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Beyond individual practices: three management profiles structure Ivorian cocoa agroforestry

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Abstract

West African cocoa farmers combine diverse practices for managing the trees associated with their plantations, but whether these practices organize into coherent profiles or vary idiosyncratically remains unknown. We test this question on a national sample of 452 farms covering, for the first time, the three major cocoa-growing « loops » of Côte d'Ivoire (109 East/South-East, 175 Centre/Centre-West, 168 South/South-West), using Multiple Correspondence Analysis (*MCA*) on 15 active management variables, followed by hierarchical agglomerative clustering (Ward's method) on the first two factorial axes (64.0% of Benzécri-corrected inertia). The number of profiles is selected by silhouette score (k = 3, silhouette = 0.353), confirmed by *K*-means (Adjusted Rand Index = 0.689) and stable under resampling (mean Adjusted Rand Index = 0.526). Three profiles emerge: a « diversified » profile (n = 241, 53.3%), combining all three tree origins and the most widespread belief in their usefulness; a « planted-dominant and specialized » profile (n = 160, 35.4%), almost exclusively of planted origin; and a « passive and poorly-advised » profile (n = 51, 11.3%), overwhelmingly spontaneous/residual, with technical extension nearly absent (4%) and the only profile with predominantly negative perceived effects. The profiles differ significantly in yield (Kruskal-Wallis, H = 9.23, p = 0.010; passive profile 141 kg/ha/yr versus 238–242 for the other two) and are not independent of the production loop (Chi², p < 0.0001). A joint model of determinants (multinomial logistic regression, cross-checked with random forest) confirms that the production loop (χ^2=26.40, p < 0.0001) and education level (χ^2=11.88, p = 0.018) are the factors most robustly associated with profile membership, ahead of ethnicity and plantation age; cooperative membership is not significant. These results indicate that cocoa agroforestry management in Côte d'Ivoire organizes into recognizable profiles, one of which, a minority, combines a yield deficit with very limited access to technical extension.

Introduction

The diversity of practices for managing the trees associated with cocoa plantations (origin (« retained at clearing, arising from uncontrolled natural regeneration, or deliberately planted ») mode of acquisition, access to technical extension) is well documented descriptively in the West African literature, but rarely analyzed as a system of correlated practices likely to form recognizable farmer profiles. The literature identifies the deliberately planted origin of associated trees as a significant agronomic determinant of cocoa yield (Konan et al., 2025) ; an observation that raises a logically prior question: is this practice isolated, or does it belong to a broader set of correlated practices (seedling production, technical extension, perceived usefulness of trees) defining distinct management profiles? And if such profiles exist, are they distributed uniformly across Ivorian territory, or are some specific to certain production loops?

Several typologies of cocoa-based agroforestry systems have been proposed in West and Central Africa, generally built at the scale of a single geographic area and based on structural criteria (density, strata, floristic composition) rather than on management practices themselves (Bruno et al., 2015, zone de Kokumbo). More recent literature highlights the value of explicitly distinguishing associated trees by

origin (residual, spontaneous or planted) as an agronomically significant axis (Konan et al., 2025), and documents, in other cocoa-growing contexts (the Colombian Amazon, Cameroon), that management profiles result from socio-historical trajectories and differentiated resource-access constraints rather than a uniform technical choice (Melo-Zipacon et al., 2025; Michel et al., 2024). To our knowledge, none of these studies has built a management typology at the Ivorian national scale, nor formally tested its independence from the production loop.

This article builds a data-driven typology from 15 active variables describing the origin, acquisition and management of the associated trees and of the cocoa plantation itself, deliberately excluding the production loop and socio-demographic variables from the active set in order to test, a posteriori, whether the resulting profiles overlap with geographic boundaries and farmer profile or not. The method combines Multiple Correspondence Analysis (Husson et al., 2017) with Ward hierarchical agglomerative clustering (Ward Jr., 1963), with the number of clusters selected by silhouette score and stability checked by resampling. Beyond describing the profiles, the literature on the determinants of agroforestry practice adoption highlights that education level (Kumah et al., 2024), ethnicity and migration status (Kouassi et al., 2023), cooperative membership (Moluh Njoya et al., 2025) or access to extension services (Yiridomoh et al., 2022) can condition the type of practices adopted; a hypothesis tested here formally rather than through simple cross-tabulation. This article pursues four objectives: to build a typology of management profiles based on self-reported practices; to test the robustness and statistical stability of these profiles; to characterize them on supplementary variables (yield, loop, socio-demographics) without having used them to build the typology; and to jointly model the determinants of profile membership using multinomial logistic regression, cross-checked with random forest. By making this heterogeneity of practices visible, this typology offers a differentiated reading of the sustainability trajectories of Ivorian cocoa farms, useful for targeting interventions tailored to each profile rather than a uniform policy.

This article addresses three research questions, each paired with a hypothesis motivated by the elements outlined above:

- Q1: Do management practices for trees associated with cocoa plantations organize into statistically distinct and reproducible profiles, or do they vary idiosyncratically from farm to farm?
- H1: practices cluster into a small number of coherent profiles, rather than varying independently of one another;
- Q2: Are these profiles distributed uniformly across Ivorian territory, or are some specific to certain production loops?
- H2: profile membership is not independent of the production loop;
- Q3: Beyond geography, do the farmer's socio-demographic factors (education level, ethnicity, migration status, cooperative membership) help explain profile membership?
- H3: education level and other socio-demographic factors remain significantly associated with profile membership, even after controlling for the production loop;

Materials and Methods

The data come from the field survey described in the source Master's thesis in agroforestry (Jean Lorougnon Guédé University, Côte d'Ivoire), conducted using survey forms (Supplementary Material: S1) among 474 cocoa farms (Adji et al., 2016). After correcting an extraction bug that had affected the Centre/Centre-West and South/South-West loops, this article uses the full sample of 452 farms with a valid production-loop classification: the outcome variable is a management profile built from self-reported practices, not a yield model, and yield (available for a subset of 409 farms) is used only a posteriori, as a supplementary interpretive variable. The aim of the analysis is to build a typology of management profiles from self-reported practices, not to explain yield: yield (available for a subset of 409 farms) therefore plays no part in constructing the profiles, and is used only afterward, as a supplementary variable to check whether the profiles also differ along this dimension.

Study area and sample

The survey covers 452 farms spread across 16 departments or sub-prefectures and 103 villages or hamlets, in the three major cocoa-growing loops of Côte d'Ivoire (Fig. 1, Table 1): Loop 1 (East/South-East, 4 departments, 109 farms), Loop 2 (Centre/Centre-West, 8 departments, 175 farms) and Loop 3 (South/South-West, 4 departments, 168 farms).

Table 1
Survey sites by cocoa-growing loop (16 departments/sub-prefectures, 103 villages and hamlets).

