

Supplements, not entry points: the stratification of agroecological knowledge access among smallholder farmers in western Kenya

Lilian Bisase

University of Eldoret

Faith Maina

University of Eldoret

Ruth Njoroge

University of Eldoret

Abigael Otinga

Regional Universities Forum for Capacity Building in Agriculture (RUFORUM)

George Ariya

gariya@uoeld.ac.ke

University of Eldoret

Research Article

Keywords: Agroecology, agricultural knowledge, information systems, farmer-to-farmer extension, Farmer Field Schools, information repertoires, Kenya

Posted Date: August 20th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10472746/v1>

License:   This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations: No competing interests reported.

Abstract

Smallholder agroecological transitions depend on knowledge, yet how farmers assemble that knowledge from competing channels is rarely measured at the level of the individual repertoire. We surveyed 386 smallholders in Busia and Siaya counties, western Kenya (September–October 2024), recording every channel each farmer used, preferred learning modalities, and implemented practices. Farmer-to-farmer exchange reached 69.4% of farmers, government extension officers 54.1% and non-governmental organisations (NGOs) 45.1%, whereas Farmer Field Schools (11.4%) and academic or research institutions (6.2%) reached few. Rather than reading this as a coverage deficit, we analysed the position each channel occupies within farmers' repertoires. Farmers used a median of three channels. No farmer named a Farmer Field School or a research institution as a sole source; users of these channels held repertoires averaging 5.0 channels against a sample mean of 2.88. Latent class analysis recovered two classes differing in breadth rather than in kind (narrow 68.8%, broad 31.2%), indicating stratification rather than segmentation. Repertoire breadth rose with income (IRR 1.13 per band) and digital comfort (IRR 1.19), and each additional channel was associated with more implemented practices (IRR 1.09) but lower odds of judging available sources sufficiently varied (OR 0.77). Access to farmer groups predicted peer sourcing (OR 2.04) yet reduced the odds of reaching a science-based channel (OR 0.60). Although 77.7% preferred hands-on demonstrations, 72.3% of these farmers reached neither Farmer Field Schools nor agricultural fairs. Structured, science-based channels function as supplements to already-broad repertoires, not as entry points into them.

1. Introduction

Agroecology is now embedded in Kenyan agricultural policy. The National Agroecology Strategy for Food System Transformation 2024–2033 commits the country to a decade-long transition built on the co-creation and horizontal sharing of knowledge, and county-level agroecology policies have followed in several counties [1]. This policy architecture rests on an empirical assumption that has rarely been tested at farm level: that the channels through which agroecological knowledge is supposed to travel actually reach the farmers they are designed for.

The assumption is not trivial. Agroecology differs from input-substitution technologies in ways that bear directly on how it can be communicated. It is knowledge-intensive rather than input-intensive; its practices are context-dependent and must be adapted rather than adopted; and the international consensus on agroecological principles gives explicit weight to the co-creation and sharing of knowledge as one of the entry points for transformation [2, 3, 4, 7]. Where a fertiliser recommendation can be transmitted as a message, an agroecological practice such as intercropping design, push–pull, or composting regimes typically requires observation, iteration, and feedback [5, 6]. This is precisely why participatory and experiential channels such as Farmer Field Schools (FFS), demonstration plots, farmer-to-farmer exchange have dominated the agroecological extension repertoire in eastern Africa, with documented effects on productivity and household income [8, 9, 10].

Yet the evidence base on how smallholders actually source agroecological knowledge remains thin and, where it exists, methodologically constrained in three respects. First, most surveys report the distribution of mentions across channels rather than the proportion of farmers each channel reaches, which conflates the popularity of a channel with its penetration and makes comparison across studies with different numbers of response options impossible. Second, channels are typically analysed one at a time, as if farmers chose between them, whereas farmers in practice assemble portfolios. The microAKIS framework where farmers' own micro-scale knowledge and innovation systems was developed precisely to shift analytical attention from the supply of advice to the assembled repertoire of the individual farmer, and its European application found that the pluralism of advisory supply did not translate into pluralism at the farm level [11, 12]. Third, and most consequentially for policy, studies rarely ask where in a farmer's repertoire a given channel sits. A channel used by 10% of farmers might be a specialised entry point serving a distinct group, or it might be an add-on that only appears once a farmer already has several other sources. These two possibilities imply opposite interventions, and prevalence statistics alone cannot distinguish them.

The distinction matters because the digital turn in agricultural advisory services has been justified largely on reach. Digital agro-advisory tools are promoted as a route around the well-documented thinness of public extension in sub-Saharan Africa [40], and meta-analytic evidence supports modest average effects of digitally delivered information on yields and input adoption [14, 15]. But recent work in Kenya and Uganda has shown that access to digital advisory services is itself stratified by device ownership, digital literacy, and connectivity cost, and that the farmers least reached by conventional extension are frequently the same farmers least able to use digital substitutes [16]. A review in this journal reached a similar conclusion for the Global South more broadly, identifying trust, digital literacy, and infrastructure as the binding constraints rather than tool availability [17]. If digital and conventional disadvantage are correlated rather than complementary, then adding channels to a system does not necessarily widen it. This matters in a setting where adoption of agroecological and climate-smart practices is already known to be constrained by access to training, land and markets rather than by awareness alone [18, 19].

This paper addresses that question directly using a survey of 386 smallholder farmers in two adjacent counties of western Kenya. We depart from the conventional descriptive approach in three ways. We measure prevalence at the level of the farmer rather than the mention. We characterize each farmer's full repertoire and ask, for every channel, what kind of repertoire its users hold. And we test whether the observed pattern of channel use is better described as segmentation, distinct groups of farmers served by distinct channels, or as stratification, in which the same ordering of channels is traversed to different depths by farmers with different resources.

Our specific objectives are: (i) to rank the reach of eleven agroecological knowledge channels and test for differences between the two counties; (ii) to characterise the structure of farmers' repertoires and locate each channel within that structure; (iii) to identify the socioeconomic and institutional correlates

of repertoire breadth and of access to structured, science-based channels; and (iv) to quantify the gap between how farmers say they prefer to learn and what the channels available to them can deliver.

2. Materials and methods

2.1 Study area

The study was conducted in Busia and Siaya counties in western Kenya, both within the Lake Victoria basin. Siaya County lies between approximately 0°26' N and 0°18' S and 33°58' E and 34°33' E, covering about 2,530 km², with bimodal rainfall of 900-1,500 mm per annum, a mean temperature near 22°C, and predominantly clay loam, sandy loam and vertisol soils supporting maize, beans, sorghum and sweet potato. Busia County lies immediately to the north-west, bordering Uganda, covering about 1,700 km² under a hot, wet tropical regime strongly influenced by Lake Victoria, with long rains from March to May and short rains from October to December. Both counties are dominated by small-scale mixed crop-livestock farming and both were included in the Kenya Climate Smart Agriculture Project, meaning that farming communities in the sampled sub-counties had prior exposure to promoted sustainable practices [20].

Three sub-counties were selected in each county and two wards within each sub-county. In Siaya these were Bondo (Yimbo East, West Sakwa), Rarieda (North Uyoma, West Asembo) and Ugunja (Ugunja, Sidindi); in Busia, Nambale (Bukhayo East, Bukhayo Central), Butula (Kingandole, Marachi North) and Teso South (Chakol South, Chakol North). The two counties are agroecologically similar but institutionally distinct, which is what makes the comparison analytically useful: they share a farming system while differing in the density and history of development-sector presence.

2.2 Sampling and data collection

The target population was smallholder farmers engaged in agroecological production in the two counties. Farmers were purposively recruited through ward-level networks and county-supported agroecology projects, with a target of approximately 400 households allocated between counties in proportion to their farming populations. Recruitment through project networks means the sample represents farmers already reached by agroecological programming rather than the general smallholder population, and the prevalence estimates reported below should be read accordingly. Data were collected by trained enumerators using a structured questionnaire administered on KoboToolbox tablets, following a pilot in Mayenje ward, Matayos sub-county, Busia. The two counties were surveyed sequentially rather than concurrently: Busia from 30 September to 11 October 2024, and Siaya from 14 to 28 October 2024.

The two counties were surveyed using form versions that differed in some county-specific modules. For the present analysis we used the harmonised subset of items asked identically in both counties, yielding an analytic sample of 386 households (Busia 176; Siaya 210) with complete data on all variables reported here. County-specific modules, including Busia's soil analysis section and Siaya's digital-tool design section, are outside the scope of this paper and are not analysed. One respondent recorded in a

seventh Siaya ward (North Sakwa) was retained in descriptive analyses but excluded from the regression models, which use ward-clustered standard errors and therefore require wards with more than one observation; regression models are estimated on $n = 385$ across 12 wards.

2.3 Measures

Knowledge channels. Respondents were asked to name their primary sources of agroecological knowledge from a fixed list, selecting all that applied. Eleven substantive options were offered: government agricultural extension officers, farmer-to-farmer exchanges, local or international NGOs, radio programmes, social media and internet, agricultural fairs and exhibitions, community-based organisations (CBOs), mobile phone applications, Farmer Field Schools, academic or research institutions, and private-sector agricultural companies. A twelfth free-text 'other' option was recorded (7 responses, 1.8%) and excluded from repertoire counts because its content is not comparable across respondents.

