

Farmers' Preferences for Integrated Soil Fertility Management Technologies in Benin: A Best–Worst Scaling Analysis

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Abstract

In a context of increasing soil degradation, understanding farmers' perceptions appears essential to promote the acceptance and sustainable adoption of integrated soil fertility management (ISFM) technologies. This study analyses maize farmers' perceptions of ISFM technologies in Benin. To achieve this objective, a survey was conducted among 394 maize farmers distributed across twelve municipalities, using stratified sampling. Perception analysis was carried out using the Best-Worst Scaling (BWS) method, which makes it possible to rank the perceived attributes of ISFM technologies. The results reveal that organic manure is the most highly valued ISFM technology (BW = 352), followed by composting (332) and agroforestry (326), while vegetative cover has the lowest relative importance (BW = 224). At the dimensional level, agronomic performance dominates farmers' perceptions ($\alpha = 0.803$), followed by environmental perception ($\alpha =$

0.656) and economic performance ($\alpha = 0.597$), whereas perceived risks and uncertainties are negatively associated with the evaluation of ISFM technologies ($\alpha = -0.341$). These results highlight a perception of ISFM technologies mainly based on their agronomic, environmental, and economic benefits, with a marked preference for organic practices such as organic manure and composting.

Keywords: Farmers' perceptions; adoption of agricultural technologies; Best-Worst Scaling; soil fertility; agricultural innovation

Introduction

Global food security is inseparable from the challenge of providing healthy, sustainable, and accessible food for all (Rafflegeau et al., 2024). This issue is intensifying daily under the combined effect of continued population growth and declining agricultural yields (Ayilara et al., 2022). According to Van Dijk et al. (2021, global food demand could increase by 30 to 62% between 2010 and 2050. In this context, Alexandratos & Bruinsma (2012) project an increase of approximately 60% in global agricultural production between 2005–2007 and 2050. Faced with this challenge, the intensification of agricultural practices, the expansion of cultivated land, and the sustainable improvement of natural resource management constitute the main response pathways mobilized (Tilman et al., 2011; Newbold et al., 2015; Ickowitz et al., 2022).

It is in this perspective that, in sub-Saharan Africa, the agricultural policies of several countries, including Benin, have widely supported the use of mineral fertilizers through input subsidy programmes and extension systems. However, intensification based solely on mineral fertilizers cannot, on its own, sustainably maintain the productive capacity of soils. Organic matter remains essential for the retention of soil moisture and nutrients, and constitutes the foundation of many technologies aimed at complementing the use of mineral fertilizers while strengthening climate resilience (Martey et Kuwornu, 2021). Integrated soil fertility management (ISFM) technologies, which are central components of sustainable agricultural intensification practices (SAIP), directly address this challenge. Their diffusion nevertheless remains considerably more difficult than that of inorganic fertilizers, which are supported by well-established extension and subsidy systems (Martey et Kuwornu, 2021). This difficulty is not only related to material and institutional constraints. It also depends on farmers' perceptions of these technologies, that is, their opinions, beliefs, and attitudes towards them (Senger et al., 2017). Empirical studies confirm the importance of this subjective dimension. Based on analyses conducted across several African sites, Spurk et al. (2025) show that individual factors, including

innovativeness, positive affirmation, perceptions of soil fertility, and farmers' knowledge, play a major role in the adoption of soil fertility management practices. Similarly, Omara et al. (2021) emphasize that the diffusion of innovations largely depends on farmers' assessment of their benefits, costs, and associated risks. This logic is consistent with the theory of planned behaviour, according to which beliefs about the expected consequences of a behaviour help shape the attitudes and intentions that precede action (Ajzen, 1991).

In the specific field of soil fertility management, Martey & Kuwornu (2021) show, in Ghana, that perceptions of climate variability and shocks influence soil fertility management choices in different ways. Kule et al. (2025) also show that perceived benefits promote the adoption of sustainable agricultural intensification practices, whereas perceived risks and costs tend to limit it. These findings suggest that the diffusion of ISFM technologies depends not only on their objective agronomic performance, but also on the relative value that farmers assign to them under their actual production conditions.

However, this literature still presents three major limitations, which the present study seeks to address jointly. First, although the effect of perceptions on the adoption of agricultural technologies has been widely documented (Mwangi et Kariuku, 2015; Ntshangase et al., 2018; Omara et al., 2021), research on SAIP remains limited (Kule et al., 2025) and research specifically focusing on ISFM technologies remains almost non-existent. Second, from a methodological perspective, most of this literature relies on descriptive statistics, dichotomous variables, or Likert scales (Kenfack Essougong et al., 2020; Martey et Kuwornu, 2021; Houndete et Djego, 2023; Kule et al., 2025). These approaches are useful for describing farmers' opinions, but they provide a less direct account of the trade-offs between several technologies. Third, the available Beninese studies appear to pay greater attention to perceptions of climate change and climate-related risks than to the comparative evaluation of agricultural technologies. Although some studies have analysed perceptions of soil fertility and preferences for soil management technologies, the multidimensional ranking of ISFM technologies remains, to our knowledge, poorly documented (Vissoh et al., 2012; Idrissou et al., 2020; Zossou et al., 2021; Moutouama et al., 2022; Savi et al., 2022).

Responding directly to the call by Spurk et al. (2025) to further examine individual factors—perceptions, knowledge and the information environment of farmers—the present study proposes to analyse maize farmers' perceptions of integrated soil fertility management technologies in five agroecological zones of Benin. It differs from the literature focused on adoption decisions or isolated evaluations by using a Best-Worst Scaling

approach, which makes it possible to identify explicit trade-offs between technologies and decision criteria. The study thus establishes a ranking of nine ISFM technologies and breaks down their evaluation according to five dimensions: agronomic performance, economic performance, ease of use, risks and uncertainties, and environmental effects. It therefore provides new empirical evidence on farmers' technology preferences and on the criteria to be considered when designing differentiated extension and support strategies.

Which integrated soil fertility management (ISFM) technology do maize farmers value the most, and which agronomic, economic, practical, environmental and risk-related criteria structure the ranking of their preferences?

