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From typology to criteria considered by farmers: what explains agroecological practice implementation in North-Sudanian Burkina Faso?

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Cropping systems in the North-Sudanian zone of Burkina Faso face significant challenges related to poor yields, declining soil fertility and harsh climatic conditions. Together these necessitate a shift toward more sustainable farming practices. Agroecology aims to enhance yields while minimizing environmental harm through the use of ecological functions and has been promoted by researchers and farmers' organizations as a solution. However, its implementation remains limited. This study investigated the criteria farmers consider when implementing agroecological practices at the farm level and how these criteria and their implementation are influenced by farm characteristics. Data collection methods included the serious game TAKIT, together with baseline and complementary household surveys (108 farmers each). Farm diversity was analyzed using a statistical typology. The influence of farm types, farm structural variables and the village location on (1) whether or not agroecological practices were implemented and (2) the criteria considered by farmers was explored. Four distinct farm types were identified: low resource endowed farms relying on off-farm income, low resource endowed farms relying on livestock income, medium resource endowed farms relying on agricultural and livestock income, and high resource endowed farms with diverse sources of income. There were no significant differences in the implementation of agroecological practices across farm types. Crop rotations were the most frequently implemented practice (by 91% of the study farmers), while the 2-by-2 line intercropping of sorghum-cowpea was the least implemented (9% of farmers). Implementation of zai pits varied significantly between villages, with farmers in Nagreonkoudogo more likely to use them than those in Tanvousse, due to differing soil characteristics. Farmers considered several criteria when deciding whether to implement agroecological practices, including the ability to improve yield and preserve soil. Constraints to their implementation included a lack of knowledge and their high labor requirements. These criteria did not differ across farm types, likely because they stem from shared environmental constraints or conditions. The study highlights the complexity of agroecological transitions in sub-Saharan Africa, and illustrates the need to adequately consider contextual conditions. The co-design of new practices, and the redesign of existing ones, should align with criteria considered by farmers.

KEYWORDS
agroecological practices, farm type diversity, farmers' criteria, practice implementation, sub-Saharan Africa

1 Introduction

The climatic conditions facing farm households in semi-arid West Africa are highly variable, including the unreliable onset and end of the rainy season, frequent dry spells and heavy rainfall events (Niang et al., 2014; Faye et al., 2018; Ollenburger et al., 2019; Huet et al., 2020). Weather variability is a major challenge to farming households, many of whom have relatively low adaptive capacity in the face of shocks (Sissoko et al., 2011). In addition to weather variability, poor soil fertility and limited access to fertilizers leads to soil depletion over the long run, rendering farming in the region challenging (Giller et al., 2011; Ripoche et al., 2015). Similar to other rural areas of Burkina Faso, agriculture is the main source of income for rural households in the North-Sudanian agroecological zone (Zampaligré and Fuchs, 2019). Projected climate change is expected to negatively impact agriculture and threaten the livelihoods of many farmers in the region (Zampaligré and Fuchs, 2019). Building farm household adaptive capacity is considered of paramount importance. To do so, farming approaches which benefit from ecological services such as the integration of legume crops in cropping systems through rotation or intercropping (Périnelle et al., 2021), and soil and water conservation (Zougmoré et al., 2014) are necessary.

Agroecology is a broad concept that encompasses both the application of ecological concepts and principles to the design and management of sustainable food systems (Gliessman, 2007) as well as the recognition and valuing of farmers' traditional knowledge. Nicholls and Altieri (2016) enumerated the following principles: recycling of biomass, enhancement of functional biodiversity, provision of favorable soil conditions for plant growth, minimization of losses (nutrients, water, light), diversification of species and genetic resources in the agroecosystem, and enhancement of beneficial biological interactions and synergies. Agroecology is increasingly being promoted in many countries, particularly in sub-Saharan Africa, as a response to agriculture's negative impacts on the environment and to deal with weather variability (Gliessman, 2021; Haggar et al., 2021). International organizations (e.g., FAO) propose agroecology as a new multidimensional framework, based on 10 elements, to improve the resilience and resource use efficiency of farming systems (Debray et al., 2019; Lancelloti, 2019; Iyabano et al., 2022). Agroecology is also a movement which promotes farmers' autonomy and their rights to produce their own food (Altieri and Toledo, 2011; Anderson et al., 2022; Iyabano et al., 2023). In fact, ideally, agroecological practices are identified and or refined based on local farmers' existing knowledge and practices (Altieri, 2002; Mier y Terán Giménez Cacho et al., 2018). At farm level, agroecological practices include a set of farming innovations, practices, technologies and knowledge which aim to use ecological principles to improve yield while preserving the environment (Kernecker et al., 2021). In the North-Sudanian region of Burkina Faso, farmers' current practices are characterized by very low input levels, resulting in poor productivity, thus suggesting a possible role for agroecological intensification to enhance both the productivity and sustainability of the farming system.