Cocoa-growing zones	Regions	Departments	Survey sites (sub-prefecture, villages and hamlets)
Loop 1 (East/South-East)	Indénié-djuablin	Abengourou	Akoikro (N'zebenou), Amelekia, Arifi, Kodjinan, Kouassibeniekro, Niable (Adoninkro, Affalikro, Assokro, Anuanuan, Anuansuê), Yakassé Feyassé (Eboissue, Sankadiokro), Konankro.
	Mé	Adzopé	Agou (N'guessankoi), Ahuikoi, Biasso, Nehanzin.
		Akoupé	N'koupé.
	Agneby-tiassa	Agboville	Petit Yapo, Grand Morié, Grand Yapo, Offa, Grand Yapo, Boka Oho, Offoumpo.
Total	3	4	28
Loop 2 (Centre/Centre-West)	Belier	Djekanou	Albertn'dakro, Djetran-Yaokro, Kocoubo, Mougnan, Wobekro.
		Toumodi	Assouvoue, Bofledo, Lahourebo, N'doukahakro.
	Haut Sassandra	Daloa	Bohoua-Bahouan, Bohouahawa, Carrefou Pk 12, Gboguhé (Keibla), M'bayakoffikro, Tapeguhé.
		Vavoua	Vavoua, Bonoufla.
		Issia	Boguédia (Mimia1, Mimia2, Mimia3), Issia, Iboguhé, Madrassokouro, Mandiassoucloi, Tetia.
		Zoukougbeu	Gregbeu (Blaikro), Guessabo (Ouatigbeu, Gorodi, Dagbrezou).
	Lac	Yamoussoukro	Kossou (Angosse, Yobouekro), Senan.
	Marahoué	Bouaflé	Benou, Bledi, Bonon (Djahakro, Saa, N'guessankro, Bokrolaye), Bozy, Garango, Koupela, Lopouafla, Pakouafla, Pakouabo, Sokrolaye, Tingodogo.
Total	4	8	51
Loop 3 (South/South-West)	Lôh-Djiboua	Divo	Bradodougou, Konankro, Pétimpé, Yobouékro, Boubo, Data, Tablédjou, Didoko, Hiré, Hiré (Boakako, Kagbé), Ogoudou (Kouamékro).
		Guitry	Warkro
	Nawa	Soubré	Alloukro, Kouadiokro, Négréagui, Oupoyo, Campement Loua-paul, Norbert Carrefour.

Cocoa-growing zones	Regions	Departments	Survey sites (sub-prefecture, villages and hamlets)
	Agneby-Tiassa	Tiassalé	Sokorogbo, Eticoon, Gnangnankansou, Dibykro, N'douci (Abéré).
Total	3	4	24

Ethical considerations and informed consent

The study involved questionnaire interviews with adult cocoa farmers and was conducted in accordance with the principles of the Declaration of Helsinki (World Medical Association, 2013), in particular voluntary participation, prior informed consent, and confidentiality. Before each survey campaign, the study was presented to the local offices of ANADER (the national rural extension agency) and to the cocoa cooperatives, which introduced the survey team to the communities. In each village and hamlet, the team first met the chief to explain the study and obtain his authorisation, in accordance with local custom. Each field mission was authorised by a mission order issued by the National Centre for Agronomic Research (CNRA).

The study was not reviewed by an institutional review board or ethics committee, so no approval reference number is available. At the time of data collection (2013–2016), Jean Lorougnon Guédé University had no ethics committee, and CNRA did not require ethical review for non-interventional questionnaire surveys of farmers on agricultural practices. The survey involved no medical procedure, no intervention, and no biological sampling, and it posed no more than minimal risk to participants.

Informed consent

was obtained verbally from each participant before the interview. The purpose, content, and intended use of the study were explained to each farmer in French or, when needed, in the farmer's own language with translation by the field guide or a relative. Farmers were told that participation was voluntary, that they could decline or stop the interview at any time, and that they were free not to answer any question. No payment or other incentive was offered. Verbal rather than written consent was chosen for three reasons:

- many respondents had limited literacy (39% had no formal schooling);
- asking farmers to sign a document is unusual in this rural context and could have created mistrust about the purpose of the survey;
- the survey collected no health data or other sensitive personal data.

No minors were interviewed: all participants were heads or managers of cocoa farms, and the youngest recorded age was 19 years. Farmers' names were replaced by codes before analysis and before the dataset was made public, and results are reported only in aggregated form.

Multiple Correspondence Analysis and clustering

A Multiple Correspondence Analysis (*MCA*, Python package « prince ») was conducted on the 15 active variables. The raw inertia associated with the first axes of an MCA systematically underestimates the share of variance actually explained when the number of active categories is high; we therefore report the Benzécri-corrected inertia (Benzécri, 1979; see also Husson et al., 2017), which, for an axis with raw inertia λ and a number of active variables Q, retains only axes such that $\lambda > 1/Q$ and weights each of them by:

$\tau_corr = [Q/(Q\text{-}1)]^2 \times (\lambda - 1/Q)^2$, followed by normalization by the sum of τ_corr over the set of retained axes.

The number of factorial axes retained for clustering is determined empirically rather than fixed a priori: tested up to ten axes, the silhouette score of the resulting clustering is maximal with the first two axes and degrades progressively beyond that, indicating that subsequent axes carry mostly noise.

Hierarchical agglomerative clustering (Ward's method; Ward Jr., 1963) was applied to farm coordinates on these two axes. At each step, Ward's criterion merges the pair of clusters A and B that minimizes the increase in total within-cluster inertia:

$$\Delta SS(A,B) = [n_A \times n_B / (n_A + n_B)] \times d(c_A, c_B)^2 ,$$

where n_A and n_B are the cluster sizes and c_A, c_B the centroids of clusters A and B. The number of clusters was selected using the mean silhouette score (Rousseeuw, 1987), tested from $k = 2$ to $k = 7$. For an observation i, the silhouette width is defined as:

$$s(i) = [b(i) - a(i)] / max[a(i), b(i)] ,$$

where $a(i)$ is the mean distance from i to the other points in its own cluster and $b(i)$ the mean distance to the points of the nearest neighbouring cluster. The robustness of the retained partition was checked in three ways. First, an independent K-means partitioning was compared to the Ward clustering using the Adjusted *Rand* Index (Hubert and Arabie, 1985), which corrects the raw *Rand* Index for the agreement expected by chance between two partitions:

$$ARI = (RI - E[RI]) / (max(RI) - E[RI]) ,$$

with a value of 1 indicating perfect agreement and a value near 0 indicating agreement equivalent to chance. Second, the stability of the partitioning was assessed by resampling (30 replications on 80% of the sample, without replacement), each replication compared to the reference partition using the same index. Third, a sensitivity analysis tested the inclusion of the cocoa planting material category among the active variables, to verify that the retained partition is not driven by this variable, which is subject to uneven completeness.

Associations between profiles and categorical supplementary variables were tested using the *Chi²* test of independence (Pearson, 1992) :

$\chi^2 = \Sigma\ (O_{ij} - E_{ij})^2 / E_{ij}$,

summed over the contingency table cells of the squared deviations between observed (O_{ij}) and expected-under-independence (E_{ij}) counts. Yield differences between profiles were tested using the Kruskal-Wallis test (Kruskal and Wallis, 1952) :

$H = [12 / (N(N + 1))] \times \Sigma_k\ (R_k^2 / n_k) - 3(N + 1)$,

which compares the rank sums R_k of k groups of size n_k within an overall sample of size N, followed by pairwise comparisons using the Mann-Whitney test (Mann and Whitney, 1947) with Bonferroni correction (factor of 3, for the three profile pairs).