Theoretical Framework

The adoption of an agricultural innovation is a multidimensional process in which technological, cognitive, economic, social, and institutional factors interact (Glover et al., 2019; Meijer et al., 2015; Nonvide, 2021). Among smallholder farmers, the decision to adopt a technology therefore does not rest solely on its potential to improve productivity, but also on its ease of use, its compatibility with existing practices, social influences, the availability of the resources required for its implementation, and the perceived costs and risks (Glover et al., 2019; Nonvide, 2021). To account for this complexity, the present study uses an integrated theoretical framework based on the Unified Theory of Acceptance and Use of Technology (UTAUT), the Diffusion of Innovations theory (DOI), and the acceptance approach based on perceived costs and risks.

The UTAUT theory Venkatesh et al., (2003) constitutes the first foundation of this framework, postulating that the acceptance of a technology is mainly determined by performance expectancy, effort expectancy, social influence, and facilitating conditions. In the context of ISFM, performance expectancy refers to the perception that these technologies can improve yield, reduce losses, decrease pesticide use, improve pest management, or increase agricultural income, while effort expectancy reflects the perceived ease of learning and using the proposed practices (Issaka et al., 2024; Nguyen et al., 2024). Social influence refers to the role of peers, farmer organizations, extension agents, development projects, and local leaders in shaping farmers' perceptions (Lee et al., 2024; Nguyen et al., 2024). Finally, facilitating conditions refer to the existence of the material, financial, informational, and institutional resources required for the effective use of technologies (Li et al., 2020). This perspective is complemented by Rogers' (2003) Diffusion of Innovations theory, according to which adoption depends on how users perceive the characteristics of an

innovation, notably its relative advantage, compatibility, complexity, trialability, and observability. Thus, an ISFM technology perceived as more effective than conventional practices, compatible with local production systems, relatively simple to implement, amenable to small-scale experimentation, and whose results are easily observable should generate a more favourable perception and a stronger intention to adopt. In this perspective, participatory trials, demonstration plots and the observation of results obtained by neighbouring farmers can help reduce uncertainty and strengthen confidence in the innovation.

However, the usefulness and positive characteristics of a technology are not necessarily sufficient to explain its adoption, particularly on farms with limited resources. This is why the model also incorporates the perception of risk and cost, in line with research on decision-making under uncertainty and the acceptance of innovations, according to which individuals simultaneously assess the expected benefits and the potential consequences of their decision. Risk perception may concern the risk of yield loss, technical failure, financial losses, uncertainty about results, or difficulties in accessing the inputs and services required, while cost perception includes not only acquisition expenses, but also costs of use, maintenance, training, and the opportunity cost of the time devoted to the technology (Crentsil et al., 2020).

Accordingly, the acceptance of ISFM technologies can be conceptualized as the result of a trade-off between the expected benefits of the innovation and the perceived efforts, costs, constraints, and risks associated with it (Kule et al., 2025). In this model, performance expectancy, facilitating conditions, social influence, relative advantage, compatibility, observability, and trialability should exert a positive influence on the perception of ISFM technologies, whereas complexity, costs, and perceived risks should influence it negatively. This perception should then condition the intention to adopt the technologies and, when the necessary resources and conditions are in place, their effective use. The proposed framework therefore makes it possible to understand the acceptance of ISFM technologies as a phenomenon that is simultaneously technological, cognitive, social, economic and institutional.

Materials and Methods

Study Area

The selection of the areas covered by the present study is based on agronomic, institutional and methodological considerations related to the objectives pursued. Thus, five agroecological zones, corresponding to the intervention areas of Agricultural Territorial Development Agencies (ATDA) 2, 4, 5, 6 and 7 of Benin, were selected. They cover the

municipalities of Bembèrèkè and Péhunco (ATDA 2), Bantè, Djidja, N'Dali and Ouèssè (ATDA 4), Agbangnizoun (ATDA 5), Kétou (ATDA 6), as well as Allada, Avrankou and Toffo (ATDA 7).

From an agronomic perspective, the selected municipalities are among the main maize-producing areas in Benin and contribute significantly to the supply of national markets and to household food security (Hien et Kaboré, 2025). They are also characterized by a wide diversity of agroecological conditions, particularly in terms of soil types, rainfall regimes, cropping systems and levels of agricultural intensification.

From an institutional perspective, the municipalities studied benefit from the interventions of actors in the national agricultural innovation system, notably through extension services, agricultural advisory services and the diffusion of ISFM technologies (Thoto et al., 2023). This institutional presence constitutes an essential condition for analysing farmers' preferences for technologies that are actually presented, promoted or potentially accessible in their production environment. The joint coverage of the five ATDAs also allows incorporation of diverse agroecological contexts, from the Sudanian zones in the North to the sub-equatorial zones in the South, including the transitional zones of the Centre. These differences relate in particular to climate, soil fertility, the availability of organic matter, access to inputs, cropping systems, agricultural advisory services and economic opportunities.

In this perspective, the spatial diversity of the study area is not only intended to ensure better geographical coverage: it also strengthens the analytical scope of the results and makes it possible to discuss their relevance beyond a single locality. Figure 1 presents the map of the study area.