In this region, agroecological practices include crop rotations, traditional intercropping, row intercropping, crop-livestock integration, agroforestry and water and soil conservation techniques such as zai pits, stone bunds, and half-moon structures (Altieri and Toledo, 2011; Rodenburg et al., 2021). Agroecological practices reduce the reliance on external agrochemical inputs through enhancing ecological processes (Bonaudo et al., 2014; Duru et al., 2015). In Burkina Faso, studies have reported the benefits of agroecological practices such as traditional intercropping and rotations, crop-livestock integration, biological control of pests and diseases and, organic fertilization, in restoring degraded land (Girard and Dugué, 2009; Zorom et al., 2013; Toillier et al., 2021; Iyabano et al., 2023). Despite advocacy by some scientists and stakeholders for agroecological practices, evidence of their implementation by farmers remains limited (Wezel et al., 2014; Kanjanja et al., 2022). This emphasizes the need to understand what farmers consider when deciding whether to implement agroecological practices and adapt them to their farming contexts.

Many factors may explain why and how farmers implement, or do not implement, agroecological practices. These include their social and ecological context (Weltin et al., 2017), farm characteristics, risk perception and preferences. Rogers (2003) mentioned attributes such as "relative advantage," "compatibility" and "complexity," which are concepts considered in the literature on innovation adoption. Ochola et al. (2013) showed that farmers considered yield, soil fertility improvement, pest and disease control and, ecological adaptability when considering the use of agroecological practices. Farm diversity is also important in describing the implementation of agroecological practices (Fanchone et al., 2020). Also in West Africa, farms strongly differ and this diversity is often captured in farm typologies, which may vary depending on the study objective and context (Falconnier et al., 2015; Kuivanen et al., 2016). For example, in the analysis of biomass management strategies in the Centre-Nord region of Burkina Faso, Assogba et al. (2022) described farm types based on variables related to resource endowment and production orientation. Berre et al. (2022) considered farm size and main crop (legume or cotton) to explore the link between farm types and crop management practices in the Haut-Bassins region of Burkina Faso. Furthermore, differences within households can be characterized, distinguishing farmers' diversity (Kuivanen et al., 2016) from farm diversity (Signorelli, 2016). In addition, researcher-promoted farming practices, such as new cultivars, could be rejected by farmers because they do not match their preference in terms of taste, yield and transformability (Tumuhimbise et al., 2012). The consideration of farmers' own criteria for implementing or rejecting agroecological practices can aid in understanding if particular agroecological practices are likely to be implemented or in suggesting how they may be adapted and made more suitable for farmers. Most studies that have examined factors influencing farmers' adoption of agroecological practices explored the relationship between the implementation of agroecological practices at farm level and socio-economic and farm structural factors via probit and tobit models (Anley et al., 2007; Zorom et al., 2013; Danso-Abbeam et al., 2019; Elisabeth and Martin, 2022). However, there are few studies considering farm type diversity in explaining practice adoption (Teixeira et al., 2018; Fanchone et al., 2020). To the best of our knowledge, no study has considered both farm type diversity and farmers' criteria to explore the implementation of agroecological practices.

Against this background, the aim of this study is to (1) document the extent of agroecological practices implementation at farm level for two villages in North-Sudanian Burkina Faso; (2) explore which criteria influence farmer decisions to implement (or not) agroecological practices; and (3) investigate the extent to which farm typologies can support the process of tailoring agroecological practices to farmers' contexts. The following hypotheses have been formulated: (A) farmers' criteria to implement agroecological practices are driven by yield and economic profit; and (B) farm-level implementation of agroecological practices differs significantly across farm types.

2 Research design and methodology

2.1 Study area

The study was conducted in the framework of the FAIR-Sahel project, which is implemented in three countries (Burkina Faso, Mali and Senegal). Its aim is to foster the agroecological intensification of the region's cropping systems to improve farmers' resilience. In Burkina Faso, the project intervention zone includes the North-Sudanian and South-Sudanian agroecological zones. This study focused on the North-Sudanian agroecological zone, particularly the villages of Nagreonkoudogo and Tanvousse, both in the rural "commune" of Nagreongo (Figure 1). Nagreongo, with a land area of about 500 km^2 is located in the Oubritenga province of the plateau central region, approximately 38 km from the capital city, Ouagadougou. The total population of the region is estimated at 35435 inhabitants (INSD, 2019). Nagreonkoudogo has a good and accessible road network, a permanent market and access to the large Ziga Dam. Tanvousse is not well connected to major roadways, with restricted access particularly during the rainy season. It also does not have a permanent market. In addition to the existence of previous contacts with a farmer organization, these villages were selected because of their contrasting contexts, covering the range of typical conditions in the "commune." In both villages, farmers rely on crop production, livestock activities and off-farm activities. Sorghum is the main crop grown whereas maize dominates in the South-Sudanian zone. Other important crops in the two villages include cowpea [*Vigna unguiculata* (L.) Walp.], maize (*Zea mays* L.),

