were classified as relational. Where functions overlapped, classification reflected the dominant mode of operation. An innovation was considered discontinued when, according to farmers, the arrangement had ceased to operate, regardless of whether they continued using the practices they had learned. Persistence was therefore assessed from farmers' reports rather than direct observation.Data were analysed using descriptive statistics. Between-group differences were assessed using Fisher's exact test for proportions, the Mann-Whitney test for quantitative variables and a permutation-based chi-square test for contingency tables with more than two categories(20,000 random permutations). Interviews and open-ended responses were subjected to manual thematic content analysis. Two binary logistic regression models, estimated by maximum likelihood, complemented these analyses. All analyses were conducted in Python using the pandas, SciPy and statsmodels libraries.

Model 1: receipt of information. The unit of analysis was the farmer. The dependent variable was coded 1 if the farmer reported receiving information about FAW from their group or another actor, and 0 otherwise.

The model was specified as follows:-

$\text{logit}\,[P(\text{Info}_i = 1)] = \beta_0 + \beta_1\,\text{Member}_i + \beta_2\,\text{Male}_i + \beta_3\,\text{Educated}_i + \beta_4\,\text{Learning}_i + \Sigma_v\,\gamma_v\,\text{Village}_{vi}$

- Member was coded 1 if the farmer belonged to a farmer group or cooperative.
- Male was coded 1 for men (reference category: women).
- Educated was coded 1 if the farmer had completed at least primary education (reference category: no formal schooling).
- Learning was coded 1 if the farmer had participated in at least one learning-oriented initiative.
- Village_v denotes indicator variables for four of the five villages (fixed effects). They control for differences in local context across villages.

Model 2: discontinuation of social innovations. The unit of analysis was each social innovation reported by a farmer. The dependent variable was coded 1 if the innovation had been discontinued after being tried.

The model was specified as follows:-

$\text{logit}\,[P(\text{Discontinued}_{ij} = 1)] = \alpha_0 + \alpha_1\,\text{Learning}_{ij} + \alpha_2\,\text{Project}_{ij} + \Sigma_v\,\delta_v\,\text{Village}_{vi}$

- Learning was coded 1 if innovation j reported by farmer i belonged to the learning dimension (reference category: relational dimension).
- Project was coded 1 if the innovation was specific to the DigiCLA project (reference category: farmer-led or mixed origin).

This model separates the effect of an innovation's function from the effect of its origin. It was first estimated with origin as the only explanatory variable, and then with both variables included. Since a farmer could report several innovations, standard errors were clustered at farmer level and made robust to heteroskedasticity. Results are reported as odds ratios (OR = exp(β)) with 95% confidence intervals. Overall model fit was assessed using the likelihood-ratio test and McFadden's pseudo-R^2.Of the 111 mentions, the only regulatory arrangement was excluded, leaving 110 observations with complete data: 51 discontinued arrangements (44 of 71 learning-oriented and 7 of 39 relational) and 59 still in use. Because most learning-oriented arrangements were also project-specific, origin and function were first analysed separately and then jointly. Model 1 included 76 farmers, 48 of whom had received information.

Results:-

Socio-economic and demographic characteristics of farmers:-

Table 1 presents the socio-economic and demographic characteristics of the surveyed farmers.

Table 1. Socio-economic and demographic characteristics of surveyed farmers (n = 76)

Variable	Category	Total (n = 76)	Members (n = 44)	Non-members (n = 32)	p
Sex (%)	Men	85.5	81.8	90.6	0.339[a]
Age (years)	Mean (standard deviation)	37.6 (12.3)	38.6 (13.6)	36.3 (10.2)	0.784[b]
Educational attainment (%)	No formal schooling	40.8	36.4	46.9	0.171[c]
	Primary	22.4	27.3	15.6	
	Secondary	30.3	34.1	25.0	
	Higher	6.6	2.3	12.5	
Main occupation (%)	Farming	88.2	86.4	90.6	0.726[a]
Experience in maize production (years)	Mean (standard deviation)	20.8 (10.8)	22.0 (12.1)	19.2 (8.7)	0.528[b]
Agricultural training in the past 3 years (%)	Yes	55.3	59.1	50.0	0.488[a]
Area planted to maize (ha)	Median (mean; standard deviation)	2.0 (4.3; 5.9)	2.0	3.0	0.007[b]
Land tenure (%)	Inheritance	86.8	90.9	81.3	0.306[a]
Maize yield (t/ha)*	Median (mean; standard deviation)	1.5 (2.6; 4.5)	1.5	1.5	0.825[b]
Member of a farmer group or cooperative (%)	Yes	57.9	-	-	-
FAW attacks in the past 3 cropping seasons (%)	Yes	97.4	100.0	93.8	0.174[a]
Estimated crop loss (%) (n = 74)	Mean (standard deviation)	32.6 (11.7)	30.8 (10.4)	35.2 (13.2)	0.217[b]

Notes: [a] Fisher's exact test; [b] Mann-Whitney test; [c] permutation-based chi-square test (20,000 draws). * Total self-reported production divided by area planted.
Source: Survey data, August-September 2026.