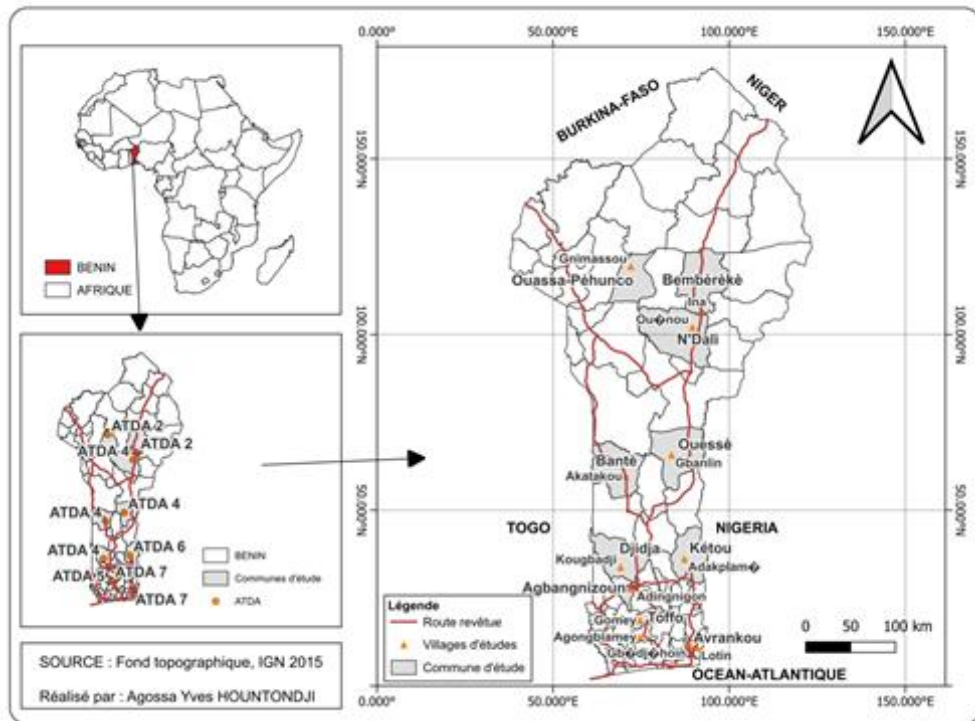


Figure 1: Map of the study area

Sampling and Data Collection

The target population of this study mainly consists of direct beneficiaries of ISFM technologies in the ATDAs eligible for the PAPAPE project. ATDA 1 was excluded because of its status as a control zone; the study therefore covered six of Benin's seven ATDAs. According to the database provided by the programme, this population comprises 4,489 farmers. To determine the minimum sample size, we applied Cochran's, (1977) formula for a finite population, with a 95% confidence level, a 5% margin of error, and a conservative proportion of 0.50, which leads to a minimum sample size of 354 farmers.

The six Agricultural Territorial Development Agencies (ATDAs) were considered as strata in order to take into account the spatial heterogeneity of the population studied. The sample size allocated to each stratum was determined using proportional allocation, in accordance with the formula $n_i = (N_i/N) \times n$, where N_i denotes the population size of stratum i , N the total population size and n the total sample size (Kish, 1965). However, the application of this allocation showed that ATDA 3 had only nine theoretical observations, a sample size considered insufficient to produce statistically reliable estimates at the stratum level.

In accordance with methodological recommendations for stratified sample surveys, strata with very small sample sizes may be grouped with similar strata or excluded from the analysis when their statistical weight is insufficient to ensure robust estimates (Rust et Kalton, 1987). In this study, ATDA 3, which accounts for only 117 beneficiaries, or 2.6% of the target population, was excluded from the analysis in order to refocus the investigation on the five selected ATDAs. This decision reduced the reference population to 4,372 beneficiaries, which served as the basis for recalculating the sample size using proportional allocation across the strata. Within the five selected ATDAs, municipalities were first selected by simple random sampling without replacement within each stratum. Farmers were then randomly selected from the beneficiary lists provided by the PAPAPE programme, using randomly generated numbers and selection proportional to the quotas set for each stratum. In order to anticipate non-responses and invalid questionnaires, oversampling was planned, bringing the initially targeted number of respondents to 400. The data collected relate to nine integrated soil fertility management (ISFM) technologies and practices, namely composting, organic manure, the use of mineral fertilizers, crop rotation, intercropping, agroforestry, improved fallow, fertilizer microdosing, and vegetative cover. For each of these technologies, farmers' perceptions were collected across several dimensions, including agronomic performance, economic performance, perceived environmental effects, ease of use, and the associated risks and uncertainties. After data cleaning, 394 usable questionnaires were retained for the analysis. The distribution of the surveyed farmers is presented in Table 1.

Table 1: Distribution of respondents by ATDA and commune

ATDA	Commune	n	% / ATDA	% / Total
ATDA 2	Bembéréké	44	55.0	11.2
	Péhunco	36	45.0	9.1
ATDA 4	Bantè	33	27.5	8.4
	Djidja	31	25.8	7.9
	N'dali	26	21.7	6.6
	Ouèssè	30	25.0	7.6
ATDA 5	Agbangnizoun	52	100.0	13.2
ATDA 6	Kétou	46	100.0	11.7
ATDA 7	Allada	33	34.4	8.4
	Avrankou	31	32.3	7.9
	Toffo	31	32.3	7.9
Total	12 communes	394	100.0	100.0

Source: Survey data, 2026. n = number of respondents

Analytical Method

To analyse farmers' perceptions of integrated soil fertility management (ISFM) technologies, this study uses the Best-Worst Scaling

(BWS) method, a preference elicitation approach that makes it possible to identify and rank the characteristics or dimensions to which farmers attach relatively more or less importance. Unlike conventional declarative scales, such as Likert scales, BWS places respondents in a situation of explicit trade-off between several criteria by asking them, in each choice set, to identify the criterion they consider the most important (Best) and the one they consider the least important (Worst). This approach therefore makes it possible to obtain a relative ranking of perceptions and to better discriminate between the criteria evaluated by farmers (Flynn et Marley, 2014; Marley et Louviere, 2005).

In the present study, perceptions of ISFM technologies are assessed through five thematic dimensions, each comprising five criteria, for a total of 25 perception criteria. These dimensions relate in particular to perceived agronomic performance, perceived economic performance, perceived environmental benefits and ease of use, to which the dimensions relating to perceived risks and uncertainties may be added, depending on the structure retained in the questionnaire.

The experimental design of the BWS questionnaire is based on a Balanced Incomplete Block Design, which makes it possible to distribute the criteria associated with each dimension across several choice sets while ensuring a comparable frequency of presentation to farmers. In each choice set, the farmer identifies the criterion he or she considers the most important (Best) and the one he or she considers the least important (Worst).

For each criterion (j), the number of selections as Best is denoted (B_j), while the number of selections as Worst is denoted (W_j). The descriptive importance of each criterion is first measured by the Best-Worst score: $BW = B_j - W_j$. To make the scores comparable across criteria, the score is normalized by the number of surveyed farmers (N) and the number of times (r) the criterion is presented to each farmer:

$$A - RS_j = \frac{B_j - W_j}{r \times N}$$

Where :

- $A - RS_j$: is the Average Raw Score of the criterion j ;
- B_j : is the number of times criterion j is selected as Best;
- W_j : is the number of times criterion j is selected as Worst;
- N : is the total number of surveyed farmers;
- r : is the number of times the criterion j appears in the choice sets for each farmer.