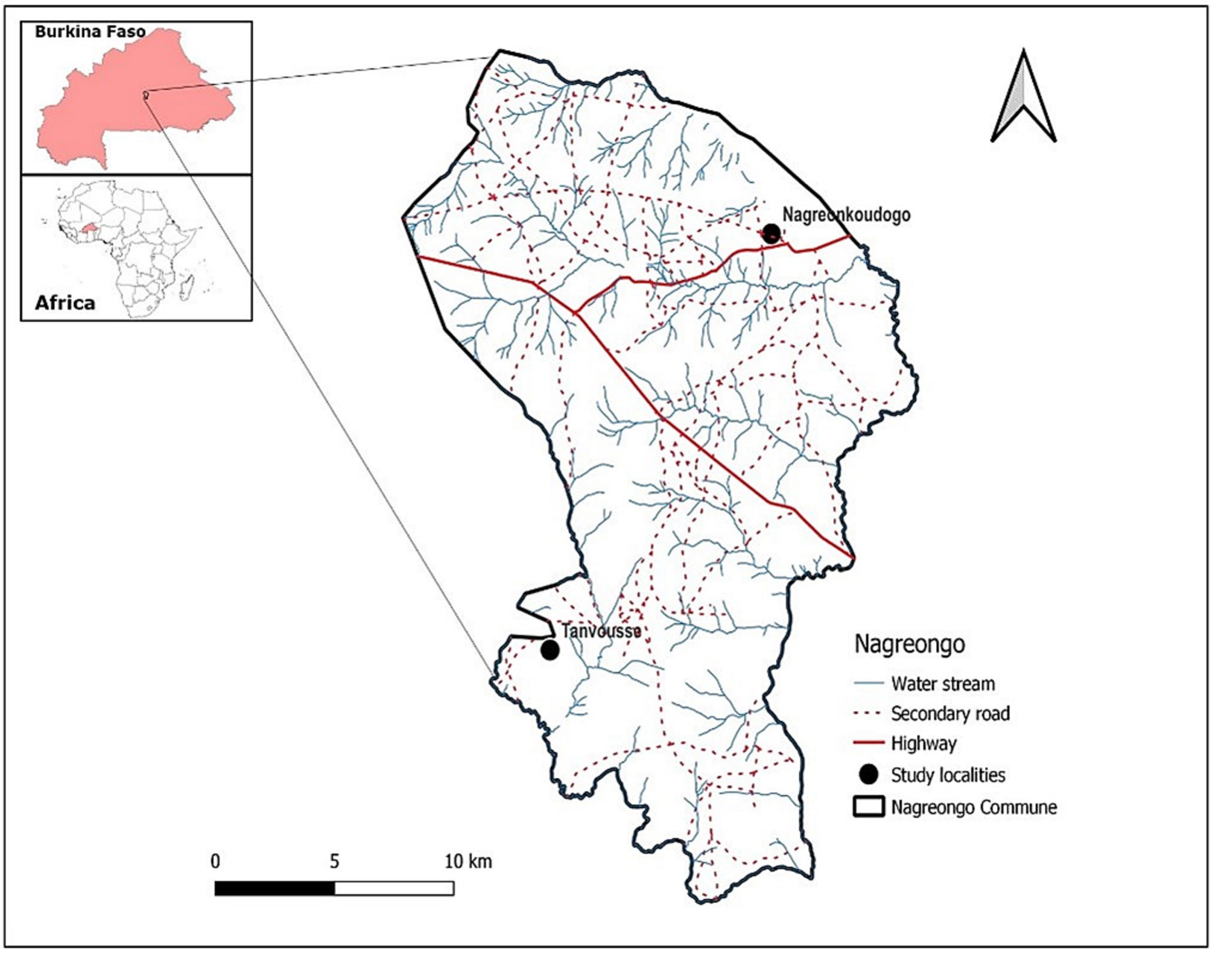

FIGURE 1
Location of the study area (Nagreongo) in Burkina Faso, West Africa. Black dots represent study sites.

groundnut (*Arachis hypogaea* L.), rice (*Oryza sativa* L.), sesame (*Sesamum indicum* L.), and Bambara groundnut [*Vigna subterranea* (L.) Verdc]. Organic cotton (*Gossypium herbaceum* Linnaeus) is grown only in Tanvousse.