For interpretation we grouped the eleven channels into three conceptual domains: informal interpersonal (farmer-to-farmer exchange, CBOs), formal institutional (extension officers, NGOs, FFS, academic or research institutions, private sector, agricultural fairs) and mediated broadcast or digital (radio, social media and internet, mobile applications). We additionally defined a structured, science-based subset comprising Farmer Field Schools and academic or research institutions, the two channels that connect farmers to codified agronomic science through a facilitated pedagogic process rather than through advice-giving or broadcast.

Repertoire breadth was the count of substantive channels named (range 0–10). Preferred learning modality was captured by a separate multiple-response item covering hands-on field demonstrations, group discussion or peer learning, step-by-step written guides, visual aids, social applications, audio-based learning, and interactive mobile applications. Implemented practices were the count of six agroecological practices the respondent reported having successfully implemented (organic farming, crop diversification, compost or manure use, agroforestry, water conservation, integrated pest management), following the convention of treating sustainable-practice uptake as a portfolio rather than a binary [21].

Covariates were sex, age band and education of the household head; a five-level annual income band harmonised across the two county instruments; total farm size in acres (log-transformed); self-rated access to extension officers and to farmer groups (four-point scale, coded 0–3); self-rated comfort using digital platforms (four-point scale); and whether the respondent had previously received formal training or certification in agroecological farming.

2.4 Analytical approach

All analyses were conducted in Python 3.12 using NumPy, SciPy, pandas and scikit-learn. Prevalence is reported as the percentage of farmers naming a channel, with Wald 95% confidence intervals. County differences in channel use were tested with Pearson χ^2 tests, or Fisher's exact test where any expected

cell was below five, and p-values were adjusted for multiple comparisons across the eleven channels using the Benjamini–Hochberg false discovery rate procedure [22]. We report both raw p-values and FDR-adjusted q-values and interpret only the latter.

To locate each channel within farmers' repertoires we computed, for every channel, the mean repertoire breadth of the farmers who used it and the share of its users for whom it was the sole named source. A channel that functions as an entry point should have users with narrow repertoires and a substantial sole-source share; a channel that functions as a supplement should have users with broad repertoires and few or no sole-source users. As a check on whether the eleven channels form a single cumulative access dimension, we computed Loevinger's coefficient of homogeneity H for the item set [23].

To test segmentation against stratification we fitted Bernoulli mixture (latent class) models to the eleven binary channel indicators, estimating models with one to five classes by expectation-maximisation with 80 random starts per solution to avoid local maxima. Model selection used the Bayesian information criterion, with entropy and minimum class size reported as auxiliary diagnostics [24, 25]. Segmentation would be indicated by classes with distinct channel profiles; stratification by classes that differ mainly in the number of channels used while preserving the same ordering.

Correlates of channel use were estimated with generalised linear models: Poisson regression with a log link for count outcomes (repertoire breadth, number of practices) and logistic regression for binary outcomes. All models include the same covariate block and report cluster-robust standard errors with wards as clusters, using the finite-sample correction appropriate to a small number of clusters [26]. With 12 clusters, cluster-robust inference is conservative but the effective degrees of freedom are limited; we therefore treat the regression results as descriptive of association rather than as precise interval estimates, and we do not interpret marginal p-values. The practice-count model is under-dispersed (Pearson dispersion 0.37) because the outcome is bounded at six; robust standard errors remain valid under quasi-likelihood and are conservative in this direction.

Preference-provision alignment was computed by mapping each preferred learning modality onto the channels capable of delivering it, hands-on demonstrations to Farmer Field Schools and agricultural fairs; group discussion or peer learning to farmer-to-farmer exchange and CBOs; visual and social-application learning to social media/internet and mobile applications; audio learning to radio, and calculating, among farmers expressing each preference, the proportion who reached at least one channel able to supply it.

2.5 Ethical considerations

The study received ethical clearance from the relevant institutional review board. Informed consent was obtained from every participant, who were told the purpose of the study and their right to withdraw at any time without consequence. The analytic dataset was anonymised prior to analysis: direct identifiers (names, contact details, enumerator usernames and free-text locations) were removed, GPS coordinates were rounded to two decimal places (approximately 1.1 km) and out-of-boundary coordinates blanked,

background audio recordings and their URLs were deleted, and each respondent was assigned an arbitrary identifier.

3. Results

3.1 Sample characteristics

The 386 respondents were predominantly farming households (82.9% reported farming as their main income source) working small holdings (median 2.0 acres; interquartile range 1.0–3.0). Male-headed households comprised 55.2% of the sample. Household heads were relatively young, with 60.6% aged 18–35, and comparatively well educated, with 45.1% having tertiary education and only 16.6% primary education (Table 1). Just over a third (34.7%) fell in the lowest annual income band of KSh 20,000–40,000.

The two counties differed on several institutional dimensions. Busia respondents were more likely to report prior agroecology training (87.5% versus 68.6%) but less likely to report good or excellent access to extension officers (43.2% versus 79.0%) or to farmer groups (62.5% versus 90.5%). No Siaya respondent reported having no access to farmer groups, against 8.5% in Busia. These contrasts anticipate the channel-level differences reported below.

Table 1
Characteristics of the 386 sampled smallholder households, pooled and by county

Variable	Category	All n (%)	Busia n (%)	Siaya n (%)
Sex of household head	Male	213 (55.2)	106 (60.2)	107 (51.0)
	Female	173 (44.8)	70 (39.8)	103 (49.0)
Age of household head	18–35	234 (60.6)	119 (67.6)	115 (54.8)
	36–60	122 (31.6)	45 (25.6)	77 (36.7)
	Above 60	30 (7.8)	12 (6.8)	18 (8.6)
Education of household head	Primary	64 (16.6)	32 (18.2)	32 (15.2)
	Secondary	148 (38.3)	67 (38.1)	81 (38.6)
	Tertiary	174 (45.1)	77 (43.8)	97 (46.2)
Annual income band (KSh)	20,000–40,000	134 (34.7)	77 (43.8)	57 (27.1)
	40,500 – 60,000	62 (16.1)	27 (15.3)	35 (16.7)
	60,500 – 80,000	57 (14.8)	19 (10.8)	38 (18.1)
	80,500 – 100,000	72 (18.7)	22 (12.5)	50 (23.8)
	Above 100,000	61 (15.8)	31 (17.6)	30 (14.3)
Main income source	Farming	320 (82.9)	153 (86.9)	167 (79.5)
	Farm-produce trading	31 (8.0)	15 (8.5)	16 (7.6)
	Other business	25 (6.5)	3 (1.7)	22 (10.5)
	Employment	10 (2.6)	5 (2.8)	5 (2.4)
Prior agroecology training	Yes	298 (77.2)	154 (87.5)	144 (68.6)
	No	88 (22.8)	22 (12.5)	66 (31.4)
Access to extension officers	None	28 (7.3)	16 (9.1)	12 (5.7)
	Limited	116 (30.1)	84 (47.7)	32 (15.2)
	Good	170 (44.0)	66 (37.5)	104 (49.5)
	Excellent	72 (18.7)	10 (5.7)	62 (29.5)
Access to farmer groups	None	15 (3.9)	15 (8.5)	0 (0.0)
	Limited	71 (18.4)	51 (29.0)	20 (9.5)

Variable	Category	All n (%)	Busia n (%)	Siaya n (%)
	Good	172 (44.6)	80 (45.5)	92 (43.8)
	Excellent	128 (33.2)	30 (17.0)	98 (46.7)
Farm size (acres)	Median (IQR)	2.0 (1.0–3.0)	2.0 (1.0–4.0)	1.5 (1.0–3.0)

IQR interquartile range. Percentages are column percentages within each county (Busia n = 176; Siaya n = 210).

3.2 Which channels reach farmers

Every respondent named at least one channel. Farmer-to-farmer exchange was the most widely used source, reaching 69.4% of farmers (95% CI 64.8–74.0), followed by government extension officers at 54.1% (49.2–59.1) and NGOs at 45.1% (40.1–50.0). The mediated channels occupied the middle of the distribution: social media and internet 30.1%, radio 22.8%, mobile applications 16.6%. The structured, science-based channels sat at the bottom: Farmer Field Schools reached 11.4% of farmers and academic or research institutions 6.2%. Private-sector companies reached 2.9% (Table 2, Fig. 1).

At the domain level, 80.3% of farmers reached at least one formal institutional channel and 71.8% at least one informal interpersonal channel, but only 15.8% reached any structured, science-based channel. The apparent strength of the formal domain is therefore carried almost entirely by extension officers and NGOs, advice-giving relationships, rather than by the facilitated learning processes that the agroecological literature identifies as the mechanism through which context-dependent practices are transmitted.

Three county contrasts survived false discovery rate adjustment. NGOs were the dominant channel in Busia, reaching 69.9% of farmers there against 24.3% in Siaya ($q < 0.001$). The pattern reversed for community-based organisations, which reached 21.4% in Siaya against 2.8% in Busia ($q < 0.001$), and for academic or research institutions, reaching 9.5% against 2.3% ($q = 0.011$). Differences in radio (27.1% versus 17.6%; raw $p = 0.026$, $q = 0.072$) and mobile applications (20.0% versus 12.5%; raw $p = 0.049$, $q = 0.107$) did not survive adjustment and we do not interpret them as county effects. Farmer-to-farmer exchange was remarkably stable across the two counties (70.0% versus 68.8%; $q = 0.79$), as was extension (57.6% versus 50.0%; $q = 0.25$).