A positive value indicates that the criterion is more frequently selected as Best than as Worst, whereas a negative value reflects a lower relative importance.

In a second step, the BWS choices are analysed using a Mixed Multinomial Logit Model, based on random utility theory. The use of this model makes it possible to account for the unobserved heterogeneity of preferences across farmers. The utility associated with criterion j for farmer i is specified as:

$$U_{ij} = V_{ij} + \varepsilon_{ij}$$

where U_{ij} denotes the total utility associated with criterion j for farmer i , V_{ij} the systematic or observable component of this utility, and ε_{ij} the random error term representing unobserved factors and idiosyncratic preferences likely to affect the choice.

To capture individual heterogeneity, the coefficient may be specified as:

$$\alpha_{ij} = \underline{\alpha}_j + \eta_{ij}$$

where $\underline{\alpha}_j$ represents the average preference coefficient for criterion j in the population studied, while η_{ij} represents the farmer-specific random component i , capturing individual deviations from the average preference.

In each BWS task, the combination of Best and Worst choices makes it possible to model the probability that a farmer selects criterion j as the most important and criterion k as the least important. This probability is expressed as:

$$P_{ijk} = \frac{\exp \exp (V_{ij} - V_{ik})}{\sum_{a \neq b} \exp \exp (V_{ia} - V_{ib})}$$

Where :

- P_{ijk} represents the probability that farmer i selects criterion j as Best and criterion k as Worst;
- V_{ij} represents the observable component of the utility associated with criterion j for farmer i ;
- V_{ik} represents the observable component of the utility associated with criterion k ;
- a and b denote, respectively, the sets of criteria that can be selected as Best and Worst, with $a \neq b$
- This procedure makes it possible to identify the criteria that contribute most strongly to farmers' preferences and to examine the extent to which these preferences differ according to their individual characteristics and those of their farms.

Finally, to facilitate the interpretation of the results, the estimated coefficients are transformed into exponential values according to $\exp \exp (\alpha_j) = e^{\alpha_j}$, and then into relative preference weights. For each of the four items (h), comprising five criteria, the relative weight of criterion j is calculated as follows:

$$P_{ijk} = \frac{\exp(\alpha_{jh})}{\sum_{k=1}^5 \exp(\alpha_{kh})} \times 100$$

where:

- P_{jh} : is the relative weight (%) of criterion j in item h;
- α_{jh} : is the preference coefficient associated with criterion j in item h;
- $\exp(\alpha_{jh}) = e^{\alpha_{jh}}$: is the exponential of the preference coefficient;
- $\sum_{k=1}^5 \exp(\alpha_{kh})$: is the sum of the exponentials of the five criteria in item h.

Thus, the BWS approach makes it possible to construct a ranking of the perception dimensions of ISFM technologies and to identify those that appear to be the most decisive in farmers' evaluations.

Results

Overall Ranking of ISFM Technologies

The Best–Worst (BW) score, calculated as the difference between the number of times a technology is designated as the best and the number of times it is designated as the least favourable, makes it possible to establish an overall ranking of the nine ISFM technologies according to the relative intensity of the preferences expressed by the surveyed farmers. The standardized score is used to account for the frequency with which technologies appear in the different choice tasks (Table 2).

Organic manure ranks first, with a standardized score of 0.48, followed by composting, with a score of 0.45. Agroforestry occupies the third position (0.35), while mineral fertilizer (NPK and urea) ranks fifth, with a score of 0.22. This ranking shows that technologies associated with the addition of organic matter are relatively more highly valued than mineral fertilizers in the trade-offs expressed by farmers. It suggests that farmers attach particular importance to practices likely to sustainably improve soil fertility and quality, beyond their immediate effects on production. This interpretation is consistent with Place et al. (2003), who emphasize that the observed preference for organic technologies may reflect a favourable perception of their complementarity. Although mineral fertilizers are widely present in some areas and benefit from institutional arrangements promoting their diffusion, they rank only fifth among the preferences expressed in the Best–Worst choices. This result highlights that the adoption or diffusion of a technology does not necessarily coincide with farmers' relative preference. In the field of agroforestry, Iiyama et al. (2018) show that technologies considered preferable by smallholder farmers are not necessarily widely adopted when the conditions for implementation, input availability,

compatibility with existing systems, management complexity and market opportunities are not met.

At the other end of the ranking, vegetative cover or mulching occupies the ninth position, with a standardized score of 0.10. Fertilizer microdosing and improved fallow rank eighth and seventh, respectively, with a score of 0.15. Nevertheless, these technologies obtain positive scores: they are therefore not rejected by farmers, but appear to be less prioritized than the other options in the comparisons made. Their lower ranking may be associated with several implementation constraints. Mulching may compete with other uses of crop residues, particularly animal feed or fuel production; its installation and maintenance may also increase labour requirements. According to Giller et al. (2009) this constraint is frequently emphasized in the literature on conservation practices in African family farming. Fertilizer microdosing, for its part, requires precise application and good control of application rates. Improved fallow, in turn, involves the temporary withdrawal of land from cultivation and benefits that may be delayed. These characteristics are likely to reduce their relative attractiveness in farms where farmers must meet short-term production and income objectives. Our results corroborate the findings of Place et al. (2003), who state that the lower ranking of some practices may be explained by the fact that they require immediate resources, particularly labour and land, whereas their agronomic benefits materialize only gradually.

Overall, the results indicate that the hierarchy of preferences does not mechanically correspond to the hierarchy of the most adopted, subsidized or promoted technologies. The review by Mhoro et al. (2023) shows that the sustainability of soil fertility management depends not only on the availability of biophysical solutions. It also depends on the socio-economic conditions in which farmers make their decisions. This conclusion reinforces the interpretation of our results: farmers may attach high importance to soil fertility and to the environmental benefits of ISFM technologies, while continuing to prioritize some practices that are more accessible or more immediately effective. This result argues in favour of extension strategies that are not limited to input access, but that also make long-term agronomic benefits visible and reduce the practical constraints associated with less highly valued technologies.