In both villages, most of the inhabitants are from the Mossi ethnic group. The area is characterized by the North-Sudanian climate with annual rainfall ranging between 700 mm and 900 mm (Damiba et al., 2020). The rainy season starts in May or June, ends in September or October, and is characterized by high variability. Soils are generally poor, with high spatial variation in quality (West et al., 2008). There are heavier loamy soils (locally called *yakka* or *bãnzinga*) in lowland areas, laterites (*kugri*) and gravels (*zîngdega*) in upland fields, and denuded clay areas (*zippelle´*) which are unsuitable for cultivation (West et al., 2008). Farmers make use of the difference in soil types to adapt to the rainfall variability by selecting fields with different water retention capacities (Ingram et al., 2002).

In the study area, agroecological practices include crop rotations, traditional intercropping, row intercropping, crop-livestock integration, agroforestry and various water and soil conservation techniques such as zai pits, stone bunds, and half-moon structures. As in other regions of the world, rotations consist of growing crops in an ordered series on the same piece of land with the aim of maintaining soil fertility and managing pests, diseases and weeds (Tanveer et al., 2019). The most common rotations in the area consist of alternating cereals and legumes (Bado and Cescas, 2006). Intercropping cereals and legumes refers to either a spatial pattern of alternating rows of a cereal and a legume (row intercropping) or alternating cereal and legume seeding holes (Ganeme et al., 2021). In the context of this study, 2-by-2 lines intercropping refers to a cereal and a legume in two alternating rows in the same plot. This is mainly practiced in Nagreongo with sorghum and cowpea. Farmers' traditional intercropping practice in the region consists of seeding a cereal and a legume crop together in same place at the same time.The practice of zai pits consists of digging pits of about 20–40 cm in diameter and 10–15 cm depth. Manure is applied in those pits (about 0.3 kg per pit) and seeds are planted in them (Zougmoré et al., 2014). Half-moon structures consist of larger pits of about 2 m in diameter and 10 to 15 cm depth. The pits accumulate water before subsequent planting with or without the application of compost, plant residues and animal manure (Sawadogo, 2011).

Starting from the above mentioned agroecological practices, various options where co-designed and tested with farmers in an agronomic experiment. The treatments considered included sorghum in rotation with cowpea, sorghum in rotation with crotalaria, sorghum in rotation with mucuna, 2-by-2 line intercropping of sorghum and cowpea, traditional intercropping of sorghum and cowpea, sorghum in zai pits, and sorghum in half-moon structures. Each treatment was evaluated in a central field experiment in both villages for three growing seasons (2021, 2022 and 2023). The experiments were managed by researchers under on-farm conditions. Field technicians were responsible for the operations, with project farmers advising on and participating in all activities. Individual farmers subsequentially implemented and adapted one or two treatments from the central field in their own fields. The central field experiment aimed at evaluating the co-designed practices in a participatory setting following the DEED cycle (Describe, Explain, Explore, Design; Descheemaeker et al., 2019). It was designed in the form of mother-baby trials (Baafi et al., 2020). In each village, 30 farmers who were interested to participate were included in the implementation of the various project activities.

2.2 Data collection

2.2.1 Participatory approach to identify considered criteria

A serious game, called TAKIT (Ornetsmüller et al., 2018), was used in this study as a means to engage farmers (Speelman et al., 2014; Ryschawy et al., 2022). TAKIT has previously been played in other studies to identify farmers' criteria when selecting a cropping system (Lairez et al., 2020). Following Ornetsmüller et al. (2018) and Lairez et al. (2020), TAKIT was played in both villages to identify criteria that farmers consider in selecting new farming practices. Two sessions of the game were organized in each village, one for women (20 participants) and one for men (20 participants), to allow female farmers to speak freely. Participating farmers were farm household heads selected by the first author using the typology derived from the baseline household survey data (see section 2.2.2) to consider farm diversity. Given the small number of female-headed households in the baseline survey, other female-headed households with similar characteristics (resource endowment, income orientation) were invited to participate.