Results

Sample overview

The final sample comprises 452 farms (109 in the East/South-East loop, 175 in Centre/Centre-West, 168 in South/South-West); Table 2 summarises the active and main supplementary variables. Almost all farms (428/452, 94.7%) have associated trees in one form or another; among them, planted origin accounts for 369/452 farms (81.6%), residual origin for 339/452 (75.0%) and spontaneous origin for 288/452 (63.7%) ; these three categories not being mutually exclusive. Tree-specific technical extension remains rare (94/452, 20.8%), and self-produced seedlings concern about half the sample (228/452, 50.4%).

Table 2
Descriptive statistics of the national sample (*n* = 452, three loops) on active and key supplementary variables.

Variable	% / Mean	Detail	n reported
Presence of associated trees	94.7%	428/452	452/452
Residual origin	75.0%	339/452	452/452
Spontaneous origin	63.7%	288/452	452/452
Planted origin	81.6%	369/452	452/452
Aligned disposition	6.2%	28/452	452/452
Self-produced seedlings	50.4%	228/452	452/452
Tree-specific technical extension	20.8%	94/452	452/452
Selected cocoa material	28.5%	129/452	452/452
Cooperative membership	43.1%	195/452	452/452
Plantation age (years)	22.8 (mean)	median 18.0	452/452
Area (ha)	3.4 (mean)	median 2.0	450/452
Yield (kg/ha/yr)	306.6 (mean)	median 225.0	409/452

authors' calculations on the national sample (*n* = 452). Origin categories are not mutually exclusive. Yield is only available for a subset of 409 farms and is used here only as a supplementary variable to interpret the profiles.

Discussion

Recognizable profiles, not an undifferentiated continuum

The central finding of this article is that management practices for trees associated with cocoa in Côte d'Ivoire do not vary idiosyncratically from farm to farm, but organize into three statistically distinct profiles, selected by an objective criterion (silhouette score) and confirmed by an independent clustering method (*K*-means, Adjusted Rand Index = 0.689) and a resampling stability test (mean Adjusted *Rand* Index = 0.526). This result confirms H1 and directly answers Q1: far from a continuum of individual practices, cocoa agroforestry management in Côte d'Ivoire organizes into a small number of recognizable configurations. The dominant axis of differentiation between Profiles 1/2, on one hand, and Profile 3, on the other, is planting intentionality (planted versus spontaneous/residual origin), an axis already identified in the literature as agronomically significant for cocoa yield (Konan et al., 2025). This typology thus situates this determinant within a broader system of correlated practices (seedling

production, technical extension, perceived usefulness of trees) rather than treating it as a variable independent of the farmer's other management choices.

The « passive and poorly-advised » profile: a minority at risk

Profile 3, although a minority (11.3% of the sample), is statistically the best-individualized of the three (mean silhouette width 0.549 versus 0.364 and 0.275) and shows a combination of traits that makes it a profile at risk rather than a simple marginal variant: a median yield nearly 40% lower than the other two profiles (141 versus 238–242 kg/ha/yr), technical extension nearly absent (4% versus 19–25%), and the only profile where perceived effects of forest trees are predominantly negative. This combination (low yield and minimal access to extension) suggests a closing loop rather than a deliberate choice of extensive management: without technical support, farmers in this profile have fewer opportunities to reconsider a negative perception of associated trees, which in turn sustains the low recourse to deliberate planting. The literature on the determinants of agroforestry practice adoption in West Africa (Kouassi et al., 2023; Kumah et al., 2024) documents similar self-reinforcing mechanisms between information deficit and agroforestry disinvestment, without however having quantified them at the scale of a national typology. This combined productive, institutional and perceptual vulnerability within a single group of farmers concretely illustrates what an agricultural sustainability approach seeks to prevent: a simultaneous lock-in across its economic (yield), institutional (access to extension) and social (trust in the tree resource) dimensions.

A typology that is partially, but not entirely, geographic

The test of independence between profiles and production loop is significant (χ^2=63.91, $p < 0.0001$), which calls for qualifying H2 rather than rejecting it: the production loop partially, but not entirely, structures profile membership. No loop is in fact composed of a single profile; including the East/South-East loop, the most homogeneous, where Profile 1 remains a 22% minority despite its dominance (78%). This result answers Q2 by qualifying the alternative posed in the introduction: management profiles are neither purely geographic (in which case each loop would be dominated by one exclusive profile) nor independent of geography (in which case the Chi-square test would be non-significant); they partially overlap with the map of the three production loops while retaining substantial internal heterogeneity within each. This intra-loop heterogeneity is itself informative: it indicates that non-geographic factors (education in particular, as confirmed by the determinants model) independently contribute to shaping the profiles, beyond the simple loop effect.

Comparison with the literature on cocoa agroforestry typologies

Earlier typologies of cocoa agroforestry systems in Côte d'Ivoire were built at the scale of a single geographic area and based on structural criteria (density, strata, floristic composition) rather than on self-reported management practices (Bruno et al., 2015, zone de Kokumbo). The present typology, built

at the national scale from the practices themselves, is therefore complementary rather than directly comparable to this structural body of work: it addresses a different question (how do farmers manage their trees?) from that posed by floristic typologies (which trees, at what density?). This complementarity opens a direct avenue for research; crossing the two approaches on the same ground would reveal whether the management profiles identified here correspond to distinct stand structures. Our results instead align more directly with two recent studies conducted in other cocoa-growing contexts: in the Colombian Amazon, where cocoa agroforest management profiles are distinguished above all by biophysical and cultural variables rather than by a uniform technical choice (Melo-Zipacon et al., 2025), and in Cameroon, where the complexity of cocoa agroforestry systems reflects socio-historical trajectories and differentiated resource-access constraints (Michel et al., 2024). The convergence of these three contexts (Côte d'Ivoire, Colombia, Cameroon) around a shared finding (management profiles respond more to socio-economic trajectories than to a single technical optimum) suggests that this result is not specific to the Ivorian context, but reflects a broader regularity of smallholder-managed tropical cocoa agroforestry.

Methodologically, this typology follows a well-established tradition of building farm typologies through statistical classification (multivariate analysis followed by hierarchical agglomerative clustering). Kuivanen et al., (2016), comparing a statistical typology to one built participatively with farmers themselves in Ghana, show that the two approaches converge on broad lines but diverge on nuances significant for targeting interventions; a finding that calls for caution regarding the external validity of a purely statistical typology such as the one presented here, and which is taken up as a perspective in the conclusion.