The surveyed farmers were predominantly men (85.5%), with a mean age of 37.6 years and extensive experience in maize production (20.8 years on average). Four in ten (40.8%) had no formal schooling. Their farms were small, with a median area of 2 ha, mostly cultivated on inherited land (86.8%) and using almost exclusively self-produced seed (96.1%). The median self-reported yield was 1.5 t/ha. All farmers were familiar with FAW, and almost all

(97.4%) had experienced attacks during the previous three cropping seasons, with average crop losses estimated at 32.6%. Group members differed from other farmers only in having a smaller area planted to maize (median of 2 ha compared with 3 ha; Mann-Whitney test, p = 0.007). With samples of this size, however, only large differences could be detected.

Forms of social innovation used by farmers:-

Overall, surveyed farmers reported 111 instances of participation in nine forms of social innovation (Table 2). Seventy-one mentions related to the learning dimension, 39 to the relational dimension and only one to the regulatory dimension.

Table 2. Social innovations reported by surveyed farmers, by dimension

Dimension	Form of social innovation	n (%)	Members (%, n = 44)	Non-members (%, n = 32)	p
Learning	Farmer field school	35 (31.5)	52.3	28.1	
	Demonstration plot	30 (27.0)	45.5	31.2	
	Communication campaign	5 (4.5)	6.8	6.2	
	DigiKiosk	1 (0.9)	0.0	3.1	
	Learning subtotal	**71 (64.0)**	**90.9**	**62.5**	**0.004**
Relational	Informal farmer group or association	19 (17.1)	31.8	15.6	
	Village meetings	17 (15.3)	15.9	31.2	
	Registered cooperative	2 (1.8)	4.5	0.0	
	Informal exchange network	1 (0.9)	0.0	3.1	
	Relational subtotal	**39 (35.1)**	**40.9**	**43.8**	**0.818**
Regulatory	Field-monitoring committee or brigade	1 (0.9)	2.3	0.0	
	Regulatory subtotal	**1 (0.9)**	**2.3**	**0.0**	**-**
Total		**111 (100.0)**			

Notes: Percentage of farmers who reported each form at least once.
Source: Survey data, August-September 2026.

Farmer field schools (31.5% of mentions) and demonstration plots (27.0%) were the most frequently reported social innovations. They were followed by informal farmer groups or associations (17.1%) and village awareness meetings (15.3%). Most mentions fell within the learning dimension (64.0%), followed by the relational dimension (35.1%). The regulatory dimension was almost entirely absent, with just one arrangement - a field-monitoring committee (0.9%). Group members participated more often in learning-oriented arrangements than non-members (90.9% of members versus 62.5% of non-members; Fisher's exact test, p = 0.004), whereas participation in relational arrangements did not differ (40.9% versus 43.8%; p = 0.818). Farmer groups thus seem to serve as an entry point to farmer field schools and demonstration plots.

According to farmers, most of these innovations were recent. Of the 94 mentions for which a date was available, 36.2% referred to initiatives established in 2021, 20.2% in 2022 and 11.7% in 2023. Overall, 68.1% of the innovations had emerged since 2021, and the DigiCLA project was most frequently identified as their origin (64.0% of mentions), followed by farmers themselves (41.4%). More than half of the innovations (56.8%) were considered project-specific, while 21.6% originated in farmer practices outside the project and 17.1% combined both sources.Farmer groups, by contrast, had deeper roots: among the 44 members, 56.8% described a pre-existing group strengthened by the project, 22.7% a group unrelated to the project and 20.5% a group established through the project.

The forms of social innovation also differed in their characteristics:-

Farmer field schools and demonstration plots were perceived as entirely new arrangements (77.1% and 80.0%, respectively) and as specific to the project (82.9% and 86.7%). They almost always involved a technician (100% and 96.7%). Informal groups and village meetings, by contrast, were described as improved or adapted forms of existing arrangements and were rarely linked to the project (31.6% and 0%, respectively). They relied much more on mutual assistance (94.7% and 70.6%) than on technicians (57.9% and 5.9%). Digital tools remained little used, particularly

outside farmer field schools and demonstration plots. Differences across the five forms mentioned at least five times were statistically significant (permutation-based chi-square test, $p \leq 0.023$).