The game was played as part of a participatory workshop in four steps. In the first step, an ice breaker was used to introduce the idea of the game to the participants. A bottle of colored water was shown to the participants and they were asked, "if I want you to drink the content of this bottle what would you like to know first about the content before accepting to drink it? You are free to ask all kind of questions about the content, but the response to your question should be yes or no." Participants then asked questions and responses were provided. In the second step, the bottle of colored water was replaced by a picture of a new farming practice. Participants were then asked: "I have just invented a new farming practice and would like you to implement it this year in your farm. What would you like to know about this practice before implementing it?." Participants were given a piece of paper to write their questions and were assisted by local technicians as most of them were illiterate. Their questions were recorded on a flipchart. Next, these questions were grouped by similarity. Participants were then asked to state the importance of the questions to them through scoring (from 3 = most important to 1 = less important). Finally, a discussion with the participants aimed to capture the criteria behind the questions posed. As a preparation for this step, their questions were assigned to respective criteria by the researcher facilitating the game session in front of the participants who in turn validated the results. For example, the question, "will the new farming practice increase yield?" was assigned to a yield related criterion and the question, "will the new farming practice increase soil fertility?" was assigned to a soil fertility criterion (refer to Supplementary Tables 1, 2).

2.2.2 Baseline household survey

A baseline household survey was conducted by the FAIR-Sahel Project in 2021 to characterize farm households and describe farming practices in the village prior to the project intervention. It was conducted at the beginning of the rainy season (May to June 2021). Questions referred to the previous cropping season. The survey collected household and farm-level data from 252 farm households in six villages. Household-level data included socioeconomic data such as household size, income, level of education and resource endowment data such as land, and livestock ownership. Farm-level data included farm characteristics such as farm size, number of cultivated fields, crops grown, fertilization applied and crop production. In each household, the household head was interviewed. Enumerators were recruited and trained to conduct the survey in the local language.

2.2.3 Complementary household survey on criteria and farm-level implementation of agroecological practices

This study conducted a complementary survey focusing on only two intervention sites of the project due to time and other resource constraints. The survey was conducted in May 2022 in Nagreonkoudogo and Tanvousse with 53 and 55 participating farmers, respectively. Farmers were selected as a subset of the baseline household survey. A few participants of the baseline survey could not be located for the follow-up survey and were replaced. This second survey collected data on farm-level implementation of agroecological practices and the criteria considered by farmers (farm household heads) in implementing practices. It was assumed that farm-level decisions are mainly taken by the household head due to cultural traditions which confer them more power than other household members. In addition, the household head is the owner of most capital-intensive farming tools in the family (Tan et al., 2005). While most household heads were male, some female household heads were also included (widows and women leading the household if the man had migrated elsewhere). Survey participants selected the criteria they considered for implementing an agroecological practice in general, and for particular practices. Criteria were predefined and listed for participants to select from. The participants stated if they had implemented any of the selected agroecological practices or not. The practices included crop rotations, 2-by-2 line intercropping, traditional intercropping and zai pits. If a farmer stated that he or she had implemented a practice, they then indicated the criteria they had considered. If not, they stated the reasons why the practice was not implemented. Due to time and resource constraints, the survey focused on the household head, farm characteristics and agroecological constraints. It is important to note that further studies should take into account the diversity of responses among members in the household and the perspectives of non-household heads, to better capture perceptions and realities around agroecology within a household.

2.3 Data analysis

2.3.1 Data cleaning

The baseline household survey data for the two villages were used to conduct the typology analysis. Farmers with missing or inconsistent data were removed. Of the 108 farmers surveyed, 84 farmers (8 female and 76 male) were considered for analysis after data cleaning, representing 43 and 41 farmers in Tanvousse and Nagreonkoudogo, respectively. After joining the two survey datasets for analysis, only 76 farmers (8 female and 68 male) remained for the subsequent criteria and implementation analysis, representing 39 and 37 farmers in Tanvousse and Nagreonkoudogo, respectively.

2.3.2 Farm typology

The farm typology analysis was conducted using the baseline household survey data. As available data did not account for intra-household variability, the typology illustrates inter-farm diversity (horizontal diversity) and not intra-farm diversity (vertical diversity) as in Michalscheck et al. (2018). The farm typology analysis was conducted with variables that describe farm resources endowment and income orientation (Table 1). Based on Assogba et al. (2022) and Berre et al. (2022), a subset of several variables was initially explored, after which a multivariate analysis was implemented to determine which variables to retain. As off-farm income was collected as a categorical variable ranging from 1 to 5 income increases from low to high, it was not possible to implement a classical principal component analysis (PCA). The factorial analysis for mixed data (FAMD) from package FactomineR in R software (Lê et al., 2008) was selected to consider both categorical and continuous variables, as in Han et al. (2021), Pereira (2019), and Visbal-Cadavid et al. (2020). The results of the FAMD analysis were used to check the contribution of the variables to the primary two PCA dimensions. A hierarchical cluster analysis (Kassambara, 2017) was subsequently implemented in R software to divide the farms into homogenous groups regarding the most influential variables of the FAMD.