The county contrast is therefore not a difference in overall connectedness, mean repertoire breadth was 2.89 in Siaya and 2.86 in Busia (Mann–Whitney $p = 0.81$), but a difference in which institutional intermediary occupies the same structural position. Busia's knowledge system is organised around external development-sector projects; Siaya's is organised around locally constituted community organisations, with a thin but non-negligible connection to research institutions.

Table 2

Prevalence of agroecological knowledge channels among smallholder farmers, pooled and by county

Channel	Domain	All % (95% CI)	Busia %	Siaya %	p	q
Farmer-to-farmer exchange	Informal	69.4 (64.8–74.0)	68.8	70.0	0.791	0.791
Government extension officers	Formal	54.1 (49.2–59.1)	50.0	57.6	0.135	0.247
NGOs (local/international)	Formal	45.1 (40.1–50.0)	69.9	24.3	< 0.001	< 0.001
Social media / internet	Mediated	30.1 (25.5–34.6)	31.8	28.6	0.488	0.597
Radio programmes	Mediated	22.8 (18.6–27.0)	17.6	27.1	0.026	0.072
Mobile phone applications	Mediated	16.6 (12.9–20.3)	12.5	20.0	0.048	0.107
Agricultural fairs / exhibitions	Formal	16.3 (12.6–20.0)	18.2	14.8	0.365	0.502
Community-based organisations	Informal	13.0 (9.6–16.3)	2.8	21.4	< 0.001	< 0.001
Farmer Field Schools	Formal	11.4 (8.2–14.6)	9.1	13.3	0.191	0.301
Academic / research institutions	Formal	6.2 (3.8–8.6)	2.3	9.5	0.003	0.011
Private sector (agri-companies)	Formal	2.9 (1.2–4.5)	3.4	2.4	0.545	0.600

n = 386 (Busia 176; Siaya 210). Farmers could name any number of channels, so columns do not sum to 100. p from Pearson χ^2 tests, or Fisher's exact test for academic/research institutions where an expected cell was below five. q are Benjamini–Hochberg false discovery rate adjusted p-values across the eleven channels. Domain: Informal = informal interpersonal; Formal = formal institutional; Mediated = broadcast or digital.

3.3 Repertoire breadth and the position of each channel

Farmers used a median of three channels (mean 2.88, SD 1.63). The distribution was strongly right-skewed: 23.3% of farmers relied on a single channel, 21.0% on two and 26.4% on three, while only 6.7% used six or more (Fig. 2a). Ninety farmers depended on one channel alone, and for 38 of them that channel was farmer-to-farmer exchange.

The position of each channel within repertoires is the central finding of this paper. Ordering channels by the mean repertoire breadth of their users produces a gradient that runs almost exactly inverse to prevalence (Table 3, Fig. 2b). Farmer-to-farmer exchange had the narrowest user repertoires (mean 3.22) and the highest sole-source share: 14.2% of its users named nothing else. NGOs (3.26) and extension officers (3.59) followed, each serving as the sole source for about 9% of their users. At the other end, users of Farmer Field Schools held repertoires averaging 4.98 channels and users of academic or research institutions 4.96, roughly 1.7 times the sample mean, and, decisively, not a single farmer in the sample named either channel as their only source. The same held for the private sector (mean 5.73; no sole-source users). Agricultural fairs had a single sole-source user out of 63.

This is not a mechanical artefact of low prevalence. Prevalence and mean user repertoire are related but separable: community-based organisations (13.0% prevalence, mean repertoire 4.66) and Farmer Field Schools (11.4%, 4.98) have similar reach but CBOs retain a 6.0% sole-source share while FFS has none. Nor is the pattern driven by a general tendency for rare items to co-occur with common ones: the eleven channels do not form a unidimensional cumulative scale (Loevinger's $H = 0.115$, bootstrap 95% CI 0.072–0.160, far below the conventional 0.30 threshold), and NGO use is negatively associated with the remaining channels, reflecting the Busia enclave. The gradient is a substantive feature of the access hierarchy, not a scaling artefact.

Read together with the co-use profile of FFS users, 81.8% of whom also used extension officers and 79.5% farmer-to-farmer exchange, the implication is that the structured, science-based channels are reached through other channels, not instead of them. They are supplements layered onto repertoires that are already broad. No farmer enters the agroecological knowledge system through a Farmer Field School.

Table 3

Position of each channel within farmers' knowledge repertoires, ordered by the mean repertoire breadth of its users

Channel	Users n	Prevalence %	Mean repertoire of users	Sole source n (% of users)
Farmer-to-farmer exchange	268	69.4	3.22	38 (14.2)
NGOs (local/international)	174	45.1	3.26	16 (9.2)
Government extension officers	209	54.1	3.59	19 (9.1)
Social media / internet	116	30.1	3.87	6 (5.2)
Radio programmes	88	22.8	4.06	5 (5.7)
Mobile phone applications	64	16.6	4.47	2 (3.1)
Community-based organisations	50	13.0	4.66	3 (6.0)
Agricultural fairs / exhibitions	63	16.3	4.89	1 (1.6)
Academic / research institutions	24	6.2	4.96	0 (0.0)
Farmer Field Schools	44	11.4	4.98	0 (0.0)
Private sector (agri-companies)	11	2.9	5.73	0 (0.0)

Sample mean repertoire breadth = 2.88 channels (SD 1.63; median 3; range 0–10). “Sole source” counts farmers for whom the channel was the only one named. Loevinger's H for the eleven-item set = 0.115 (bootstrap 95% CI 0.072–0.160), indicating that the channels do not form a unidimensional cumulative scale.

3.4 Stratification rather than segmentation

Latent class analysis confirmed this reading. The Bayesian information criterion selected a two-class solution (BIC 3971.0 against 4032.5 for one class and 4000.2 for three; entropy 0.608, smallest class 31.2%). Critically, the two classes differ in breadth rather than in kind (Fig. 3). Class 1 (68.8%) is a narrow, socially embedded repertoire: farmer-to-farmer exchange (65.4%), NGOs (48.6%) and extension officers (41.1%) with everything else below 25% and the science-based channels near zero (FFS 2.0%, research institutions 0.8%). Class 2 (31.2%) shows higher probabilities on every channel except NGOs, and the increase is largest precisely on the channels that were rarest overall: mobile applications rise from 7.3% to 37.1%, agricultural fairs from 5.7% to 39.6%, CBOs from 4.1% to 32.5%, FFS from 2.0% to 32.0% and research institutions from 0.8% to 18.2%.

A segmented system would have produced classes with crossing profiles, one group reached by digital channels, another by institutional ones. Instead, the profiles are nested: Class 2 does what Class 1 does, and more. Members of Class 2 averaged 4.72 channels against 2.15 for Class 1, and were higher on

income (mean band 3.44 versus 2.34), tertiary education (55% versus 41%) and digital comfort (2.97 versus 2.60). Class 2 was more common in Siaya (37.6%) than Busia (17.0%), but was present in both. The knowledge system in these two counties is stratified by depth of access, not partitioned into complementary niches.

3.5 Correlates of repertoire breadth and of channel access

Poisson regression on repertoire breadth (Table 4) identified income as the clearest gradient: each step up the five-band income scale was associated with a 12.8% increase in expected repertoire breadth (IRR 1.13, 95% CI 1.07–1.19). Digital comfort carried a similar association (IRR 1.19, 1.10–1.29), as did being aged 36 or above relative to 18–35 (IRR 1.23, 1.12–1.35). Primary education was associated with a narrower repertoire relative to secondary (IRR 0.81, 0.67–0.99) and tertiary education with a wider one (IRR 1.13, 1.01–1.26). County was not associated with breadth once these covariates were included (IRR 0.90, 0.67–1.21), consistent with the descriptive result.

Modelling access to the structured, science-based channels separately sharpens the stratification finding. Each income band raised the odds of reaching FFS or a research institution by 63% (OR 1.63, 1.31–2.03) and tertiary education by 72% (OR 1.72, 1.03–2.86). Neither prior agroecology training (OR 1.29, 0.43–3.85) nor self-reported access to extension officers (OR 1.29, 0.85–1.96) was associated with reaching these channels.

The most consequential single coefficient in the analysis is the negative association between farmer-group access and science-based channel use. Better self-rated access to farmer groups more than doubled the odds of naming farmer-to-farmer exchange (OR 2.04, 1.42–2.92) but reduced the odds of reaching a structured, science-based channel by about 40% (OR 0.60, 0.37–0.99). Peer networks, in other words, are strongly associated with peer sourcing and inversely associated with the bridge into codified science. Within this sample, farmer groups operate as a closed loop rather than as a conduit.