Table 2: Overall ranking of ISFM technologies according to the Best-Worst score

ISFM attribute	Best	Worst	BW (Best-Worst)	Standardized score	Mean BW	Standard deviation	Rank
Composting	363	31	332	0.45	0.47	0.39	2nd
Organic manure (dung, poultry droppings)	373	21	352	0.48	0.84	0.29	1st
Mineral	347	47	300	0.22	0.28	0.16	5th

fertilizers (NPK, urea)							
Crop rotation	349	45	304	0.27	0.41	0.30	4th
Intercropping	330	64	266	0.18	0.15	0.13	6th
Agroforestry	360	34	326	0.35	0.46	0.34	3rd
Improved fallow	314	80	234	0.15	0.10	0.08	7th
Fertilizer microdosing	313	81	232	0.15	0.08	0.07	8th
Vegetative cover (mulching)	309	85	224	0.10	0.05	0.03	9th

Spatial Distribution of ISFM Technologies across ATDA Intervention Areas

The analysis of variance reveals statistically significant differences between intervention areas for the nine ISFM technologies. The *p*-values are below 0.001 for eight technologies and equal to 0.0088 for vegetative cover. These results indicate that the proportion of farmers reporting each technology, according to the coding retained, varies across ATDAs. This heterogeneity is consistent with studies showing that soil fertility management practices vary according to agroecological conditions, household characteristics, communities, access to resources, and institutional arrangements (Place et al., 2003; Ruzzante et al., 2021). This justifies the value of a spatial coverage including differentiated agroecological and institutional contexts (Table 3).

The most marked differences concern mineral fertilizers, composting, organic manure, and fertilizer microdosing. Mineral fertilizers show very high proportions in ATDAs 2, 4 and 5, with values of 0.958, 0.972 and 1.000, respectively, whereas they are absent in ATDA 6. Conversely, organic manure and composting reach their highest levels in ATDAs 6 and 7: organic manure reaches 0.572 and 0.841, respectively, while composting reaches 0.698 and 0.521. This opposition suggests the existence of distinct territorial configurations of soil fertility management, characterized by a greater presence of mineral inputs in some areas and a greater valorization of organic resources in others. Moreover, the strong presence of mineral fertilizers in some areas does not coincide with their rank in the overall preference hierarchy, where they occupy the fifth position. This difference between presence and relative preference is consistent with Zossou et al. (2021), who show that Beninese farmers evaluate fertility technologies according to several attributes, including their accessibility, cost, speed of effects and expected benefits.

The differentiation between agroecological zones may be related to several mechanisms that are not directly tested in the available data. In the northern and central areas (ATDAs 2, 4 and 5), the importance of the cotton

sector may contribute to facilitating access to mineral fertilizers. The Beninese cotton sector indeed relies on institutional arrangements for input supply and support, while cotton constitutes an important activity for many rural households. When fertilizers are accessible within the framework of cotton production, their use may be extended to food crops, particularly maize. This possibility may help explain the strong presence of mineral fertilizers in ATDAs 2, 4 and 5. In a study conducted among maize farmers in Malanville, Banikoara and Bembèrèkè, Tovihoudji et al. (2023) report that 95.4% of farmers use mineral fertilizers occasionally or regularly. Their study also shows that cotton and maize are the main crops in the systems studied, that cotton–maize rotations are practised, and that the NPK formula used on maize plots is mainly the cotton-based formula. These results corroborate the important place of mineral fertilizers in northern agricultural systems, as well as their integration with systems involving cotton.

A learning-by-experience mechanism may also be considered. Farmers who observe yield gains associated with mineral fertilizers in a cash crop may be more inclined to assign them a productive value in food crops. The findings of Honfoga (2018) emphasize that, in cotton–cereal systems, maize may benefit from the residual effects of fertilizers applied to cotton. This interpretation is consistent with the work of Marra et al. (2003) who show that learning and experience can reduce the uncertainty associated with agricultural technologies and modify farmers' evaluation of them. However, this interpretation is not directly corroborated by our data, as the survey does not allow us to identify farmers' specific experience in the use of fertilizers on cotton or to measure knowledge transfer between crops.

In ATDAs 6 and 7, the strong presence of organic manure and composting may reflect a greater availability of organic resources or a better integration of these resources into local production systems. Studies on oil-palm-based agroforestry systems in Benin show, in particular, that the use of organic manure can contribute to improving soil fertility and the performance of the associated maize crop. The presence of livestock, agro-industrial residues, or poultry manure may also reduce the distance between sources of organic matter and plots. Yemadje et al. (2023) show, on the Adja plateau, that the application of farmyard manure in systems combining oil palm and maize improves certain indicators of soil fertility, stimulates earthworm activity and increases maize yields compared with the use of mineral fertilizers alone.

The relatively high presence of crop rotation and intercropping in some areas may be related to the integration of legumes into Beninese cropping systems. In the North and Centre, soybean may constitute a plausible contextual explanation for the importance of these practices. This interpretation is consistent with Tovihoudji et al. (2023) who report the use

of maize–legume rotations and intercropping among soil fertility management options in maize-based production systems in northern Benin. In the South, the work of Eilittä et al. (2004) reports the use of *Mucuna pruriens* in short fallows or relay intercropping with maize in production systems, notably to contribute to maintaining soil fertility. However, these studies do not allow us to establish directly that the presence of soybean in the North and Centre, or that of mucuna in the South, alone explains the levels of rotation and intercropping observed in each ATDA; this relationship is a contextual hypothesis consistent with the results of our study.

Vegetative cover shows the lowest proportions across all areas, with 0.096 in ATDA 6, 0.042 in ATDA 2, 0.029 in ATDA 7, and null values in ATDAs 4 and 5. Although the difference between ATDAs is statistically significant, the magnitude of the proportions remains low. This technology may be constrained by competition between crop residues and other uses, particularly animal feed, fuel, or conversion into organic matter. It may also require additional labour and protection of residues against grazing. According to Giller et al. (2009), in mixed farming systems in sub-Saharan Africa, cereal residues constitute an important forage resource, so that maintaining them on the plot may create a trade-off with livestock feeding.