A comparison of the learning and relational dimensions shows that their profiles overlap little (Figure 2).

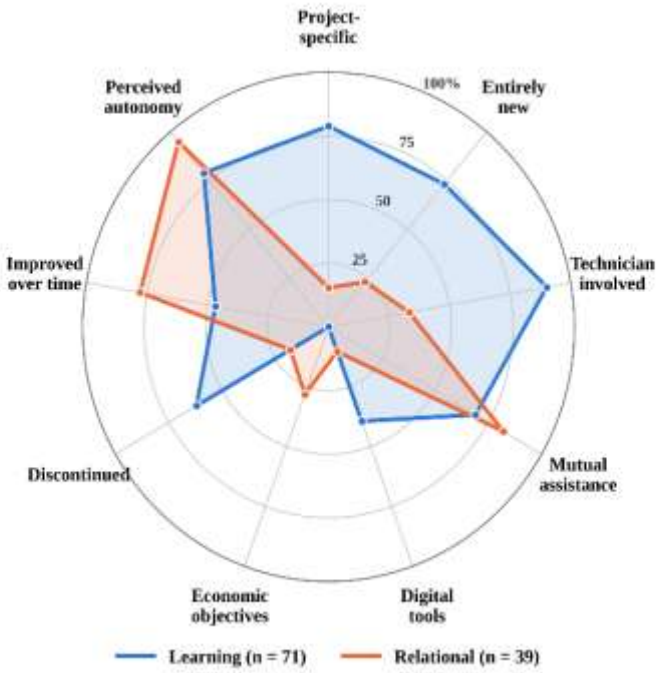

Figure 2. Profile of social innovations by dimension (% of mentions)

Source: Survey data, August-September 2026.
The learning dimension was characterised by project origin, novelty, technician involvement, use of digital tools and discontinuation, whereas the relational dimension was characterised by mutual assistance, economic objectives, improvement over time and perceived autonomy. Differences were significant for project origin, novelty, technician involvement and economic objectives (Fisher's exact test, $p < 0.001$ for each), as well as for the use of digital tools ($p = 0.001$). Mutual assistance did not distinguish the two dimensions ($p = 0.177$). Since multiple mentions from the same farmer are not independent, these tests should be interpreted as indicative.

The interviews show how these arrangements work in practice. In farmer field schools and on demonstration plots, small groups of farmers meet with a technician on a shared plot. They test control methods (preparing extracts, determining doses and application techniques), observe the results and then draw on what they have learned in their own fields. Farmer groups operate through meetings, training sessions and collective decisions, sometimes in smaller subgroups. Village meetings bring together farmers, the village chief and local notables to discuss problems, share information and announce the arrival of projects or support organisations. The only monitoring committee identified consisted of a group responsible for regularly inspecting fields.

Farmers described these arrangements in practical terms:-
"*We all go to a shared field where the technician demonstrates the method, and we watch and ask questions if we do not understand something*" (Interview excerpt, Farmer 1, Gomez-Kparou, August 2026). On a demonstration plot, "*the technician sets up a plot to show us how to prepare the mixture and use it to treat our fields*" (Interview excerpt, Farmer 2, Bouyerou, August 2026). "*We have a chairperson, a secretary and a treasurer in the group. We hold meetings to pass information on to members*" (Interview excerpt, Farmer 3, Gomez-Kparou, August 2026). The objectives of farmer groups often extend beyond FAW management alone, as illustrated by the following farmer: "*collective marketing of produce and bulk purchasing of inputs to reduce prices, FAW control and mutual assistance*" (Interview excerpt, Farmer 4, female, Gomez-Kparou, August 2026). Village meetings rely on local authorities: "*During these meetings, everyone explains their problems, and together with the local authorities we were able to find solutions*" (Interview excerpt, Farmer 5, Bouyerou, August 2026).

Collective rules for FAW management:-

Formalised rules for collective FAW management were scarce. Only 8 of the 76 farmers (10.5%) reported that their group or organisation had formal collective rules for FAW management. Where such rules existed, they had always been developed jointly with members. They mainly concerned arrangements for participation in decision-making (6 of 8 cases), and less often the fields covered or a common schedule for monitoring or treatment (3 of 8 cases each). Field-monitoring arrangements were provided for in only two cases, and formal sanctions in just one. In practice, the sanction applied was a warning (7 of 8 cases), with no fines or exclusions. Only 14.5% of farmers reported a mechanism for resolving conflicts related to pest control.