The remaining channel models behave as validity checks and confirm the county story. Self-rated extension access strongly predicted naming extension officers (OR 2.28, 1.42–3.68), as it should. Being in Siaya reduced the odds of naming an NGO by more than 80% (OR 0.17, 0.07–0.38), the single largest county effect in the analysis. Extension access was negatively associated with both NGO use (OR 0.48, 0.26–0.88) and mediated-channel use (OR 0.66, 0.47–0.94), a substitution pattern consistent with farmers turning to alternatives where the public service is thin. Female-headed households were more likely to name extension officers (OR 2.01, 1.11–3.62) and farmer-to-farmer exchange (OR 1.48, 1.01–2.19), but no more likely to reach science-based channels, a pattern consistent with evidence that gender gaps in advisory access are widest for the more institutionalised service types [39].

Table 4
Correlates of repertoire breadth, access to structured science-based channels, and implemented practices

Predictor	Repertoire breadth IRR (95% CI)	Any science-based channel OR (95% CI)	Farmer-to-farmer exchange OR (95% CI)	Practices implemented IRR (95% CI)
County: Siaya (ref. Busia)	0.90 (0.67–1.21)	1.94 (0.53–7.11)	0.65 (0.20–2.15)	0.66 (0.58–0.75)***
Female household head	1.09 (0.98–1.21)	1.22 (0.61–2.42)	1.48 (1.01–2.19)*	1.00 (0.93–1.08)
Head aged 36+ (ref. 18–35)	1.23 (1.12–1.35)***	1.64 (0.86–3.10)	2.00 (1.09–3.68)*	1.11 (1.00–1.23)*
Education: primary (ref. secondary)	0.81 (0.67–0.99)*	0.58 (0.19–1.76)	0.56 (0.22–1.44)	0.97 (0.86–1.10)
Education: tertiary (ref. secondary)	1.13 (1.01–1.26)*	1.72 (1.03–2.86)*	1.83 (1.04–3.21)*	0.98 (0.91–1.05)
Income band (1–5)	1.13 (1.07–1.19)***	1.63 (1.31–2.03)***	1.21 (0.89–1.65)	1.04 (0.99–1.10)
Log farm size (acres)	0.93 (0.83–1.03)	0.81 (0.50–1.30)	0.68 (0.48–0.98)*	1.09 (1.03–1.16)**
Access to extension (0–3)	0.91 (0.82–1.02)	1.29 (0.85–1.96)	0.67 (0.37–1.22)	0.98 (0.89–1.07)
Access to farmer groups (0–3)	0.96 (0.86–1.06)	0.60 (0.37–0.99)*	2.04 (1.42–2.92)***	0.98 (0.91–1.05)
Digital comfort (1–4)	1.19 (1.10–1.29)***	1.11 (0.65–1.89)	0.96 (0.69–1.32)	1.09 (1.00–1.19)
Prior agroecology training	1.07 (0.81–1.41)	1.29 (0.43–3.85)	1.25 (0.63–2.49)	1.06 (0.89–1.27)
Repertoire breadth (n channels)	-	-	-	1.09 (1.05–1.13)***
Uses science-based channel	-	-	-	0.86 (0.77–0.95)**
Uses mediated/digital channel	-	-	-	0.94 (0.85–1.05)
McFadden pseudo-R ²	0.057	0.146	0.089	0.062

n = 385 across 12 wards; the single respondent in a thirteenth ward is excluded from regression models. IRR incidence rate ratio from Poisson regression with a log link; OR odds ratio from logistic regression. All models include an intercept (not shown) and ward-clustered robust standard errors. * p < 0.05; p <

0.01; * $p < 0.001$. “Science-based channel” = Farmer Field Schools or academic/research institutions. With only 12 clusters, interval estimates should be read as indicative of direction and magnitude rather than as precise bounds.

3.6 What repertoire breadth is associated with

Breadth was associated with practice. Each additional channel corresponded to a 9% increase in the expected number of agroecological practices implemented (IRR 1.09, 1.05–1.13), controlling for the full covariate block. Farm size was also positively associated (IRR 1.09 per log-acre, 1.03–1.16), and Siaya respondents reported fewer practices than Busia respondents (IRR 0.66, 0.58–0.75). Notably, once breadth was in the model, using a structured, science-based channel carried a small negative coefficient (IRR 0.86, 0.77–0.95); we read this as a compositional artefact rather than a causal effect, since these channels appear only in the broadest repertoires and breadth is already in the model.

Breadth was inversely associated with satisfaction. Each additional channel reduced the odds of agreeing that there was enough variety in the agroecological information sources available by roughly a quarter (OR 0.77, 0.61–0.96). Overall, 73.6% of respondents said there was not enough variety, and 47.4% said the information they receive does not cover all relevant aspects of agroecological farming. Prior training raised the odds of judging variety sufficient (OR 3.06, 1.20–7.77), and better extension access did likewise (OR 1.64, 1.11–2.44), but the more channels a farmer actually used, the less adequate the overall supply appeared. This is a coherent pattern rather than a contradiction: farmers who reach further into the system are better placed to see what it does not contain.

3.7 The preference-provision gap

Farmers were clear about how they want to learn. Hands-on field demonstrations were preferred by 77.7% of respondents, far ahead of group discussion or peer learning (54.1%), written guides (36.8%), visual aids (35.5%) and social applications (35.0%). Audio learning (22.0%) and interactive mobile applications (17.9%) were the least preferred.

The channels available to them do not match. Among the 300 farmers who preferred hands-on demonstrations, 72.3% reached neither a Farmer Field School nor an agricultural fair, that is, 56.2% of the entire sample expressed a preference for experiential learning while having no demonstration-based channel in their repertoire. Recent stated-preference work in the same region likewise finds that western Kenyan farmers rank practices they can observe and trial above those they must take on trust [38]. This is by far the largest alignment gap in the data (Table 5, Fig. 4). By contrast, the preference for group discussion and peer learning was largely met: 75.6% of those expressing it reached farmer-to-farmer exchange or a CBO, a gap of only 13.2 percentage points of the sample.

The digital modalities occupy an intermediate position and carry their own constraint. Barriers to accessing agroecological information were overwhelmingly infrastructural: 77.5% of respondents cited poor internet connectivity and 68.1% high data costs, well ahead of lack of devices (28.5%), content not being available in local language (25.1%), limited digital skills (23.8%) and unreliable information (23.6%).

Radio and social media were each used as media by about half the sample, but only 22.8% and 30.1% respectively named them as sources of agroecological knowledge specifically, a gap between general media use and agroecological content that suggests the constraint lies in what is broadcast rather than in whether farmers are listening.

Table 5
Alignment between preferred learning modality and the channels farmers actually reach

Preferred learning modality	Prefer it % of 386	Of those, reach a channel that can deliver it (%)	Unmet n	Unmet % of 386
Hands-on field demonstrations	77.7	27.7	217	56.2
Group discussion or peer learning	54.1	75.6	51	13.2
Step-by-step written guides	36.8	-	-	-
Visual aids (video, charts, diagrams)	35.5	51.1	67	17.4
Social applications (WhatsApp, live video)	35.0	60.7	53	13.7
Audio-based learning (radio, podcasts)	22.0	41.2	50	13.0
Interactive mobile applications	17.9	26.1	51	13.2

Delivering channels: hands-on demonstrations → Farmer Field Schools or agricultural fairs; group discussion → farmer-to-farmer exchange or community-based organisations; visual aids and social applications → social media/internet or mobile applications; audio → radio; interactive applications → mobile applications. Step-by-step written guides have no corresponding channel in the source list and are reported for completeness only.

4. Discussion

4.1 A stratified rather than a segmented knowledge system

The headline descriptive result, informal peer exchange dominant, structured pedagogic channels marginal, is consistent with a broad literature on agricultural knowledge in eastern Africa [8, 10, 27]. What the repertoire analysis adds is an account of why the formal-informal gap is so persistent. The eleven channels are not competing alternatives from which farmers select according to preference or fit. They are arranged in an accessibility gradient that farmers traverse to different depths, and the depth reached is associated with income, education and digital confidence.

The latent class result makes this explicit. Had the system been segmented, we would expect classes with crossing profiles: a digitally connected group, an NGO-dependent group, an extension-dependent group. Instead, the two recovered classes are nested, with the broad class dominating the narrow one on ten of eleven channels. The one exception is instructive: NGOs, the only channel more probable in the narrow class, are also the channel with the strongest county effect. NGO reach in Busia is a project footprint, not a position in a hierarchy, which is exactly why it behaves differently from the rest.

This finding parallels the European microAKIS evidence, where advisory pluralism at system level did not produce pluralistic repertoires at farm level [11]. The mechanism appears different, privatisation of advisory services in Europe, resource stratification in western Kenya, but the implication converges. Counting channels in a system says very little about what any individual farmer can reach, and reforms that add supply without addressing the ordering of access will reproduce existing distributions.

4.2 Structured channels as supplements, not entry points

The most policy-relevant result is the absence of sole-source users for Farmer Field Schools and research institutions. Zero out of 44 FFS users and zero out of 24 research-institution users named these as their only source, while their mean repertoires exceeded the sample mean by roughly 70%. On the evidence of this sample, no farmer arrives at agroecological knowledge through a Farmer Field School; farmers arrive at Farmer Field Schools after they are already connected.