The results relating to agroforestry, improved fallow, and fertilizer microdosing also confirm the localized nature of some technologies. Agroforestry reaches 0.361 in ATDA 5 but remains almost absent in ATDAs 2, 4 and 6. Improved fallow is mainly present in ATDA 7, with 0.449, while fertilizer microdosing reaches 0.449 in the same area. These differences may reflect differences in access to land, demonstration programmes, labour requirements or technical skills. They emphasize that ISFM technologies do not form a uniform package whose diffusion would be independent of local contexts. The observed spatial differentiation is compatible with the work of Place et al.(2003), who show that integrated soil fertility management practices vary according to agroecological conditions, communities and household characteristics.

Overall, Table 3 therefore shows that intervention areas differ in terms of the technologies to which farmers are exposed and that they use. ATDAs 2, 4 and 5 are characterized by a strong presence of mineral fertilizers, whereas ATDAs 6 and 7 show a more marked presence of organic manure and composting. This configuration argues in favour of a territorially differentiated approach to extension. A uniform policy may be less effective than a strategy that articulates mineral and organic technologies in areas where they are complementary, while taking into account the availability of resources, cropping systems and local technical capacities.

Table 3: ISFM technologies by ATDA zone

ISFM technology	ATDA 2	ATDA 4	ATDA 5	ATDA 6	ATDA 7	F	p
Composting	0.222	0.000	0.125	0.698	0.521	37.78	0.000
Organic manure	0.361	0.028	0.166	0.572	0.841	34.22	0.000
Mineral fertilizers	0.958	0.972	1.000	0.000	0.634	23.40	0.000
Crop rotation	0.347	0.666	0.486	0.358	0.754	10.80	0.000
Intercropping	0.028	0.055	0.500	0.248	0.493	19.33	0.000
Agroforestry	0.014	0.000	0.361	0.020	0.144	22.91	0.000
Improved fallow	0.000	0.000	0.236	0.076	0.449	24.03	0.000
Fertilizer microdosing	0.014	0.000	0.305	0.013	0.449	35.07	0.000
Vegetative cover	0.042	0.000	0.000	0.096	0.029	3.44	0.0088

Ranking of the Criteria Structuring Farmers' Perceptions

Beyond the ranking of the technologies themselves, the Best-Worst analysis was applied to five dimensions of perception, each broken down into five evaluation criteria. For each dimension, a MaxDiff (α_j) was estimated from the frequencies of selection as “more important” (B_j) and “less important” (W_j) for each criterion, and then converted into a relative weight (P_j) summing to 100% within each dimension. Table 4 summarizes the mean score (α) of each dimension, which indicates its overall salience in farmers' perceptions.

This ranking of dimensions provides several insights. Agronomic performance ($\alpha = 0.803$) and environmental perception ($\alpha = 0.656$) dominate farmers' perceptions by a wide margin, far ahead of economic performance ($\alpha = 0.597$) and, even more so, ease of use ($\alpha = 0.374$). This result suggests that, contrary to the assumption in the literature on technology adoption that cost constraints and ease of use would be the main perceived barriers, the surveyed farmers base their evaluation of ISFM technologies primarily on perceived agronomic effectiveness and perceived environmental benefits. The strong importance attached to environmental benefits in our study is consistent with Rizzo et al. (2024), whose systematic review shows that environmental values can contribute to the adoption of sustainable agricultural innovations.

The most distinctive result concerns the dimension of risks and uncertainties, whose mean coefficient is negative ($\alpha = -0.341$), the only dimension in this case. This means that, on average, farmers select statements relating to risk as “less important” more often than as “more important” in their overall evaluation of ISFM technologies. In other words, although risk perception is present, it occupies a secondary place compared with perceived agronomic and environmental benefits, a result that nuances approaches to technology adoption that present risk aversion as a systematically dominant barrier. It can be related to the work of Atta &

Micheels (2020), who show, based on a Best–Worst analysis conducted among cereal and oilseed producers in Saskatchewan, that the importance attached to risks varies according to their nature and according to the characteristics of farms and farmers.

These results extend those of our previous study on the adoption of ISFM technologies, conducted among the same farmers. Whereas that study showed that the most adopted technologies are those whose effects are quickly perceptible, with mineral fertilizers ranking first, the Best–Worst analysis reveals that farmers attach priority importance to the agronomic performance and environmental benefits of technologies. This comparison highlights a gap between the value criteria expressed and the practices actually adopted. Farmers seem to recognize the importance of farm sustainability and value technologies likely to improve soil fertility in the long term; however, in their concrete decisions, they prioritize options that provide rapid and observable results.

This suggests that adoption depends not only on a positive perception of environmental benefits, but also on the ability of technologies to address the immediate constraints of farms. Mineral fertilizers may thus be prioritized not because farmers ignore sustainability issues, but because they provide a rapid productive response in a context where the needs for yield, income and food security are pressing. The challenge for public policy is therefore not only to strengthen awareness of sustainable fertility management, but also to design mechanisms that make sustainable practices technically accessible, economically viable and sufficiently effective in the short term to respond to farmers' actual trade-offs. Our observation is consistent with the review by Mhoro et al. (2023), which shows that the sustainability of soil fertility management depends not only on the availability of biophysical solutions. It also depends on the socio-economic conditions in which farmers make their decisions.