Determinants of profile membership: geography and education matter, ethnicity warrants caution

The joint model of determinants confirms and quantifies the intuition drawn from the cross-tabulations: the production loop is by far the most robust predictor (χ^2=26.40, random-forest importance = 0.264), followed by education (χ^2=11.88, importance = 0.157). This result partially confirms H3: education level remains significantly associated with profile membership even after controlling for the production loop, which is consistent with the literature documenting a link between education and perceptions of cocoa agroforestry (Kumah et al., 2024). The direction of the association is itself informative: a secondary or higher education level reduces the relative probability of belonging to the planted-dominant profile rather than the diversified profile, while a primary level reduces that of belonging to the passive profile; suggesting that education acts less as a straightforward determinant of "more management" than as a factor of practice diversification.

The association between ethnicity and management profile, although statistically significant (p = 0.025), calls for cautious interpretation. Burkinabé/Mossi ethnicity is associated with an increased relative probability of belonging to the passive profile (*OR* = 5.28), and Agni ethnicity with a reduced relative probability of belonging to the planted-dominant profile (*OR* = 0.19). Rather than seeing this as an effect

of ethnic identity as such, a plausible explanation points to land and tree tenure in the Ivorian cocoa belt, where most plantations were established by migrant farmers, notably Baoulé and Burkinabé, under customary arrangements (tutorat, then « plant-to-share ») that often separate ownership of the land from ownership of the planted trees. This explanation must, however, be qualified: the economic literature on Ivorian cocoa tenure shows that tenure insecurity can, on the contrary, incentivize migrant farmers to invest more - planting becoming a strategy to assert de facto control over the land, particularly as trees approach productive maturity (Bros et al., 2019). The passive profile, markedly less planted than the other two, therefore does not correspond directly to this investment-as-security mechanism, and could instead reflect arrangements in which ownership of the trees themselves, not only of the land, remains uncertain for the farmer; a hypothesis our data cannot resolve but that would merit direct testing.

Migration status does not account for the ethnicity-profile association

The interpretation proposed above (that the association between ethnicity and profile reflects differences in land and tree tenure rather than ethnic identity itself) might lead one to expect a direct effect of migration status. This is not, however, what our data show: adding origin/migration status as a supplementary covariate does not significantly improve model fit (p = 0.987), and no category comes close. This null result is itself informative: it suggests that the mechanism at work is not self-reported migration status as such, but more plausibly the precise terms of the land and tree arrangements actually experienced by the farmer - a dimension that a simple declared origin status does not capture, since a Burkinabé farmer settled for several generations may be subject to arrangements very different from those of a recent migrant. The economic literature on Ivorian cocoa tenure further confirms that the effect of land security on investment depends less on migration status as such than on the precise terms of the arrangement and the horizon to tree maturity (Bros et al., 2019). Directly documenting these arrangements (rather than migration status alone) would be a natural extension of this work.

Limitations

Several limitations should be noted. The stability of the partitioning, although statistically validated (mean Adjusted *Rand* Index = 0.526 under resampling), remains moderate: replication on 80% of the sample does not systematically reproduce the reference partition, which calls for caution in generalizing the exact boundaries between profiles, without calling their existence into question. The data come from a cross-sectional survey conducted in 2013–2016 (Adji, 2016); the reported associations between profile, yield and socio-demographic determinants should therefore be read as correlations observed at a given point in time, not as causal relationships, and may have evolved since ; notably under the effect of certification and extension programs deployed since then. The typology itself is statistical in nature and has not been validated participatively with farmers or extension agents, a step that Kuivanen et al. (2016) show capable of revising the boundaries of a purely statistical typology. Finally, the historical evaluation of extension impact in Côte d'Ivoire shows that its effect is not uniform across crops: Romani (2003) documents a net yield gain attributable to extension for food crops between 1997 and 2000, but a more ambiguous effect for cocoa and coffee, with advised farmers possibly having reduced their effort

on these crops; a reminder that access to technical extension, although strongly associated with Profile 1 in our data, is not a lever whose effect on cocoa yield can be presumed automatic or linear.

Conclusion

Based on a sample of 452 farms covering, for the first time, the three cocoa-growing loops of Côte d'Ivoire, this study identifies three statistically distinct and robust agroforestry management profiles (diversified; planted-dominant and specialized; passive and poorly-advised), confirming that farmers' practices organize into recognizable configurations rather than a continuum. These profiles partially overlap with the geography of the production loops; education and, more cautiously, ethnicity add to these as robust determinants.

By linking yield, access to extension and tenure security within a single at-risk profile, these results situate Ivorian cocoa agroforestry management within the broader field of agricultural sustainability, which extends beyond productive performance alone. The passive profile (a minority, but combining a yield deficit with near-total absence of extension) should be the priority target of differentiated extension services, supported by clearer land and tree tenure arrangements and better integration with the economic valorization of agroforestry products. Participatory validation of the typology, longitudinal monitoring of this profile, and replication in other West African contexts would help test its relevance beyond Côte d'Ivoire. This typology thus offers value-chain stakeholders an operational tool for targeting support to farmers according to their actual management profile, rather than generic categories.

Declarations

Ethics statement

This study adhered to the principles of the Declaration of Helsinki. Formal ethical approval was not obtained because no ethics committee existed or was required by the host institutions for non-interventional farmer surveys at the time; verbal informed consent was obtained from all participants (see Materials and Methods).

Declaration of competing interest

The authors declare no competing interests.

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Author Contributions

BIA. Developed the methodology, collected survey data, analysed the data and wrote the paper. AAA. Developed the methodology, collected survey data and supervised the work. AME, KKE and DSA supervised the work.

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Data availability

The datasets analysed as part of this study are available at: Adji, B. I., Assiri, A. A., Assi, M. E., & Kassin, K. E. (2026). Raw survey and floristic inventory data on cocoa-based agroforestry systems in Côte d'Ivoire (three cocoa-growing "loops", 2013–2016): anonymized version [Dataset]. Zenodo. https://doi.org/10.5281/zenodo.22016383