Farmers' views on these arrangements were cautious. Although 80.3% believed that collective rules would reduce the spread of the pest between fields and 73.7% considered collective management more effective than individual management, 38.2% were neutral about their confidence in existing monitoring mechanisms. Collective FAW management also faces several challenges (Figure 3).

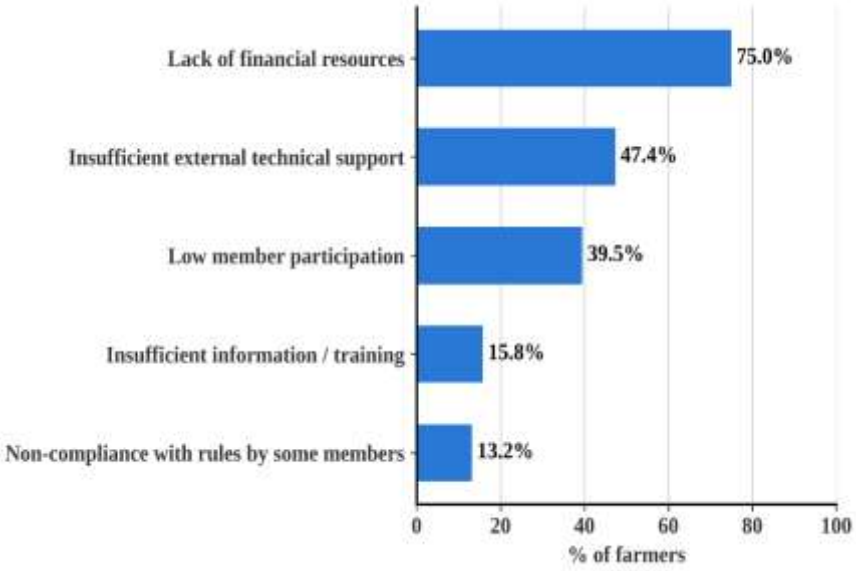

Figure 3. Challenges encountered in collective FAW management (n = 76; percentages may exceed 100%) Source: Survey data, August-September 2026.

The challenges most frequently mentioned were a lack of financial resources (75.0%), insufficient external technical support (47.4%) and low member participation (39.5%). Only 13.2% of farmers mentioned non-compliance with rules, which largely reflects how rarely such rules exist.

Information flows and adoption of pest-management practices:-

Figure 4 presents farmers' access to information about FAW, the channels through which this information circulates, its content and the pest-management methods used. Overall, 63.2% of farmers reported receiving information about FAW from their group or another actor (Figure 4A), while 36.8% received none, despite being involved in a collective arrangement. Among farmers who received information, it circulated primarily through group meetings (93.8%) and word of mouth among farmers (75.0%), followed by telephone calls (47.9%) and social media or mobile applications (27.1%); local radio was never mentioned (Figure 4B). Exchanges were mostly occasional (85.5% of farmers) and rarely weekly (9.2%). They focused on recommended pest-management techniques (85.4%), the schedule of training sessions and farmer field schools (70.8%), and the availability and price of inputs (66.7%) (Figure 4C). Early warnings about pest presence and experience-sharing among farmers were each mentioned by only 12.5% of informed farmers, even though all farmers believed that information-sharing helped them detect FAW earlier.

Information often passed through a chain of intermediaries:-

"*the technicians contact the group leader so that they can pass the information on in advance*" (Interview excerpt, Farmer 6, Kakara, August 2026);

"*when there are meetings, they call the chairperson, who then shares the information with us*" (Interview excerpt, Farmer 7, female, Gomez-Kparou, August 2026).

In one group, the leader was "*the person who understood French better*" (Interview excerpt, Farmer 6, Kakara, August 2026). The town crier, in turn, was paid to announce meetings: "*we give him a little money to encourage him*" (Interview excerpt, Farmer 8, Bouyerou, August 2026).