2.3.3 Criteria and implementation

In exploring the extent to which agroecological practices are implemented, first individual agroecological practices were analyzed, while combined sets of agroecological practices were analyzed in a second step. This reflects the reality that farmers generally implement several practices at the same time. The analysis was conducted using descriptive statistics. In investigating the criteria considered by farmers to implement agroecological practices (or not), we first identified the most frequently considered

TABLE 1 Variables considered in the construction of the farm typology (n = 84).

Variable	Units	description	min	max	mean
Cultivated land area	ha	The size of all the areas cultivated by the farmer	1	12	3.15
Cattle herd size	head	Number of cattle owned by the farmer	0	30	2.19
Small ruminants herd size	head	Number of small ruminants owned by the farmer	0	70	12.56
Agricultural income	PPP** (USD)	Income from selling agricultural products	0	11,150	976
Crops number	–	Number of crops grown by the farmer	1	5	1.63
Total adult equivalent	Adult Eq	Total adults equivalent	0.3	13.3	3.48

**PPP, purchasing power parity, it eliminates difference in price level between countries and adjusts the exchange rate accordingly. It is calculated by dividing the cost of x good in local currency by the cost of the same good in US dollars.

criteria in implementing agroecological practices in general. Frequency was also used to check the main criteria and constraints considered by farmers for the implementation of each agroecological practice. Chi-square and fisher's test were used to test the influence of farm types and farm structural variables on farmers' criteria. As for the influence of farm type and farm structural variables on the level of implementation, the Kruskal-Wallis' rank sum test was used. Power estimation for the different tests was run using the "pwr" package in R software to check the power of the different statistics regarding the sample size (Supplementary Table 3).

3 Results

3.1 Farm type diversity

The variables used in the typology analysis contributed 42.5% to the first two components in the factorial analysis (Figure 2). The FAMD of quantitative variables showed that the influential variables for the first dimension (number of crops and area of cultivated land) were mainly related to land use. Influential variables for the second dimension (number of small ruminants, income from agriculture and number of cattle) were mainly related to income and livestock. For the qualitative variables, low- and middle-off-farm income levels were influential for the first dimension, while low- and high-income levels were influential for the second dimension.

Four farm types were identified (Figure 2). The first was the low resource endowed farms relying on livestock (LRE_LI, $n = 35$). They relied on income from livestock, though they actually had the lowest average number of cows (0.7 head) and the lowest average number of small ruminants (7.2 head). The average cultivated land size was about 2.3 ha. The second farm type was the low resource endowed farms relying on off-farm income (LRE_OFF, $n = 28$). Farms in this type had less cultivated land and possessed few small ruminants. Their average cultivated land and average number of small ruminants were 3.3 ha and 8 head of livestock, respectively. Farmers from this group had on average 331 USD in term of Purchasing Power Parity (PPP) from agricultural income and 107 USD PPP from livestock income. This type was second only to the high resource endowed farm type (described later) in terms of the importance of off-farm income. The third farm type identified was the medium resource endowed farms (MRE, $n = 19$). Farms in this group had an average cultivated land area of 4.5 ha. They grew on average at least two crops, and were thus considered more diversified than the other farm types. They had on average 23 small ruminants. Farmers in this farm type earned agricultural and livestock income of 2,520 and 1,693 USD PPP, respectively. The fourth farm type was the high resource endowed farms (HRE, $n = 2$). This type of farms had the most resources, particularly livestock. On average, they owned about 22 cattle and 62 small ruminants. Farmers in this farm type had the highest average agricultural and livestock income totaling 8,595 and 8,054 USD PPP, respectively. However, the group was only represented by two farms in the entire survey, both located in Nagreonkoudogo village. In terms of resources, they were unique with twice as much resources as the MRE farms and large households of 20 members on average. Identified farm types were discussed with representatives of the local farmers' organization in the village who validated them based on their expertise on farming system diversity in the region.

3.2 Criteria considered by farmers for farm-level implementation of selected agroecological practices

The TAKIT game revealed 20 criteria considered by farmers when deciding whether to implement agroecological practices on their farms. The criteria mentioned by most of the farmers included: soil preservation, yield improvement, soil quality improvement, adaptation to land, adaptation to commonly used fertilizers (i.e., NPK, manure and urea), easy access to practice, and low tools requirement (Figure 3). Soil preservation and yield improvement were considered by more than 85% of the farmers. Easy access to the practice and low tools requirement were considered by less than 40% of the farmers.