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Figures

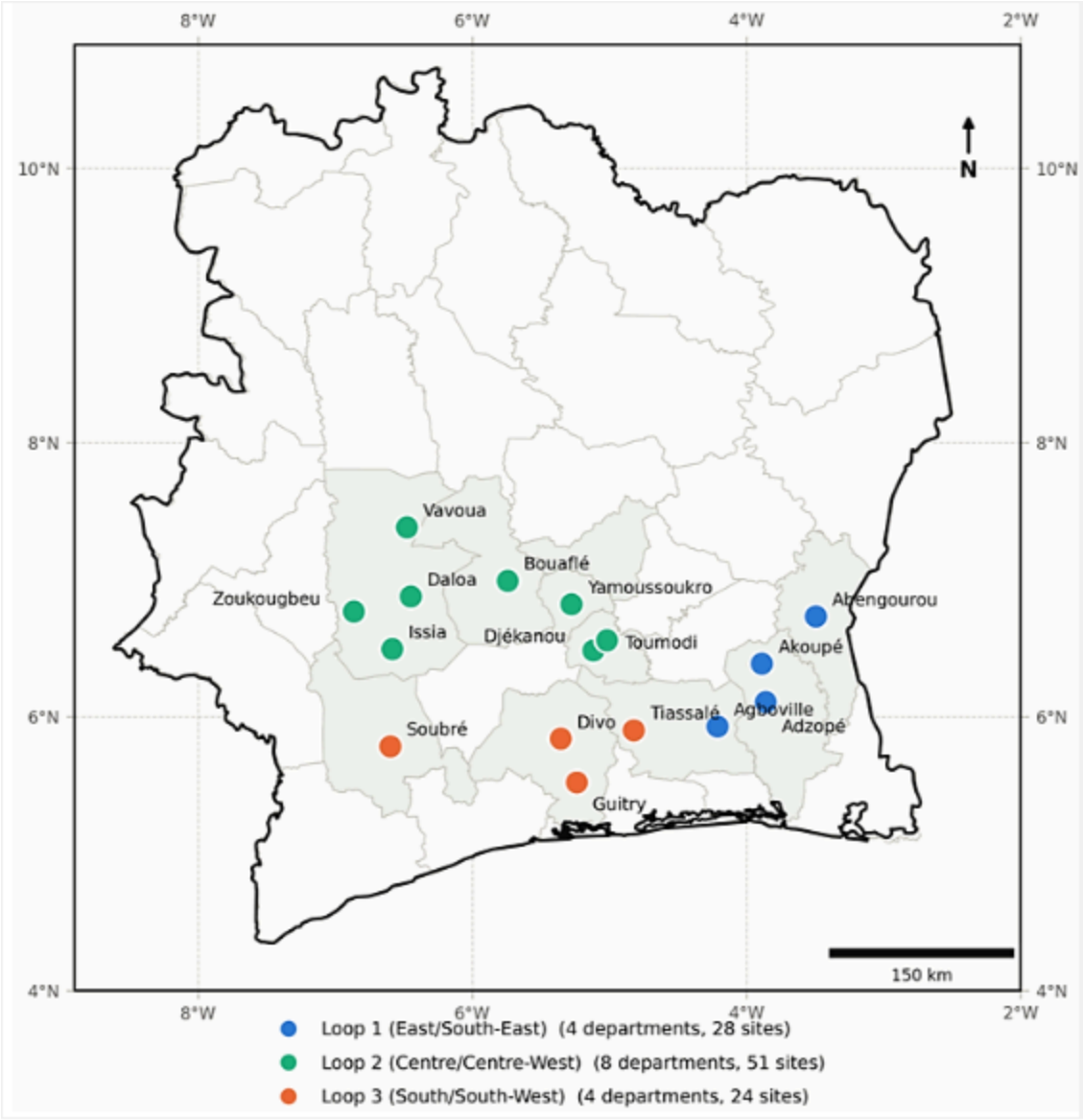


Figure 1

Location of the 16 survey departments (coloured by production loop), grouping the 103 recorded survey sites (villages and hamlets; see Table 1).

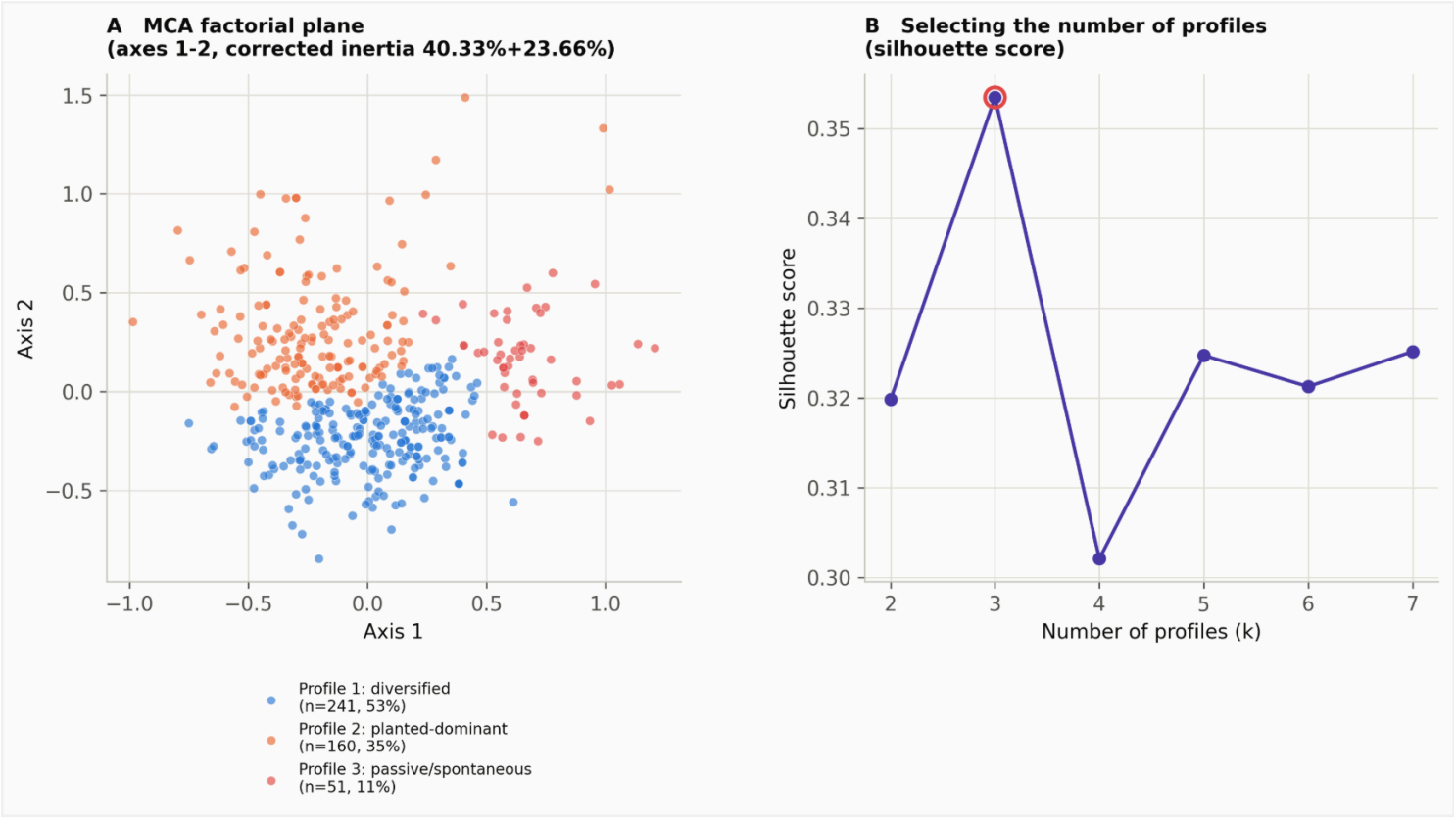


Figure 2

(A) Multiple Correspondence Analysis factorial plane (axes 1-2, Benzécri-corrected inertia 40.3%+23.7%), coloured by the three retained profiles. (B) Silhouette score by number of profiles tested (*k*=2 to 7); the red circle marks the maximum (*k*=3, retained).