This reframes a long-standing debate. The FFS impact literature is broadly positive on outcomes for participants, with documented gains in productivity and income in East Africa and in the human and social capital of participating communities [8, 9, 28]. Our results do not contest those findings; they are about selection into the channel rather than its effect once entered. But the two questions have been conflated in practice. If FFS effects are estimated on a population that is already among the best-connected in the community, then scaling FFS coverage will not, by itself, reach the farmers who currently rely on a single channel, and 23.3% of our sample does. Coverage targets expressed as numbers of farmers trained are compatible with no change at all in who the system reaches.

The corollary for the design of any integrated agroecological information tool, a live policy question in both counties, is that recruitment pathways matter more than content. A tool that farmers must already be connected to discover will replicate the FFS pattern. The channels that do function as entry points in these data are farmer-to-farmer exchange, extension officers and, in Busia, NGOs; these are the only realistic recruitment surfaces for reaching narrow-repertoire farmers.

4.3 Peer networks as a closed loop

The negative association between farmer-group access and science-based channel use (OR 0.60) deserves emphasis because it runs against a common assumption in extension design. Farmer groups are routinely treated as multipliers: train a group, and knowledge diffuses outward and upward. Social learning evidence supports the horizontal component of this claim [29, 30, 31]. Our data are consistent with strong horizontal circulation, farmer-group access doubled the odds of peer sourcing, but give no

support to the vertical component. Farmers with the best group access were less likely, not more, to reach a Farmer Field School or a research institution.

We are cautious about interpreting this causally. The cross-sectional design cannot distinguish a closed-loop mechanism (dense peer networks satisfying information needs and reducing search) from a substitution mechanism (farmers with strong groups facing lower marginal returns to institutional channels) or from an artefact of where groups happen to be dense. What can be said is that in this sample the peer network is not observably operating as a bridge to codified agronomic science, and that programme designs assuming otherwise carry an unverified premise. The wider literature on integrating farmers' and formal knowledge argues that such integration requires deliberate brokerage rather than proximity alone [32], and these results are consistent with that argument.

4.4 Two counties, one structure, different intermediaries

Busia and Siaya reached almost identical repertoire breadth by different institutional routes. In Busia, NGOs reached 69.9% of farmers and CBOs 2.8%; in Siaya the figures were 24.3% and 21.4%. Farmer-to-farmer exchange and extension were statistically indistinguishable between the two.

The two configurations carry different risks. Busia's dependence on externally funded projects is characteristically time-limited: NGO presence is a function of project cycles, and the farmer-to-farmer extension literature has documented repeatedly that volunteer and project-based approaches decay when funding ends [10, 33, 34]. Siaya's community-based configuration is more locally rooted and therefore plausibly more durable, and it is accompanied by higher self-rated access to extension (79.0% good or excellent, against 43.2%) and to farmer groups. It is also, notably, the county with more contact with research institutions. But Siaya farmers reported both fewer implemented practices and lower prior training rates, which suggests the community configuration currently delivers connection more effectively than it delivers technical content.

Neither configuration matches the pluralistic advisory ideal in which public, private and civil-society providers occupy complementary niches [13]. Neither county's structure should be read as a template. The point is that the same accessibility ordering, peer exchange at the base, science-based channels at the apex, held in both, despite very different intermediary landscapes. That robustness is what makes the stratification argument more than a description of one county's project history.

4.5 Wanting demonstrations, receiving broadcasts

Seventy-eight percent of farmers wanted hands-on field demonstrations, and nearly three-quarters of them had no demonstration-based channel available. This is the most actionable single number in the study, and it points in the opposite direction to the current trajectory of advisory investment.

The mismatch is not a case of farmers rejecting digital channels. A third of respondents wanted to learn through social applications and a similar share through visual aids, and about half used radio or social media as general media. Recent Kenyan work confirms that well-timed digital messaging can reinforce

sustainable practice adoption in this region [35]. But the infrastructural constraints reported here, 77.5% citing poor connectivity and 68.1% citing data costs, mean that digital channels cannot substitute for the experiential modality farmers most want, and the evidence on digital advisory tools in the Global South consistently identifies these same constraints alongside trust as the binding limitations [17, 36, 37]. The efficient reading of these data is complementarity with a specific division of labour: digital channels for time-sensitive, low-bandwidth content (weather, pest alerts, market prices), and physical demonstration for the context-dependent, adaptive practices that constitute agroecology proper.

The finding that broader repertoires are associated with lower satisfaction reinforces this. Farmers who reach more of the system are not more content with it; they are better informed about its gaps. Adding channels of the kind already present does not appear to resolve perceived inadequacy.

4.6 Limitations

Six limitations bound these conclusions. First, the design is cross-sectional, so all associations are correlational; the direction of the relationships between income and repertoire breadth, and between farmer-group access and science-based channel use, cannot be established here.

Second, recruitment was purposive through project networks, so the sample over-represents farmers already connected to agroecological programming. This inflates the absolute reach figures reported in Table 2 relative to the general smallholder population. It does not affect the paper's central claim, which concerns the ordering of channels within farmers' repertoires rather than their population prevalence. If anything, a project-connected sample makes the absence of sole-source users for structured channels more striking, since these are the farmers most likely to have reached them.

Third, channel use is self-reported from a fixed list, which necessarily imposes the survey designers' taxonomy on farmers' own categories and cannot capture intensity, recency or quality of contact: a farmer who spoke to an extension officer once a year and one in weekly contact are recorded identically.

Fourth, the structured, science-based category contains only two channels and 61 farmers. Its behaviour is consistent and striking, but a survey instrument designed specifically to test the entry-point hypothesis would ideally include a wider range of facilitated learning formats, such as demonstration plots, lead-farmer schemes or on-farm trials, to establish whether the pattern holds across the pedagogic family or is specific to Farmer Field Schools.

Fifth, with twelve wards, cluster-robust inference is conservative but imprecise; the regression coefficients should be read as indicating direction and rough magnitude rather than as precise estimates, and we have avoided interpreting marginal significance throughout.

Sixth, the study covers two adjacent counties in one agroecological zone with prior climate-smart agriculture project exposure, so the specific prevalence figures should not be extrapolated to Kenya as a whole. The structural finding, that channels are ordered by accessibility and that the science-based ones sit at the apex, is the portable claim, and warrants testing elsewhere.

5. Conclusion

Smallholders in Busia and Siaya obtain agroecological knowledge primarily from each other (69.4%), from government extension officers (54.1%) and from NGOs (45.1%). Farmer Field Schools (11.4%) and academic or research institutions (6.2%) reach few. But the reason those channels reach few is not that they serve a distinct constituency: they serve the farmers who are already best connected. Not one farmer in 386 named a Farmer Field School or a research institution as a sole source of agroecological knowledge, and the users of those channels held repertoires roughly 70% broader than the sample average.

The agroecological knowledge system in these two counties is stratified rather than segmented. A two-class latent structure separates a narrow, socially embedded majority from a broad, institutionally connected minority that does everything the majority does and more, with class membership tracking income, education and digital confidence. Structured, science-based channels are supplements to broad repertoires, not entry points into them.

Three implications follow. Programmes should be evaluated on whom they recruit, not only on how many they train; a Farmer Field School that fills its places from the best-connected quartile can meet its coverage target while leaving the access distribution unchanged. Recruitment into structured learning should run deliberately through the channels that do function as entry points, peer exchange, extension officers and, where present, NGOs, rather than relying on farmers to find their way in. And investment should follow the demonstrated preference: 77.7% of farmers want hands-on field demonstrations and 72.3% of them have no demonstration-based channel, a gap that no volume of broadcast or digital content will close given the connectivity and cost constraints farmers themselves report.

Kenya's National Agroecology Strategy commits to the co-creation and horizontal sharing of knowledge over the coming decade. The horizontal element is already working in western Kenya, and working well. What is missing is the vertical connection between that dense peer layer and the codified agronomic science the strategy also invokes and, on this evidence, the farmer groups that were expected to provide that connection are not currently doing so.

Declarations

Funding: This work was supported by Flemish Interuniversity Council-University Development Cooperation (VLIR-UOS), grant number KE2022TEA516A101. The funder had no role in study design, data collection, analysis, interpretation, or the decision to submit.

Ethics approval and consent to participate: The study protocol was reviewed and approved by the University of Eldoret Institutional Research Ethics Committee, and the research was carried out in accordance with the principles of the Declaration of Helsinki and the National Guidelines for Ethical Conduct of Research in Kenya issued by the National Commission for Science, Technology and Innovation (NACOSTI; Licence No. NACOSTI/P/24/39785). Administrative permission and community-

entry support were obtained from the County Governments of Siaya and Busia. Eligible farmers were purposively recruited from county-supported agroecology projects. Informed consent was obtained from all participants before any data were collected. Verbal, rather than written, informed consent was used because the study was a minimal-risk, paperless household survey, because of limited literacy among some participants, and to avoid collecting unnecessary identifying signatures. The approved verbal informed consent procedure was documented electronically by the enumerator selecting the participant's response in a mandatory consent field in KoboToolbox before the questionnaire could proceed. No interview data were collected unless the participant had provided informed consent. The survey data were collected electronically using KoboToolbox and anonymized before analysis.

Data availability statement: The anonymized dataset supporting the findings of this study is available in Zenodo at <https://doi.org/10.5281/zenodo.21531518> under public access under a CC BY 4.0 license.