Table 4: Relative salience of the five perception dimensions

Perception dimension	Overall perception (α moyen)	Standard deviation
Agronomic performance	0.803	0.084
Environmental perception	0.656	0.055
Economic performance	0.597	0.150
Ease of use	0.374	0.058
Perceived risks and uncertainties	-0.341	0.108

Agronomic Performance Criteria

Table 5 shows that the increase in agricultural yields is the most highly valued agronomic criterion, with a relative weight of 21.84% and an α_j coefficient of 0.893. Improvement in soil fertility ranks second, at 20.76%, followed by the durability of effects over time, at 20.50%. This ranking indicates that farmers primarily evaluate ISFM technologies based

on their ability to improve the productivity and fertility of their own plots. However, the almost equivalent importance attached to the durability of effects shows that a preference for yield is not necessarily incompatible with a long-term concern. Rather, farmers appear to seek technologies capable of combining immediate performance with the maintenance of the productive capacity of soils. Improvement in soil structure and quality has a weight of 19.34%. This criterion therefore remains important, but it is a slightly lower priority than yield, fertility and durability. Resilience to climate hazards ranks last, at 17.56%, while still receiving a positive assessment. This latter result does not mean that farmers disregard climate issues. Rather, it suggests that climate resilience is less directly used as a priority criterion when compared with more immediately observable benefits, such as yield or improved fertility. A technology's ability to reduce climate vulnerability may be difficult to observe directly, particularly when climate shocks are irregular or when effects become apparent over several growing seasons. The ranking of agronomic criteria is consistent with the findings of Wolf et al. (2023), who show that farmers closely associate soil fertility with yield stability and the resilience of cropping systems to climate change. Furthermore, the systematic review by Agyekum et al. (2024) confirms that farmers associate climate-smart practices with benefits such as improved fertility, yields, income, and climate resilience.

Table 5: Ranking of farmers' perceived agronomic performance criteria for ISFM technologies

Evaluation criterion	B_j	W_j	Coefficient (α_j)	$\text{Exp}(\alpha_j)$	Relative weight (P_j)
Increase in agricultural yields	373	21	0.843	2.322	21.84%
Improvement in soil fertility	363	31	0.893	2.443	20.76%
Durability of effects over time	374	47	0.830	2.293	20.50%
Improvement in soil structure and quality	349	45	0.772	2.163	19.34%
Greater resilience to climate hazards	330	64	0.675	1.964	17.56%

Economic Performance Criteria

The increase in agricultural income clearly dominates the economic dimension, with a relative weight of 24.95% and a coefficient of 0.827. The other criteria have more similar weights: cost control, 19.76%; reduction in expenditure on chemical inputs, 19.66%; and income stability, 19.26%. The item relating to excessively high cost has a positive coefficient of 0.406 and the lowest relative weight within the dimension, at 16.37% (Table 6). These results indicate that farmers primarily associate the economic performance of ISFM technologies with their ability to generate additional income. Cost reduction is an important consideration, but it is less of a priority than increasing income. Farmers therefore appear to evaluate technologies

according to the relationship between the resources committed and the expected economic benefits, rather than solely according to the level of initial expenditure. These findings are consistent with the review by Piñeiro et al. (2020), which shows that sustainable agricultural practices are more widely adopted in the short term when they provide visible economic or production benefits. However, the similar weights associated with cost control and the reduction in expenditure on chemical inputs show that farmers remain attentive to the resources committed. They do not appear to evaluate technologies solely according to their initial cost, but rather according to the relationship between the necessary expenditure and the expected economic benefits. This interpretation is consistent with studies emphasizing that farmers make trade-offs between yields, costs, and profits when evaluating an agricultural innovation (Michler et al., 2019). The “excessively high cost” criterion has a positive coefficient of 0.406 and the lowest relative weight within the economic dimension. This result does not mean that financial constraints are absent. Farmers appear to reason in terms of overall profitability rather than solely on the basis of initial expenditure; that is, according to the relationship between the costs incurred, productivity gains, potential savings on inputs, and expected profits. This interpretation is consistent with Michler et al. (2019), who show, in Ethiopia, that an agricultural technology may be adopted despite the absence of a statistically significant yield gain when it reduces production costs and increases farm profits.

Table 6: Ranking of farmers’ perceived economic performance criteria for ISFM technologies

Evaluation criterion	B_j	W_j	Coefficient (α_j)	$\text{Exp}(\alpha_j)$	Relative weight (P_j)
Increase in agricultural income	360	34	0.827	2.2874	24.95%
Control of use costs	314	80	0.594	1.8111	19.76%
Reduction in expenditure on chemical inputs	313	81	0.589	1.8019	19.66%
Improvement in income stability	309	85	0.569	1.7657	19.26%
Perception of excessively high cost	277	117	0.406	1.5009	16.37%

Ease-of-Use Criteria

The relative weights are fairly close, ranging from 18.09% to 20.86%. This low dispersion indicates that no single criterion strongly dominates perceptions of ease of use. Ease of practical implementation ranks first (20.86%), followed by compatibility with usual practices (20.43%) (Table 7). This ranking suggests that farmers attach slightly greater importance to the practical feasibility of ISFM technologies and their consistency with the current organization of farms than to their conceptual simplicity alone. This result is consistent with Rogers’ (2003) Diffusion of Innovations theory, according to which a technology’s compatibility with

users' values, previous experiences and needs can facilitate its uptake, whereas high perceived complexity can hinder its adoption.

Ease of understanding (19.03%), low labour requirements (18.65%) and input accessibility (18.09%) occupy slightly lower positions, but their weights remain close to those of the two leading criteria (Table 7). These results therefore do not allow us to conclude that labour constraints or constraints on access to inputs are secondary. Rather, they show that farmers consider all these conditions to be interdependent when assessing the feasibility of ISFM technologies. This interpretation is consistent with the work of Masso et al. (2017) on soil fertility management in sub-Saharan Africa, which identifies limited access to improved agricultural inputs, insufficient understanding of practices and their benefits, and limited financial capacity among the factors likely to hinder the adoption of integrated soil fertility management practices.

For extension policies, these results support an integrated approach to farmer support. The objective is to make technologies not only technically understandable, but also compatible with production systems and feasible under actual farm conditions.