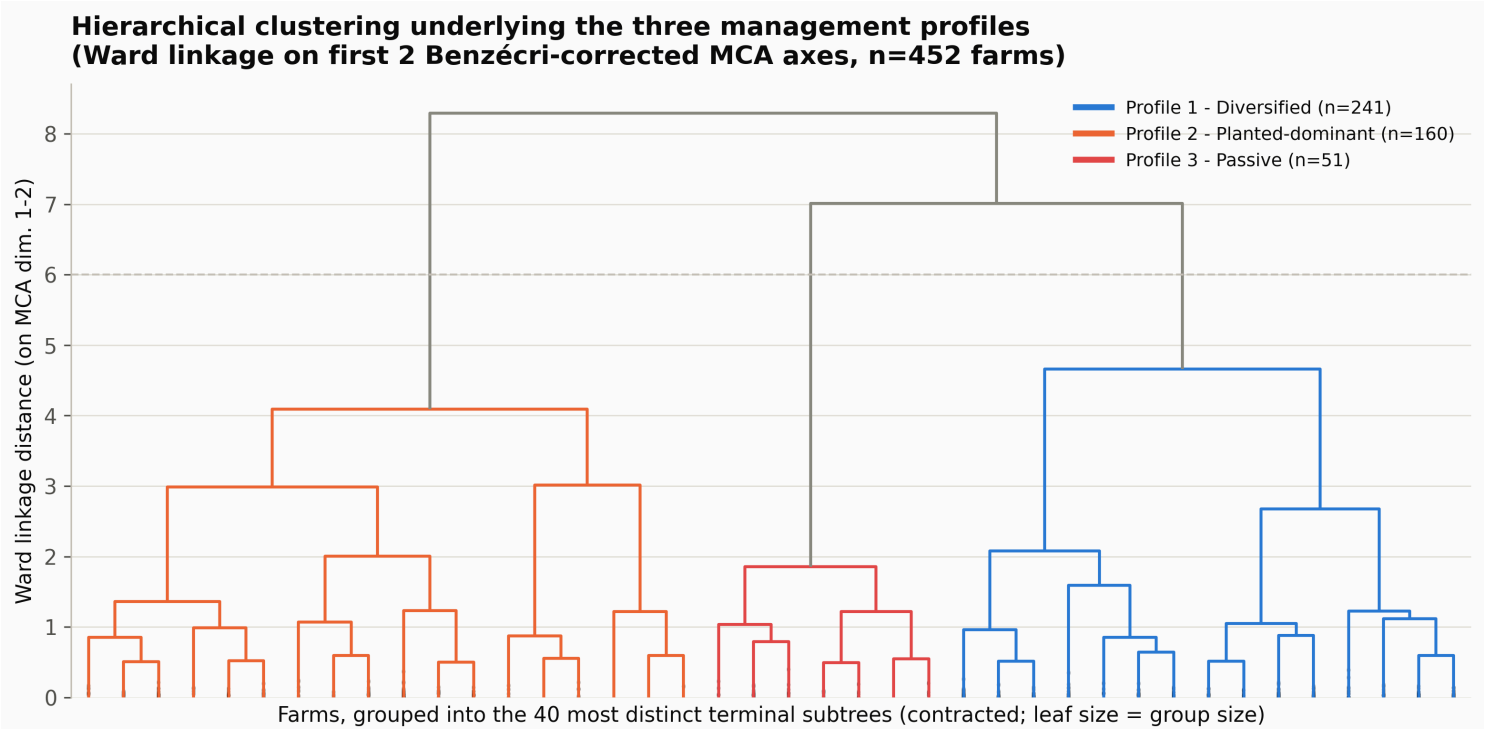


Figure 3

Hierarchical clustering (Ward linkage) underlying the three management profiles, on the first two Benzécri-corrected *MCA* axes (*n*=452 farms; dendrogram truncated to its 40 most distinct terminal subtrees for legibility). Colours mark the retained *k*=3 partition (same clusters as Figures 2 and 4-8).

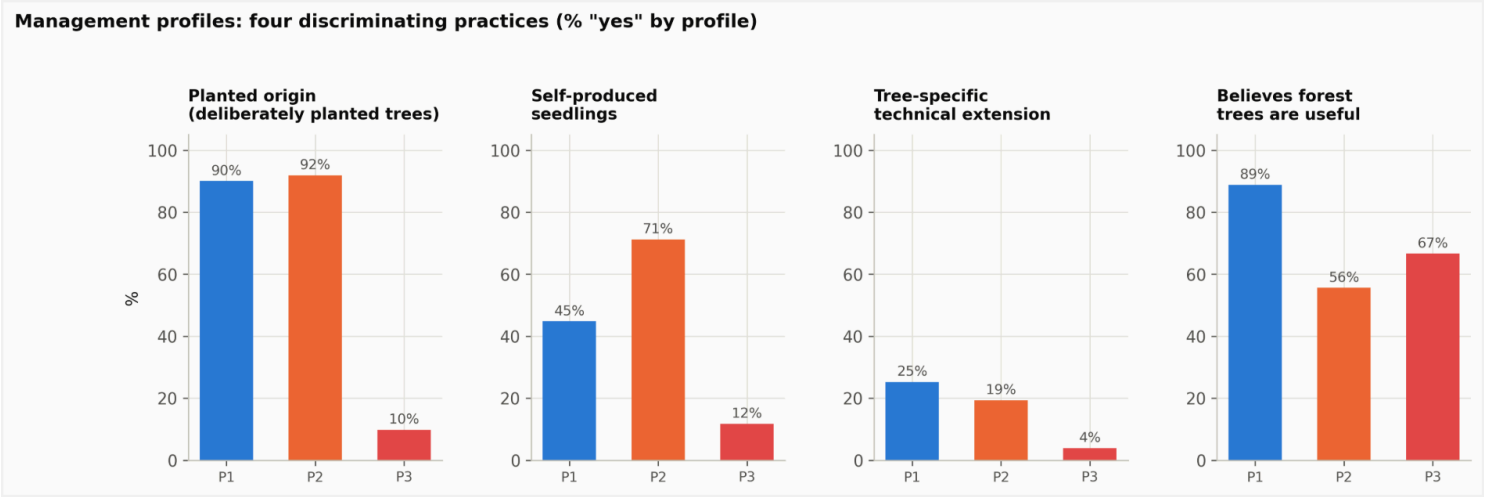


Figure 4

Four practices discriminating the three management profiles (% « yes » by profile, national sample *n*=452): planted origin of associated trees, self-produced seedlings, tree-specific technical extension, and belief in the usefulness of forest trees. P1 = diversified profile; P2 = planted-dominant profile; P3 = passive/poorly-advised profile.