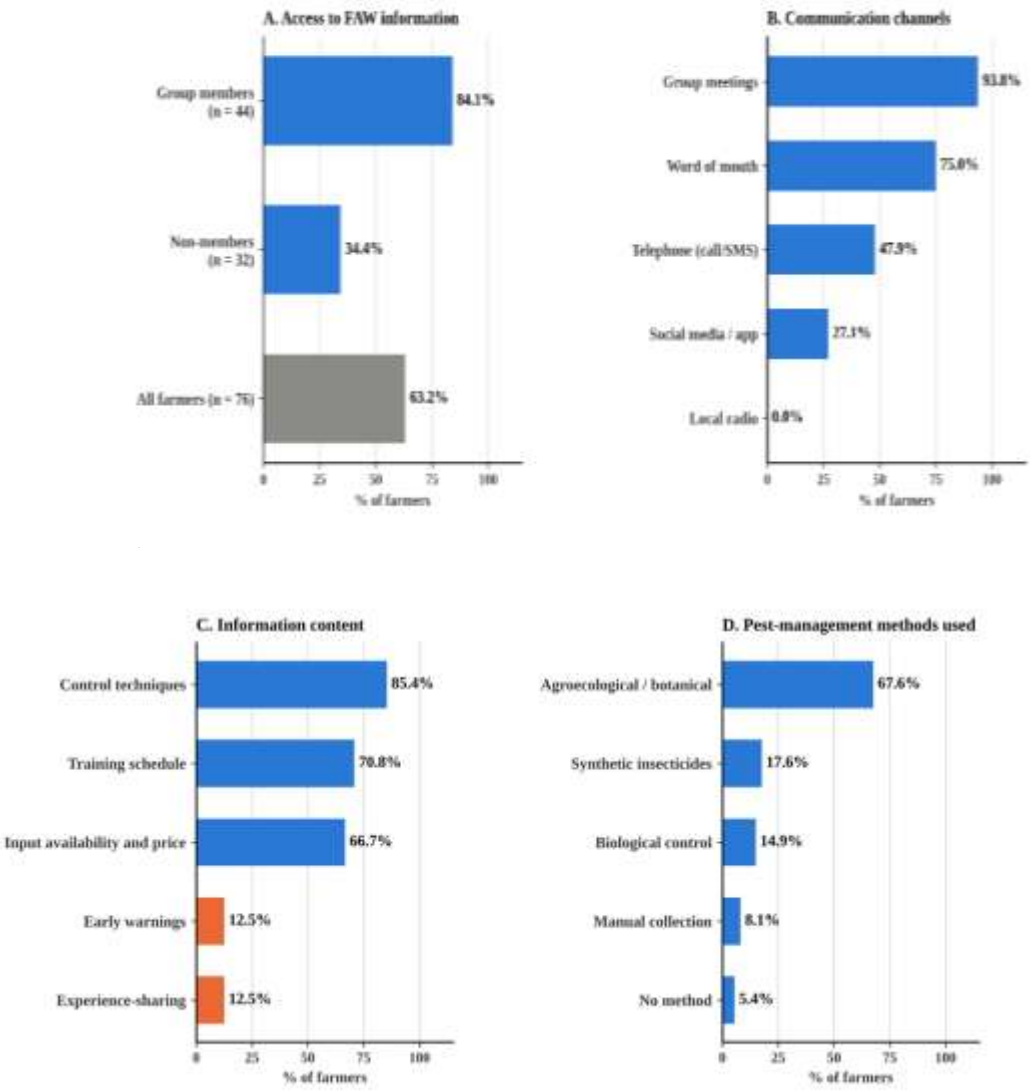

Figure 4. Access to information (A), communication channels (B), information exchanged (C) and pest-management methods used (D)

Source: Survey data, August-September 2026.

In all, 77.0% of farmers used at least one pest-management practice that they considered innovative. Agroecological or botanical practices predominated (67.6%), well ahead of synthetic insecticides (17.6%), biological control (14.9%) and manual collection of caterpillars (8.1%) (Figure 4D). Only 5.4% of farmers reported using no method. The preparations mentioned combined neem seeds or leaves, tobacco, chilli, soap or detergent, and leaves of *Hyptis*, *Vernonia* and basil. Finally, 42.3% of the reported innovations were said to have been replicated in another village and 4.5% in another municipality, although farmers did not know whether this had happened for half of them (50.5%). When they did know, they identified neighbouring farmers, as in the case of one farmer who had shared an innovation with "my neighbours who had not taken part" (Interview excerpt, Farmer 9, Kakara, August 2026).

Association tests add to these findings. Membership in a farmer group was strongly associated with access to information about FAW: 84.1% of members received information, compared with 34.4% of non-members (Fisher's exact test, $p < 0.001$). This association remained after controlling for differences between villages, gender, education and participation in a learning-oriented initiative (Table 3, Model 1: OR = 8.5; 95% CI: 2.3-31.0), whereas none of the other variables had a significant effect. Women, who were few in number (n = 11), more often reported receiving information than men (90.9% versus 58.5%; $p = 0.047$), but this difference disappeared in the model. Finally, farmers involved in a group or village meeting were less likely to report implementing an innovative practice "independently of any group" (50.0% versus 95.5%; $p < 0.001$), suggesting that, for them, pest management is primarily a collective activity. This last finding is exploratory.