3.2.1 Criteria and constraints considered by farmers for farm-level implementation of each practice

Several agroecological practices were implemented at farm level by the farmers in the study. Crop rotation was widely practiced, as indicated by about 91% of the participants (Figure 4). Farmers explained that they implement crop rotations to ensure soil fertility over time, increase yield, reduce plant diseases and improve their soils. They also believed that they had the knowledge, the knowhow and access to do so. During the group discussion, farmers argued that "most of us know the types of crops that should be alternating for rotations to preserve soil fertility." They further mentioned that it is easy to implement rotations if one has enough land. Crop rotations were not implemented in some farms because of land scarcity. In these cases, cereals were grown continuously as the main staple crops.

Most farmers (about 70%) implemented traditional intercropping on their farms (Figure 4). They did so primarily because of high yield and capacity for soil improvement. They also considered their knowledge and knowhow of the practice, its capacity to attenuate the negative effects of climate shocks and easy access. Farmers who did not implement traditional intercropping (about 30%, Figure 4) mentioned that it requires hard manual labor. Indeed, implementation of traditional intercropping is labor demanding for both sowing and weeding.

For zai pits, 62% of the farmers implemented them on their farm (Figure 4) because of their capacity to increase yield, improve soil fertility and avoid the negative effects of dry spells. For the farmers who did not implement this practice, its unsuitability for their fields was stated as a reason, mirroring scientific evidence that lowland areas are not suitable for zai pits (Slingerland and Stork, 2000).

The 2-by-2 line intercropping was implemented by only 9% of farmers (Figure 4). Reasons for implementation included yield increase, soil improvement, soil preservation and management of crop diseases. For the majority of farmers who did not implement this practice, explanations included their lack of knowledge, limited knowhow and labor constraints. Indeed, this practice was not commonly observed in the study villages. Unlike the traditional intercropping which farmers claimed to have learned from their parents and grandparents, the 2-by-2 line intercropping was mainly