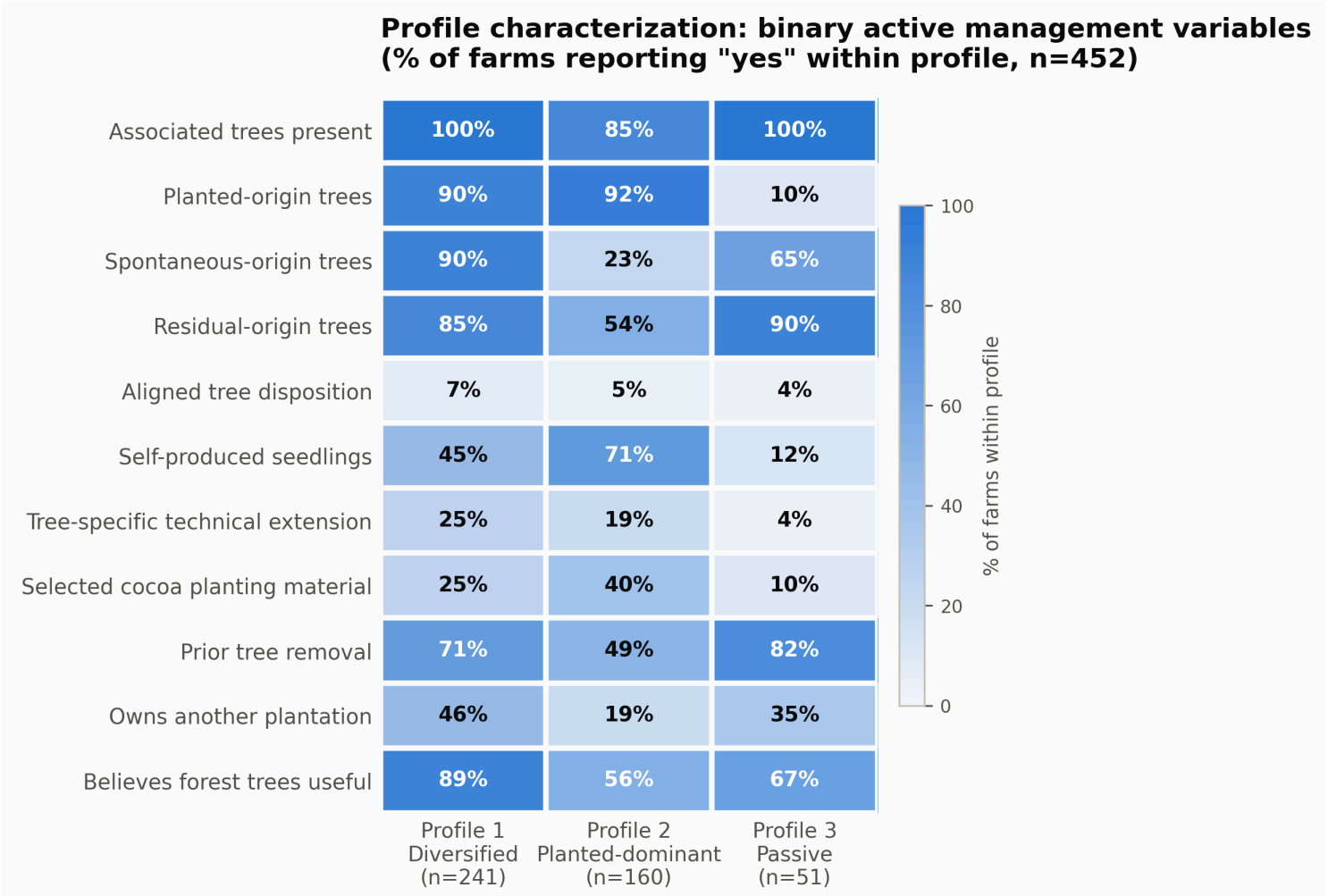


Figure 5

Profile characterization: binary active management variables (% of farms reporting « yes » within profile, *n*=452).

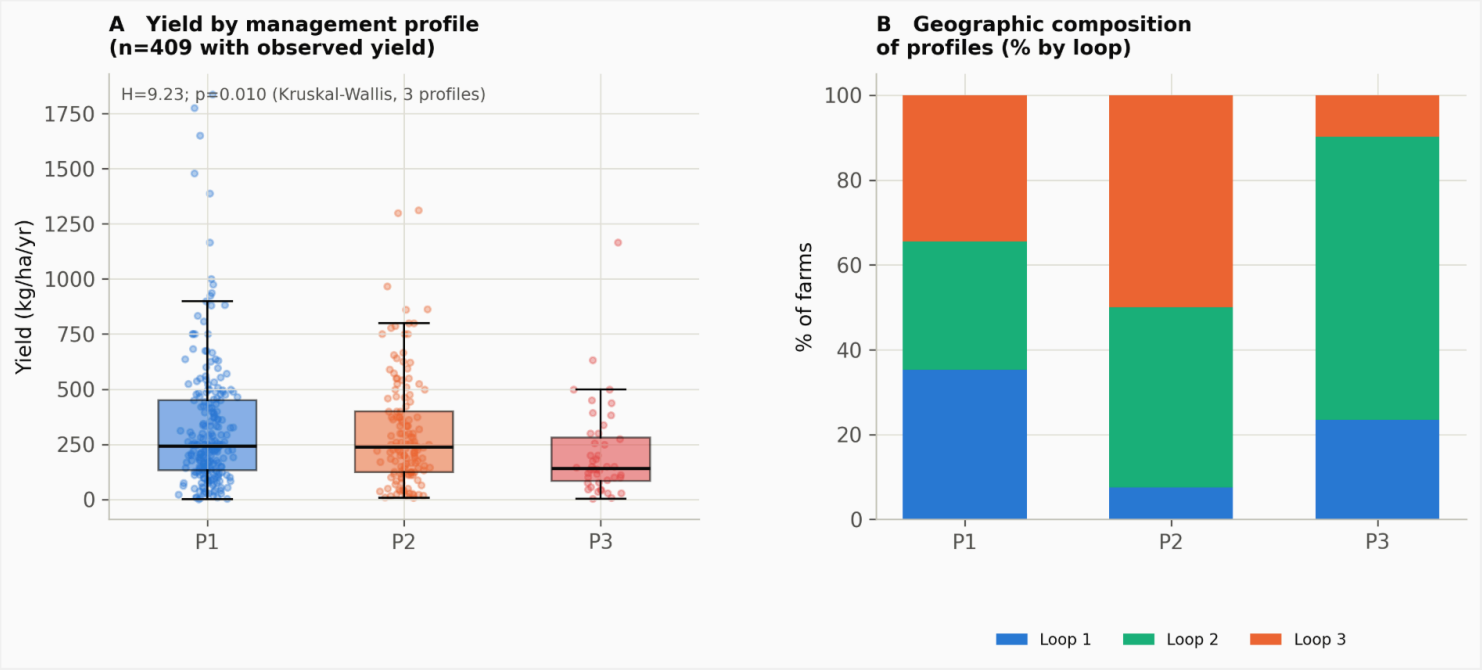


Figure 6

(A) Yield by management profile (*n*=409 farms with observed yield; *H*=9.23, *p*=0.010, Kruskal-Wallis test). (B) Geographic distribution of the three profiles across the three production loops (% by profile).