Consent to publish declaration: Not applicable.

Competing interests: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author contributions: **L.B.:** Conceptualization, Methodology, Investigation, Formal analysis. **F.M.:** Supervision, Editing. **R.N.:** Supervision, Editing, Funding. **A.O.:** Supervision, Editing, Funding. **G.A.:** Writing-original draft and further analysis, Supervision, Funding, Review and editing. All authors read and approved the final manuscript.

Clinical trial number: Not applicable

Acknowledgements: We are deeply grateful to the smallholder farmers of Siaya and Busia Counties, who generously gave their time, trust, and insights, and without whom this study would not have been possible. We thank the agricultural extension officers and ward administrators of the County Government of Siaya and Busia for facilitating community entry and supporting fieldwork, and our field assistants and enumerators for their diligence and professionalism during data collection. We further acknowledge the Flemish Interuniversity Council - University Development Cooperation (VLIR-UOS) for supporting this research under Project No. KE2022TEA516A101.

References

1. Ministry of Agriculture and Livestock Development. National agroecology strategy for food system transformation 2024–2033. Nairobi: Government of Kenya; 2024.
2. Wezel A, Herren BG, Bezner Kerr R, Barrios E, Gonçalves ALR, Sinclair F. Agroecological principles and elements and their implications for transitioning to sustainable food systems. A review. *Agron Sustain Dev*. 2020;40:40. <https://doi.org/10.1007/s13593-020-00646-z>.
3. Food and Agriculture Organization of the United Nations. The 10 elements of agroecology: guiding the transition to sustainable food and agricultural systems. Rome: FAO; 2018.

4. High Level Panel of Experts on Food Security and Nutrition. Agroecological and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition. Rome: Committee on World Food Security; 2019.
5. Gliessman SR. Agroecology: the ecology of sustainable food systems. 3rd ed. Boca Raton: CRC; 2015.
6. Bezner Kerr R, Madsen S, Stüber M, Liebert J, Enloe S, Borghino N, et al. Can agroecology improve food security and nutrition? A review. *Glob Food Sec.* 2021;29:100540. <https://doi.org/10.1016/j.gfs.2021.100540>.
7. Anderson CR, Bruil J, Chappell MJ, Kiss C, Pimbert MP. From transition to domains of transformation: getting to sustainable and just food systems through agroecology. *Sustainability.* 2019;11:5272. <https://doi.org/10.3390/su11195272>.
8. Davis K, Nkonya E, Kato E, Mekonnen DA, Odendo M, Miiro R, et al. Impact of farmer field schools on agricultural productivity and poverty in East Africa. *World Dev.* 2012;40:402–13. <https://doi.org/10.1016/j.worlddev.2011.05.019>.
9. van den Berg H, Jiggins J. Investing in farmers—the impacts of farmer field schools in relation to integrated pest management. *World Dev.* 2007;35:663–86. <https://doi.org/10.1016/j.worlddev.2006.05.004>.
10. Kiptot E, Franzel S. Farmer-to-farmer extension: opportunities for enhancing performance of volunteer farmer trainers in Kenya. *Dev Pract.* 2015;25:503–17. <https://doi.org/10.1080/09614524.2015.1029438>.
11. Madureira L, Labarthe P, Marques CS, Santos G. Exploring microAKIS: farmer-centric evidence on the role of advice in agricultural innovation in Europe. *J Agric Educ Ext.* 2022;28:549–75. <https://doi.org/10.1080/1389224X.2022.2123838>.
12. Knierim A. Why use the microAKIS concept? *J Agric Educ Ext.* 2025;31:437–48. <https://doi.org/10.1080/1389224X.2024.2402307>.
13. Birner R, Davis K, Pender J, Nkonya E, Anandajayasekeram P, Ekboir J, et al. From best practice to best fit: a framework for designing and analyzing pluralistic agricultural advisory services worldwide. *J Agric Educ Ext.* 2009;15:341–55. <https://doi.org/10.1080/13892240903309595>.
14. Fabregas R, Kremer M, Schilbach F. Realizing the potential of digital development: the case of agricultural advice. *Science.* 2019;366:eaay3038. <https://doi.org/10.1126/science.aay3038>.
15. Aker JC. Dial A for agriculture: a review of information and communication technologies for agricultural extension in developing countries. *Agric Econ.* 2011;42:631–47. <https://doi.org/10.1111/j.1574-0862.2011.00545.x>.
16. Kansiime MK, Mugambi I, Rware H, Alokkit C, Aliamo C, Zhang F, et al. Challenges and capacity gaps in smallholder access to digital extension and advisory services in Kenya and Uganda. *Front Agric Sci Eng.* 2022;9:642–54. <https://doi.org/10.15302/J-FASE-2021423>.
17. Ofosu-Ampong K, Abera W, Mesfin T, Abate T. Digital agro-advisory tools in the global south: a behavioural analysis of impacts, and future directions. *Discov Agric.* 2025;3:40.

<https://doi.org/10.1007/s44279-025-00190-y>.

18. Kithinji BM, Echessa BK, Kabaka LC, Bakari EK. Enhancing adoption of agroecological practices among smallholder farmers in Kenya. In: Onyeneke RU, Emenekwe CC, Nwajiuba CU, editors. *Energy transition, climate action and sustainable agriculture*. Cham: Springer; 2025.
https://doi.org/10.1007/978-3-031-83165-2_27.
19. Musafiri CM, Kiboi M, Macharia J, Ng'etich OK, Kosgei DK, Mulianga B, et al. Adoption of climate-smart agricultural practices among smallholder farmers in Western Kenya: do socioeconomic, institutional, and biophysical factors matter? *Heliyon*. 2022;8:e08677.
<https://doi.org/10.1016/j.heliyon.2021.e08677>.
20. Kenya National Bureau of Statistics. 2019 Kenya population and housing census, volume I: population by county and sub-county. Nairobi: KNBS; 2019.
21. Kassie M, Teklewold H, Jaleta M, Marennya P, Erenstein O. Understanding the adoption of a portfolio of sustainable intensification practices in eastern and southern Africa. *Land Use Policy*. 2015;42:400–11. <https://doi.org/10.1016/j.landusepol.2014.08.016>.
22. Benjamini Y, Hochberg Y. Controlling the false discovery rate: a practical and powerful approach to multiple testing. *J R Stat Soc Ser B Stat Methodol*. 1995;57:289–300.
<https://doi.org/10.1111/j.2517-6161.1995.tb02031.x>.
23. Mokken RJ. A theory and procedure of scale analysis, with applications in political research. The Hague: Mouton; 1971.
24. Lazarsfeld PF, Henry NW. Latent structure analysis. Boston: Houghton Mifflin; 1968.
25. Nylund KL, Asparouhov T, Muthén BO. Deciding on the number of classes in latent class analysis and growth mixture modeling: a Monte Carlo simulation study. *Struct Equ Model*. 2007;14:535–69.
<https://doi.org/10.1080/10705510701575396>.
26. Cameron AC, Miller DL. A practitioner's guide to cluster-robust inference. *J Hum Resour*. 2015;50:317–72. <https://doi.org/10.3368/jhr.50.2.317>.
27. Lwoga ET, Stilwell C, Ngulube P. Access and use of agricultural information and knowledge in Tanzania. *Libr Rev*. 2011;60:383–95. <https://doi.org/10.1108/00242531111135263>.
28. Waddington H, Snilstveit B, Hombrados J, Vojtkova M, Phillips D, Davies P, et al. Farmer field schools for improving farming practices and farmer outcomes: a systematic review. *Campbell Syst Rev*. 2014;10:1–335. <https://doi.org/10.4073/csr.2014.6>.
29. Conley TG, Udry CR. Learning about a new technology: pineapple in Ghana. *Am Econ Rev*. 2010;100:35–69. <https://doi.org/10.1257/aer.100.1.35>.
30. BenYishay A, Mobarak AM. Social learning and incentives for experimentation and communication. *Rev Econ Stud*. 2019;86:976–1009. <https://doi.org/10.1093/restud/rdy039>.
31. Bandiera O, Rasul I. Social networks and technology adoption in northern Mozambique. *Econ J*. 2006;116:869–902. <https://doi.org/10.1111/j.1468-0297.2006.01115.x>.