Table 7: Ranking of farmers' perceived ease-of-use criteria for ISFM technologies

Evaluation criterion	B _j	W _j	Coefficient (a _j)	Exp(a _j)	Relative weight (P _j)
Ease of practical implementation	285	109	0.355	1.4264	20.86%
Compatibility with usual practices	281	113	0.447	1.5637	20.43%
Ease of understanding	267	127	0.426	1.5315	19.03%
Low labour requirement	263	131	0.335	1.3980	18.65%
Accessibility of required inputs	257	137	0.305	1.3569	18.09%

Perceived Risk and Uncertainty Criteria

The five criteria in Table 8 have negative coefficients, indicating that, overall, they are selected as the least important more often than as the most important. Difficulty in mastering the techniques is the risk criterion with the least negative coefficient, with $\alpha = -0.173$, and has the highest relative weight within the dimension, at 23.54%. The slow emergence of results comes next, at 20.85%. This pattern shows that, when farmers are asked to compare the different risks, difficulty in mastering the techniques, and the time before effects become apparent are relatively the most important concerns. In contrast, uncertainty about results and the risk of reduced yield are less frequently selected as priority criteria. This ranking suggests that farmers are more concerned about their ability to implement ISFM technologies correctly and the time required to observe their effects than about the general risk of a decline in yield.

The position of difficulty in mastering the techniques is corroborated by Kenfack Essougong et al. (2020), who show that a lack of knowledge and

experience constitutes a significant constraint on the use of soil fertility management practices. Our results therefore point in the same direction, indicating that implementation constraints may be more salient than general agronomic risks. This interpretation is also indirectly corroborated by Lee et al. (2026), who show that extension services and labour availability positively influence the intensity of use of ISFM practices. This distinction has an important implication for public policy. The results do not necessarily support a policy aimed at reducing an agronomic risk perceived as high. Rather, they suggest the value of strengthening practical training, field demonstrations, and technical support. The diffusion of ISFM technologies could therefore become more effective by making implementation steps easier to understand and the time required to obtain results more predictable.

Table 8: Ranking of farmers' perceived risk and uncertainty criteria for ISFM technologies

Evaluation criterion	B_j	W_j	Coefficient (a_i)	$Exp(a_i)$	Relative weight (P_j)
Difficulty of technical mastery	163	231	-0.365	0.6940	23.54%
Slowness of results obtained	139	255	-0.442	0.6428	20.85%
Potential reduction in yield	112	282	-0.431	0.6505	18.21%
Perceived high level of risk	125	269	-0.294	0.7452	19.42%
Uncertainty of results	110	284	-0.173	0.8411	17.99%

Environmental Perception Criteria

Soil protection is the most highly valued environmental criterion, with a relative weight of 21.21% and a coefficient of 0.716, which echoes the finding already established at the agronomic level: farmers perceive soil fertility and soil health as a central issue, both productive and environmental. It is followed by the reduction of land degradation and the contribution to sustainable agriculture, each with 20.37%. This hierarchy is consistent with the work of Orchard et al. (2017), who show that farmers primarily perceive land degradation through its effects on fertility, productivity, and livelihoods (Table 9). Our results therefore support the idea that farmers' environmental perception is strongly linked to the observable effects of practices on their own plots.

Soil protection is valued more highly than the general preservation of natural resources, which obtains 18.31%. This difference suggests that farmers primarily assess environmental benefits according to their proximity to agricultural performance: protected soil is perceived as more fertile, more productive, and better able to sustain yields. This interpretation is consistent with Kihara et al. (2023), who show that soil health contributes not only to increased agricultural productivity, but also to the conservation of organic matter, the reduction of erosion, the improvement of water infiltration and retention, as well as other ecosystem services such as climate regulation and water quality.

However, the relative weights are relatively close, ranging from 18.31% to 21.21%. Environmental perception therefore appears coherent, with no marked opposition between its different components. Farmers recognize the effects of ISFM technologies on soils, land degradation, agricultural sustainability, environmental quality and natural resources. However, a favourable perception of these benefits does not guarantee their translation into actual practices. Orchard et al. (2017), show that farmers' responses to land degradation are constrained by the limited availability of land, the shortening and irregularity of agricultural seasons, as well as the lack of awareness, access, and knowledge regarding inputs. This conclusion supports the idea that farmers may recognize the importance of soil protection while facing difficulties in implementing the corresponding practices. This interpretation is also compatible with the synthesis by Kihara et al. (2023), which emphasizes that, despite the existence of technologies capable of improving soil health, their implementation remains limited in sub-Saharan Africa.

Table 9: Ranking of farmers' perceived environmental criteria for ISFM technologies

Evaluation criterion	B_j	W_j	Coefficient (α_j)	$Exp(\alpha_j)$	Relative weight (P_j)
Contribution to soil protection	338	56	0.716	2.0457	21.21%
Reduction of agricultural land degradation	330	64	0.675	1.9643	20.37%
Contribution to sustainable agriculture	330	64	0.675	1.9643	20.37%
Improvement of environmental quality	324	70	0.645	1.9054	19.75%
Preservation of natural resources	309	85	0.569	1.7657	18.31%

Conclusion

The results show that farmers' perceptions of integrated soil fertility management (ISFM) technologies are based on a multidimensional assessment combining agronomic, economic and environmental benefits, as well as the constraints associated with their implementation. Agronomic performance and environmental benefits are the dimensions most strongly valued by farmers, while economic performance also occupies an important place in their evaluation. At the level of criteria, increased yields, improved incomes, and soil improvement and protection appear to be the most salient attributes. Ease of use acts more as an operational condition likely to facilitate the implementation of technologies, whereas criteria associated with risks and uncertainties are relatively less often considered priorities.

These results highlight a close connection between agricultural productivity and the sustainability of natural resources in farmers' representations. The simultaneous importance attached to yield gains and the conservation of soil fertility suggests that the acceptability of ISFM technologies does not rest solely on their ability to increase production in the short term, but also on their perceived contribution to maintaining the

productive potential of farms. This complementarity between immediate benefits and longer-term effects is a key element for understanding the conditions of acceptance and, potentially, the sustainable adoption of ISFM technologies.

From a public policy perspective, these results suggest that ISFM diffusion strategies would benefit from moving beyond an approach focused exclusively on input availability or general awareness of environmental benefits. Extension systems should prioritize the empirical demonstration of agronomic and economic gains, notably through demonstration plots and local references, while making more explicit the delayed benefits associated with soil restoration and conservation. They should also strengthen technical support for farmers in order to reduce learning and implementation difficulties. Finally, adapting extension messages to available resources, local practices and the specific constraints of farms appears essential to transform a favourable perception into an intention to adopt and then into effective and sustainable use of ISFM technologies.

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