Origin, evolution and discontinuation of social innovations:-

Nearly half of the social innovations identified (46.8%) had been discontinued after being tried. This rate varied substantially by dimension (Figure 2). Learning-oriented arrangements had been discontinued in 62.0% of cases (71.4% for farmer field schools and 60.0% for demonstration plots), compared with 17.9% for relational arrangements (21.1% for farmer groups and 5.9% for village meetings). The difference was significant (Fisher's exact test, $p < 0.001$). Relational arrangements were also more likely to evolve: 77.8% had undergone successive improvements, compared with 46.7% of learning-oriented arrangements ($p = 0.010$; based on the 87 mentions with available information). The only monitoring committee identified had also been discontinued. Figure 5 details this contrast by type of innovation.

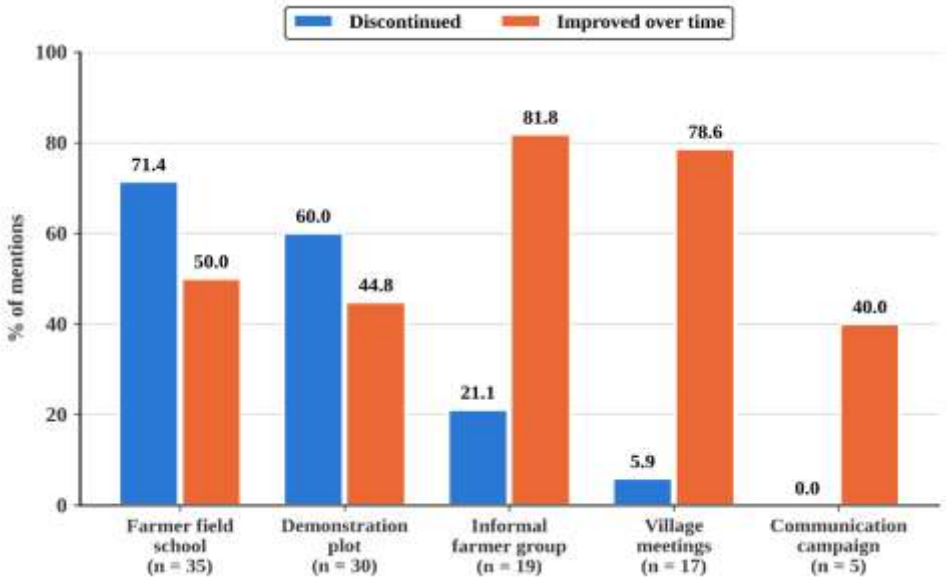

Figure 5. Discontinuation and improvement of social innovations by type
Source: Survey data, August-September 2026.

Farmer field schools and demonstration plots were more often discontinued than improved, whereas farmer groups and village meetings were rarely discontinued and were mostly improved over time.

The reasons given for discontinuation (43 innovations) point to the weight of external support. In 35 cases (81.4%), farmers cited the end or departure of the project, or the absence of a technician to guide them: "*it was the project that had made this innovation available to us, so everything stopped after they left*" (Interview excerpt, Farmer 10, Kakara, August 2026). "*after the project left, there was no one else to train us*" (Interview excerpt, Farmer 11, Gomez-Kparou, August 2026). In 16.3% of cases, discontinuation followed a recommendation by the project itself. Cost and labour shortages were each mentioned only once, while ineffectiveness was never cited. Farmers also anticipated this dependence: 94.9% believed that relational arrangements would continue to function without external support, compared with 78.9% for learning-oriented arrangements ($p = 0.029$).

Table 3. Factors associated with information receipt and innovation discontinuation

Variable	OR	95% CI	p
Model 1: receipt of information (farmers, n = 76)			
Member of a farmer group	8.51	2.33-31.05	0.001
Male (ref. female)	0.19	0.02-2.08	0.175
Educated (ref. no formal schooling)	0.97	0.26-3.67	0.968
Participates in a learning arrangement	1.85	0.36-9.48	0.459
Village fixed effects; pseudo-R^2 = 0.30; likelihood-ratio test: p < 0.001			
Model 2: discontinuation of innovation (mentions, n = 110)			
Learning dimension (ref. relational)	8.01	2.59-24.75	< 0.001
Innovation specific to the DigiCLA project	1.75	0.59-5.16	0.310
Village fixed effects; standard errors clustered by farmer; pseudo-R^2 = 0.19			

Notes: OR: odds ratio; CI: confidence interval.
Source: Survey data, August-September 2026.