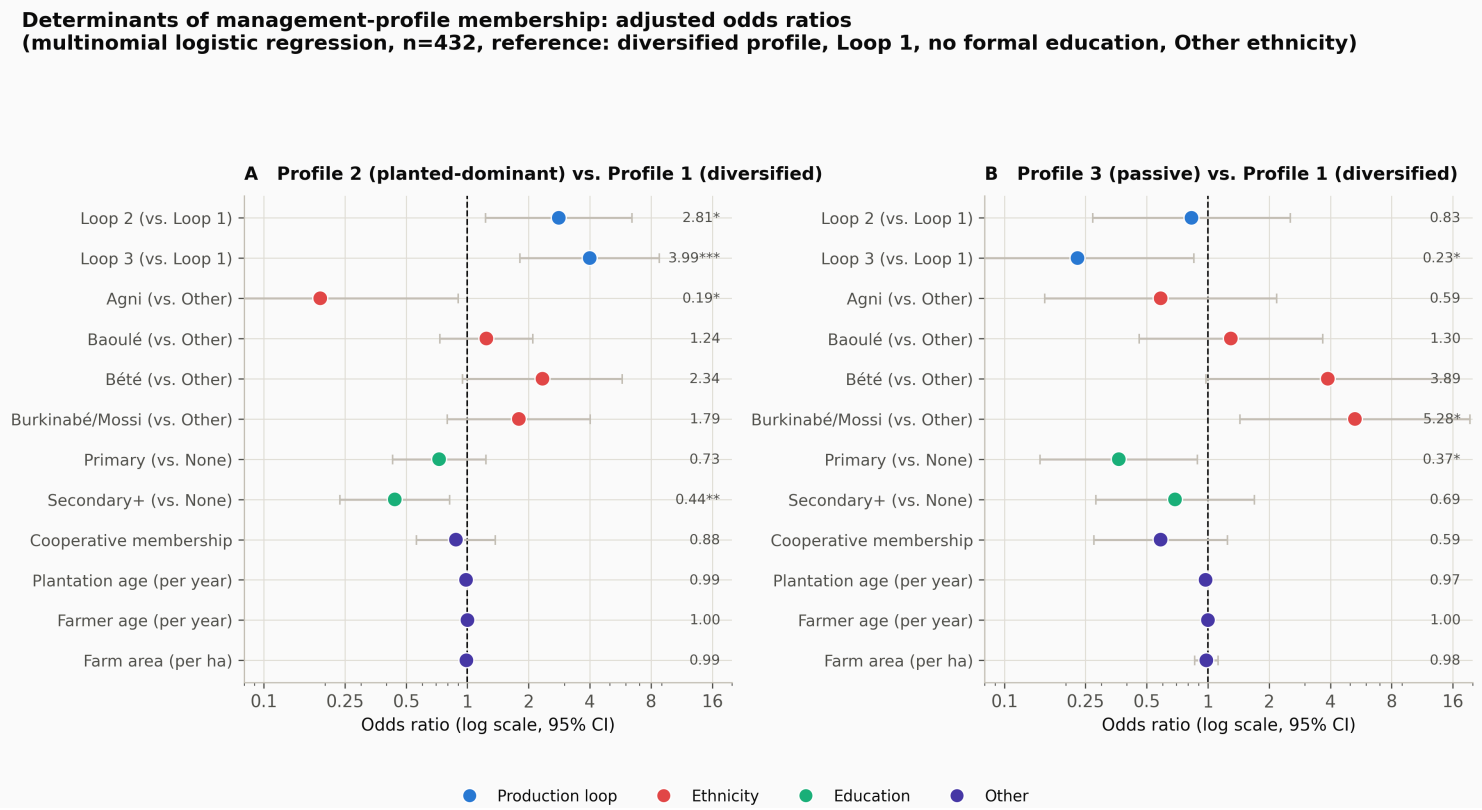


Figure 7

Determinants of management-profile membership: adjusted odds ratios and 95% confidence intervals (multinomial logistic regression, *n*=432). (A) Profile 2 (planted-dominant) vs. Profile 1 (diversified). (B) Profile 3 (passive) vs. Profile 1 (diversified). Reference categories: Loop 1, no formal education, Other ethnicity. ** p<0.05, ** p<0.01, *** p<0.001*.

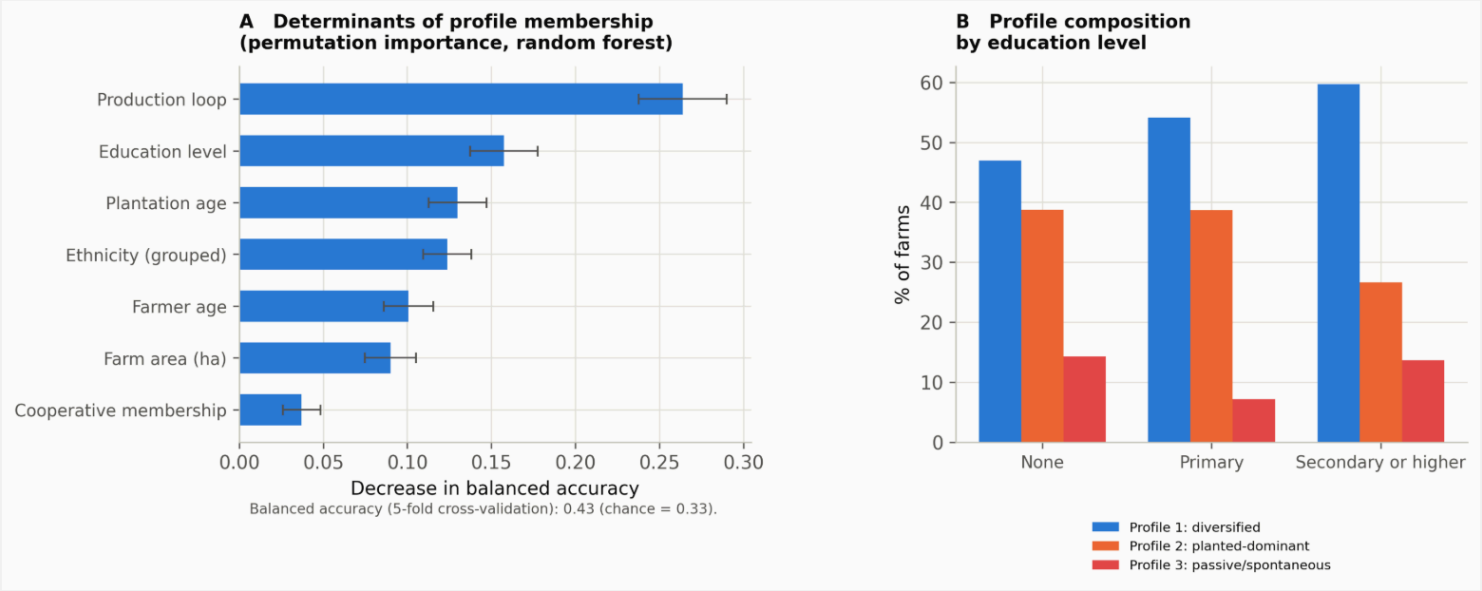


Figure 8

(A) Determinants of management-profile membership: permutation importance (decrease in balanced accuracy), random forest trained on the seven socio-demographic and geographic predictors (*n*=432, 5-fold cross-validation). (B) Distribution of the three management profiles by farmer education level (% by education level).