32. Šūmane S, Kunda I, Knickel K, Strauss A, Tisenkopfs T, Rios IDI, et al. Local and farmers' knowledge matters! How integrating informal and formal knowledge enhances sustainable and resilient agriculture. *J Rural Stud.* 2018;59:232–41. <https://doi.org/10.1016/j.jrurstud.2017.01.020>.
33. Nakano Y, Tsusaka TW, Aida T, Pede VO. Is farmer-to-farmer extension effective? The impact of training on technology adoption and rice farming productivity in Tanzania. *World Dev.* 2018;105:336–51. <https://doi.org/10.1016/j.worlddev.2017.12.013>.
34. Kiptot E, Franzel S, Hebinck P, Richards P. Sharing seed and knowledge: farmer to farmer dissemination of agroforestry technologies in western Kenya. *Agrofor Syst.* 2006;68:167–79. <https://doi.org/10.1007/s10457-006-9007-8>.
35. Blekking J, Waldman K, Nyaidho O, Otieno D. Temporally relevant SMS reminders can reinforce adoption of sustainable agricultural practices. *Environ Behav.* 2026. <https://doi.org/10.1177/00139165251390702>.
36. Klerkx L, Jakku E, Labarthe P. A review of social science on digital agriculture, smart farming and agriculture 4.0: new contributions and a future research agenda. *NJAS Wagening J Life Sci.* 2019;90–1. <https://doi.org/10.1016/j.njas.2019.100315>.
37. Steinke J, van Etten J, Müller A, Ortiz-Crespo B, van de Gevel J, Silvestri S, et al. Tapping the full potential of the digital revolution for agricultural extension: an emerging innovation agenda. *Int J Agric Sustain.* 2021;19:549–65. <https://doi.org/10.1080/14735903.2020.1738754>.
38. Zander KK, Drucker AG, Aluso L, Mengistu DK, Fadda C, Termote C, et al. Using best-worst scaling to inform agroecological interventions in Western Kenya. *Environ Dev Sustain.* 2026;28:4715–39. <https://doi.org/10.1007/s10668-024-05173-5>.
39. Ragasa C. Improving gender responsiveness of agricultural extension. In: Quisumbing AR, Meinzen-Dick R, Raney TL, Croppenstedt A, Behrman JA, Peterman A, editors. *Gender in agriculture: closing the knowledge gap*. Dordrecht: Springer; 2014. pp. 411–30. https://doi.org/10.1007/978-94-017-8616-4_17.
40. Deichmann U, Goyal A, Mishra D. Will digital technologies transform agriculture in developing countries? *Agric Econ.* 2016;47:21–33. <https://doi.org/10.1111/agec.12300>.

Figures

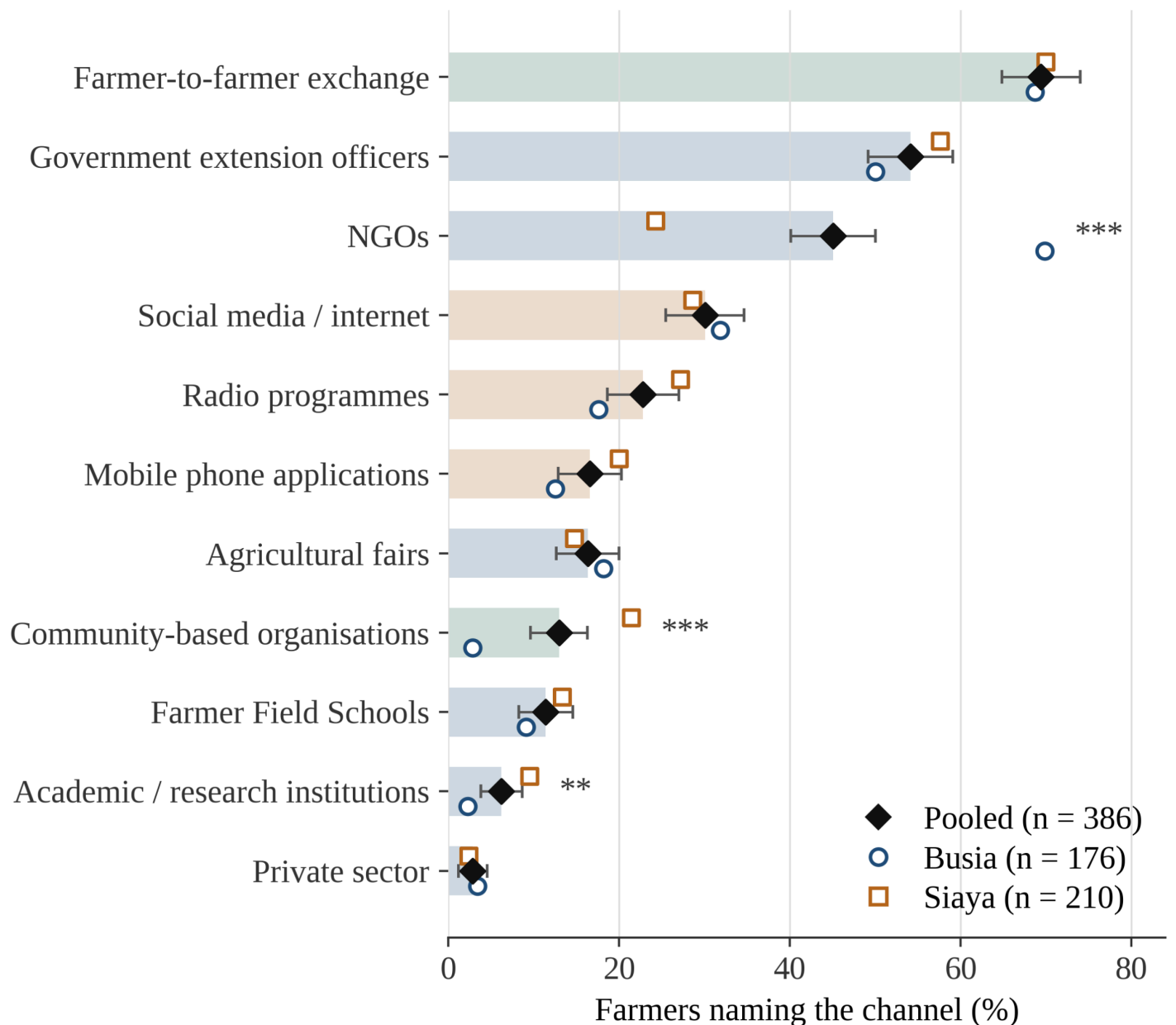


Figure 1

Prevalence of eleven agroecological knowledge channels among 386 smallholder farmers in Busia and Siaya counties, western Kenya. Black diamonds show pooled prevalence with 95% confidence intervals; open circles and squares show county-specific prevalence. Bar shading indicates the conceptual domain of each channel. Asterisks mark differences between counties surviving Benjamini-Hochberg adjustment ($q < 0.05$; * $q < 0.001$)

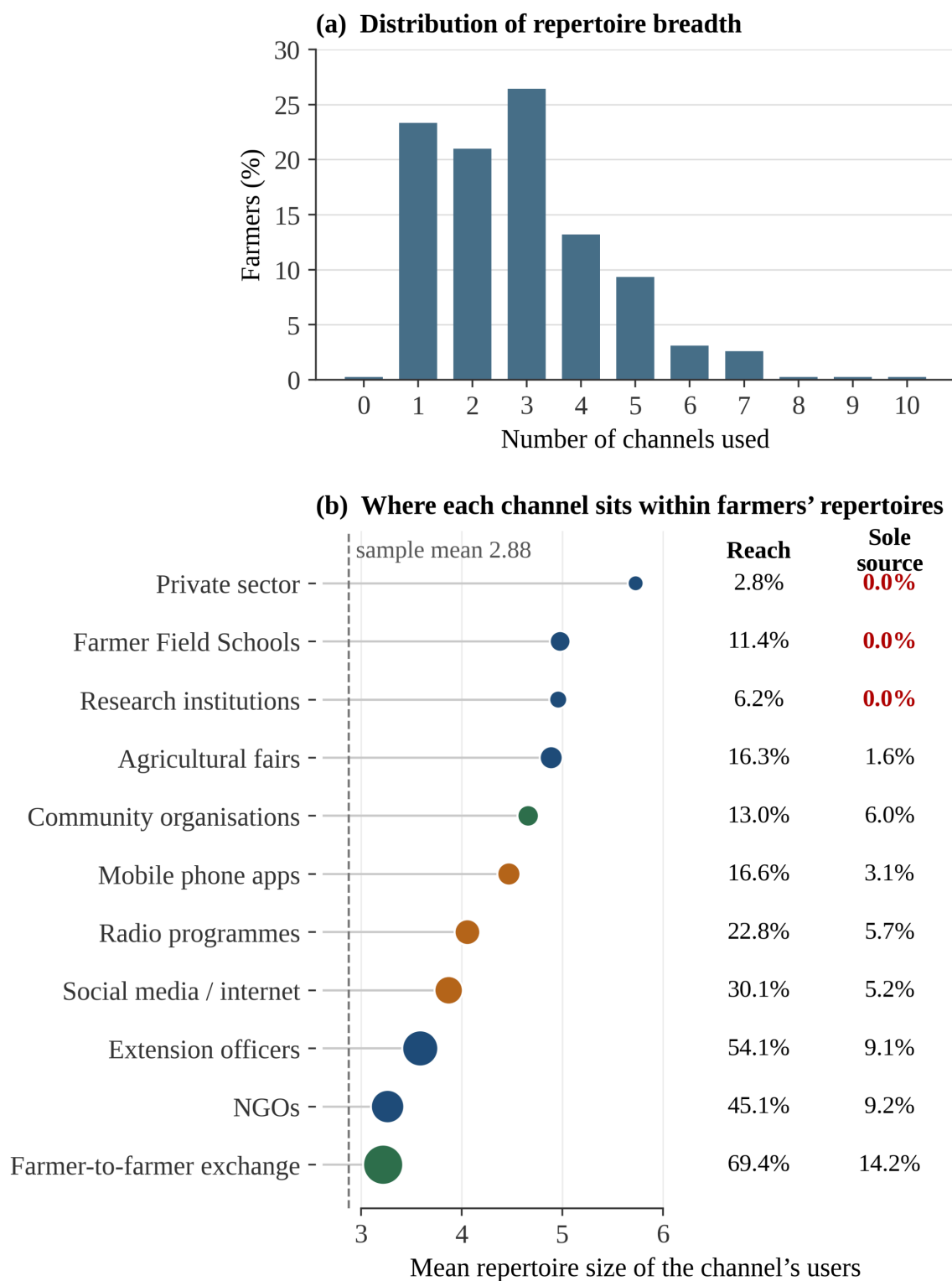


Figure 2

Structure of farmers' knowledge repertoires. a Distribution of the number of channels named per farmer. b Relationship between the prevalence of a channel and the mean repertoire breadth of the farmers who use it; marker area is proportional to the share of a channel's users for whom it is the sole named source, and marker colour indicates conceptual domain as in Fig. 1. The dashed line marks the sample mean repertoire breadth