When considered on its own, origin appeared to be a determining factor: the odds of discontinuation for a project-specific innovation were almost five times those for an innovation of farmer-led or mixed origin (OR = 4.90; 95% CI: 1.78-13.46; p = 0.002). Once the dimension was added to the model, this effect was no longer significant (OR = 1.75; p = 0.310), whereas the learning dimension remained strongly associated with discontinuation (OR = 8.01; 95% CI: 2.59-24.75), controlling for village (Table 3, Model 2). The apparent effect of origin thus arose because project-driven innovations were mostly learning-oriented arrangements: discontinuation was associated with the function of the arrangement rather than with its origin. Persistence also mattered for individual practices: farmers with at least one innovation still in use were more likely to have improved their own pest-management practices (41.5% versus 15.2%; Fisher's exact test, p = 0.021).

Perceived effects of social innovations:-

All farmers perceived a reduction in caterpillar damage since they had become involved in collective pest management: 71.1% reported a marked reduction and 28.9% a slight reduction. Among the 62 farmers who had taken part in DigiCLA project activities, all believed that the practices they had learned had reduced caterpillar populations in their fields, lowered their expenditure on synthetic chemical products and improved their knowledge of pest-management methods. A total of 95.2% felt able to train another farmer. Views were more divided, however, on the source of their progress: 51.6% attributed it equally to their own practices and those introduced by the project, while 43.5% disagreed with this statement. These findings are based on self-reports rather than field measurements of crop damage, and the near absence of negative responses calls for cautious interpretation.

Discussion:-

Collective learning without collective regulation:-

The social innovations used in N'Dali primarily support collective learning. The predominance of farmer field schools and demonstration plots is consistent with the arrangements described for FAW management in Africa (Cokola et al., 2023; Toepfer et al., 2019), whose effectiveness in improving knowledge and adoption has been well established (Waddington et al., 2014). The findings from N'Dali point in the same direction: 77.0% of farmers implement at least one innovative pest-management practice, mainly agroecological, and the information they exchange focuses primarily on control techniques. Collective regulation, on the other hand, is still embryonic. Formalised rules were mentioned by only 10.5% of farmers; they mainly concern member participation in decision-making, rarely field monitoring, and provide for little more than warnings as sanctions. Viewed against Ostrom's (1990) design principles, as applied to FAW by Durocher-Granger et al. (2023, 2026), collective-choice arrangements exist where rules are in place, but monitoring and graduated sanctions are almost entirely absent. Early warnings show the same gap: all farmers recognise that information helps them detect the caterpillar earlier, yet only 12.5% of informed farmers actually receive alerts. Yet Toepfer et al. (2019) regard shared detection as a prerequisite for landscape-level management. The social innovations examined therefore improve individual pest control without yet organising collective FAW management, even though a large majority of farmers consider collective management more effective and expect rules to limit the spread of the pest between fields.

Induced social innovations and innovations appropriated by farmers:-

The contrast observed in the persistence of social innovations is the main finding of this study. Learning arrangements, which were new to farmers, designed by the DigiCLA project and facilitated by technicians, had been

discontinued in 62.0% of cases, most often because external intervention had come to an end. Farmer groups and village meetings, by contrast, were improved or adapted forms of pre-existing arrangements based on mutual assistance; they persisted and continued to evolve after the intervention. In the process described by Ourrach and Touhami (2023), the former appear to have stalled between experimentation and appropriation, whereas the latter progressed beyond that stage. This is in line with Neumeier's (2012) definition, according to which a social innovation truly comes into being only once it has been adopted by the group concerned and translated into new forms of collaboration.

The multivariate analysis supports this interpretation: once the dimension of the innovation is taken into account, the external origin of the arrangement is no longer associated with its discontinuation. Two strands of the literature support this. First, farmer field schools often struggle to persist and spread beyond projects because qualified facilitators are lacking (Waddington et al., 2014). Second, the gains made through development projects can be sustained only if resources, capacities, motivation and links with other actors are strengthened before external support is withdrawn (Rogers & Coates, 2015). In N'Dali, discontinuation was not attributed to a lack of effectiveness, which no farmer mentioned. Rather, it reflected dependence on technicians, a role that had not been transferred to local organisations, as well as a lack of financial resources, the main difficulty reported. The fact that most farmer groups predated the project and were strengthened rather than created by it points in the same direction. It is consistent with Houngbo et al. (2020): solutions developed by farmers on the basis of their own experience and organisations are the most likely to last.