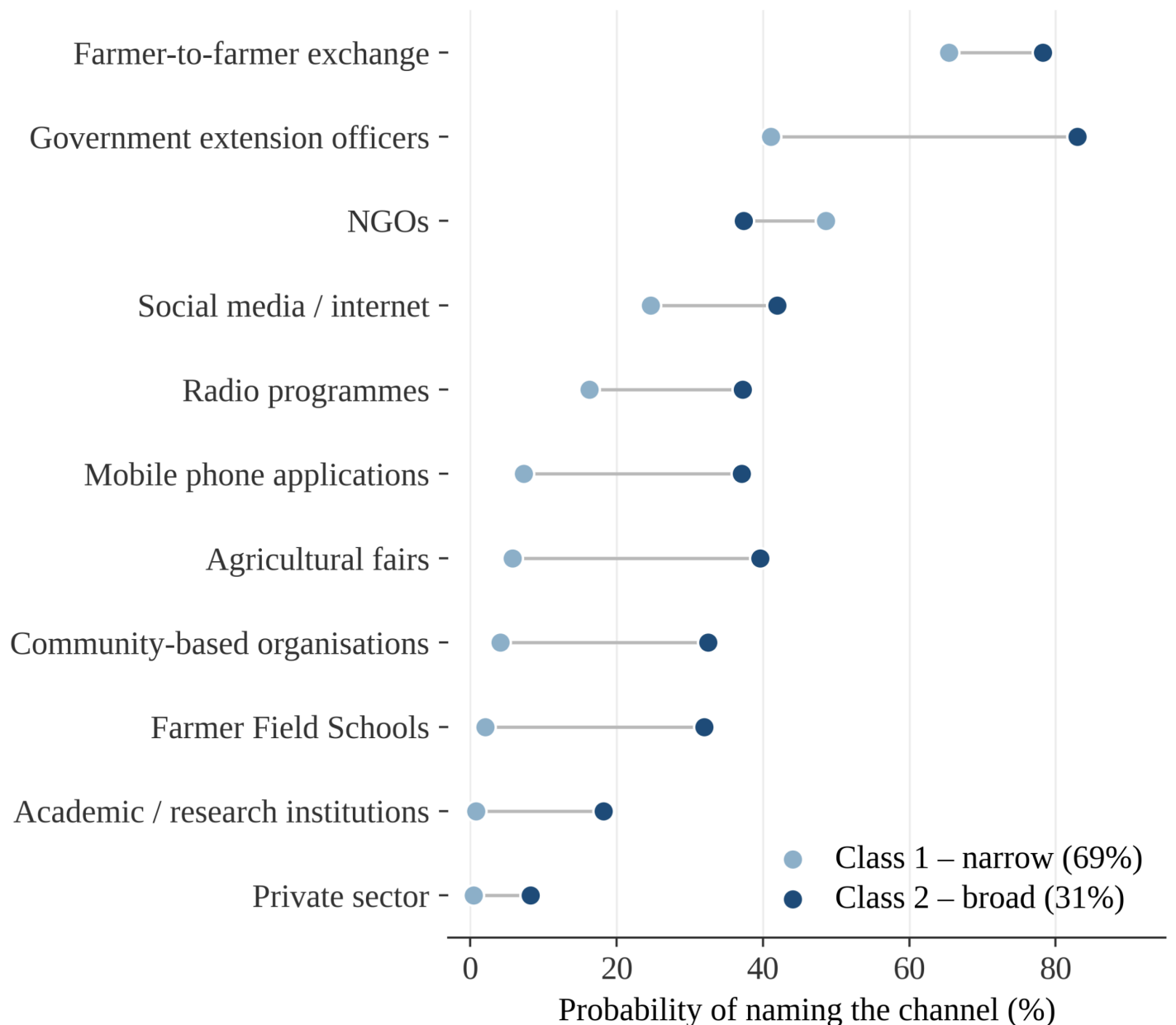


Figure 3

Item-response probabilities from the two-class latent class model of knowledge-source repertoires, selected by the Bayesian information criterion. Class 2 exceeds Class 1 on every channel except NGOs, and the difference is largest on the channels that are rarest overall, indicating stratification by depth of access rather than segmentation into distinct niches

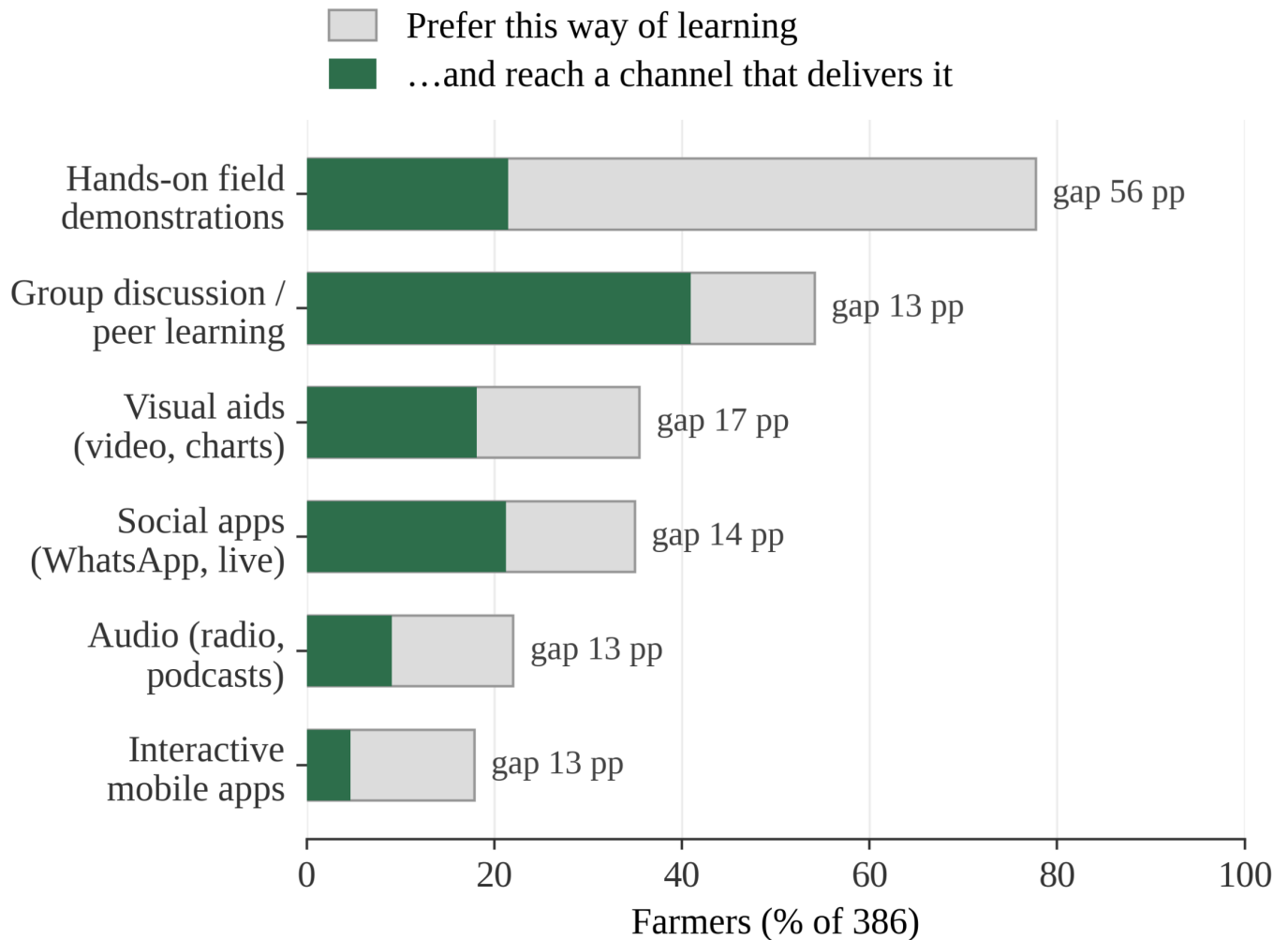


Figure 4

Gap between preferred learning modality and the channels farmers actually reach. Grey bars show the percentage of all 386 farmers expressing each preference; green bars show the percentage who both express the preference and reach at least one channel capable of delivering it