Practice adoption and information flows:-

Farmers favoured agroecological and botanical practices over synthetic insecticides. This finding differs from that of Zanzana et al. (2025), who identified chemical pesticides as the main method of pest management in Benin. It is, however, consistent with the low-cost options proposed by Harrison et al. (2019), and is likely explained by the composition of the sample, which consisted entirely of farmers exposed to the agroecological support provided by the DigiCLA project. Similarly, in Zimbabwe, Sithole et al. (2025) found that farmers' choice of FAW control strategies was associated with their characteristics and access to extension services. The importance of farmer-group meetings and word of mouth in information flows is consistent with the role of interpersonal channels observed in northern Benin (Assogba et al., 2022) and the role of farmer groups in disseminating information (Sessou et al., 2022). These relational arrangements are precisely those that persist after the project ends; they provide the strongest basis for the sustained circulation of practices. The tests support this: the odds of receiving information were more than eight times higher for members of a farmer group than for other farmers, after adjustment for their level of education.

The contrast between practices that persist and arrangements that disappear also qualifies the apparent failure suggested by the discontinuation of farmer field schools. In Rogers' (2003) terms, diffusion has succeeded at the level of practices: they have reached the confirmation stage and continue to spread through neighbourhood networks. This fits with recent work that locates successful diffusion in relationships between adopters and local opinion leaders, rather than in the initial introduction arrangement alone (Dearing & Singhal, 2020). It also qualifies the finding that knowledge gained through farmer field schools spreads only weakly to non-participants (Waddington et al., 2014), since farmers in N'Dali specifically identified neighbours who had not taken part in the project.In northern Togo, Bakker et al. (2022) similarly observed that farmers continued to change their practices two years after farmer field school activities had ended. What was not appropriated was the collective infrastructure for learning. Farmer groups act as intermediaries in this process: their members are more likely to receive information and more often pass practices on to others. Pangapanga-Phiri et al. (2024) similarly observed in Malawi that sustained adoption rests on strengthened farmer groups and demonstrations facilitated by host farmers. In this sense, the relational dimension keeps diffusion going after the project has left.

Implications for farmer support:-

These results have three implications for farmer support in the agroecological transition. First, learning arrangements should be linked from the outset to farmer groups and village meetings, which are more likely to endure, rather than being run in parallel to them; this would also address the low member participation reported by 39.5% of farmers. Second, training farmer facilitators from within these groups would make it possible to transfer the facilitation role before technicians withdraw, in line with the sustainability conditions identified by Rogers and Coates (2015), and would respond to the dependence on technicians, although farmer-to-farmer extension raises its own sustainability dilemmas (Boyd & Spencer, 2022); indeed, 95.2% of farmers said they felt able to train another farmer. Finally, managing FAW at the landscape level would require support for the emergence of local rules:

shared field monitoring, early warnings among neighbours and jointly agreed intervention schedules. The project's digital tools, which are currently little used, and mobile phones, already used by nearly half of informed farmers, could support such alert systems. Given the lack of financial resources, these arrangements would need to rely on locally mobilised resources.

Conclusion:-

This article analysed the social innovations used by maize farmers in N'Dali to manage fall armyworm. Nine forms were identified, dominated by farmer field schools and demonstration plots, most of which emerged through the DigiCLA project. Among participants, these innovations were associated with the widespread adoption of innovative, mainly agroecological, pest-management practices and information flows that relied primarily on farmer groups and exchanges among farmers.

However, these innovations organise collective learning far more than the collective regulation required to manage a mobile pest: formal rules are exceptional, shared monitoring and early warnings remain marginal, and the only sanction applied is a warning. Their persistence also varies. Learning arrangements, which are new and dependent on technicians, are discontinued when support is withdrawn, whereas relational arrangements appropriated by farmers persist and evolve. Sustainable collective FAW management therefore appears to depend less on multiplying training arrangements than on embedding them in organisations that farmers themselves sustain. It would also require support for the emergence of local monitoring and alert rules.

These conclusions should, however, be read in light of the study's limitations. The sample was limited to DigiCLA participants, which restricts its representativeness and may have led to overestimating information access, adoption and perceived effectiveness. The reliance on retrospective self-reports also **limits** data reliability.

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Ethics statement:-Farmers were informed of the study's objectives; their informed consent was obtained orally before each interview, and the data were anonymised.

Author contributions:-ASSOGBA S. C.-G.: study design, supervision, writing and revision of the article; HOUNSA E.: data collection and analysis, contribution to writing; FOSSOU F. F. S.: design and configuration of the KoboToolbox questionnaire, support with data analysis.

Conflict of interest:-The authors are affiliated with LRIDA, which is responsible for the DigiCLA project examined in this study. This position was taken into account when interpreting the findings.

Data availability:-The data are available from the corresponding author upon reasonable request.

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