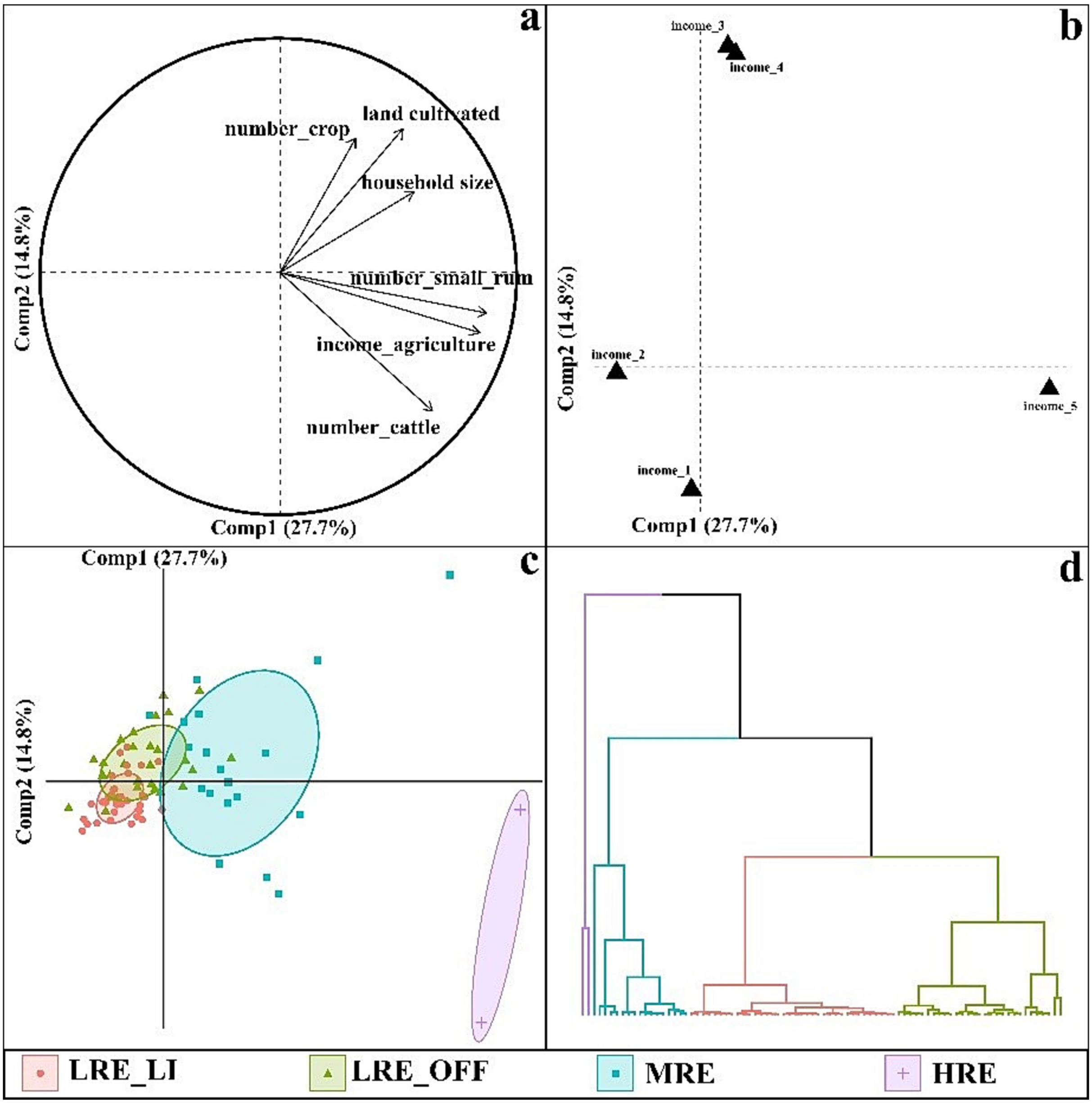

FIGURE 2
Factor map for quantitative (a) and qualitative (b) variables describing resource endowment and income orientations. For quantitative variables, the arrows represent the influential variables for the first two dimensions of the PCA. The qualitative variables refer to off-farm income level, increasing from low (1) to high (5). Individual map (c) and Dendrogram (d), both showing the individual farms into four clusters or farm types.

experienced through interactions with extension workers and project interventions.

3.2.2 Criteria considered by farmers and farm types

Any criterion considered by at least 40% of the farmers was retained for further analysis to explore differentiation among farm types. Farmers from each of the four farm types considered yield improvement (Figure 5). Although we observed some interesting differences between farm types regarding the relative importance of soil preservation, adaptation to usual fertilizers and low tools requirement, none of the differences were statistically significant. Similar to farm types, gender and age groups of the farmers did not significantly influence the choice of criteria. Overall, in the study villages, resource endowment, income orientation and crop diversification did not significantly influence the criteria that farmers considered when implementing agroecological practices. Since criteria consideration showed only minor differences across farm types, we consider the criteria for the whole sample of farms, regardless of farm types, for the remainder of this manuscript.

3.2.3 Implementation of individual practices across villages and farm types

Across villages, there were no significant differences in terms of the frequency of implementation of any practice except for zai pits. Zai pits were practiced more in Nagreonkoudogo than in Tanvousse

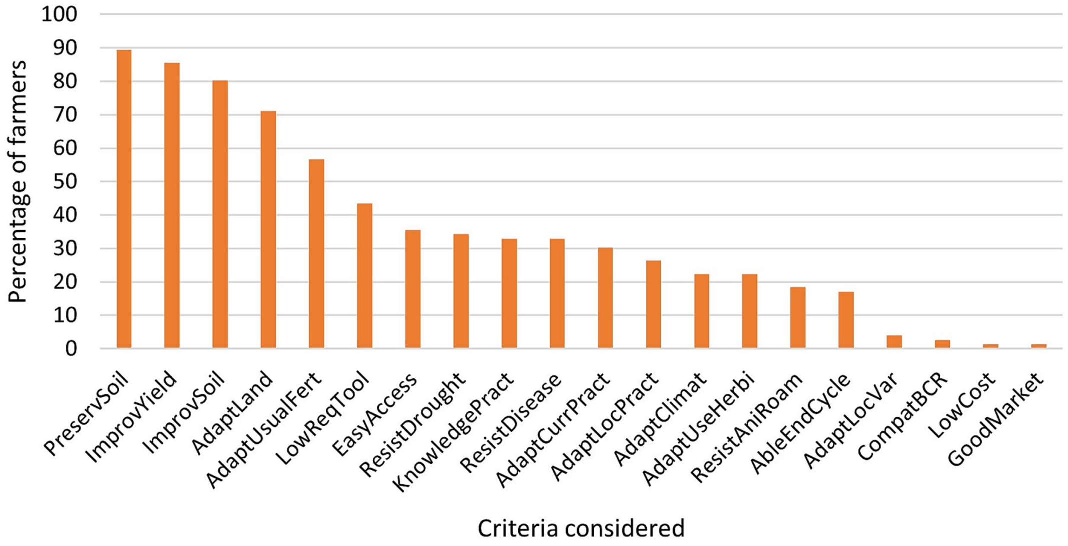

FIGURE 3
Percentage of farmers considering the criteria for implementing practices, PreservSoil = soil preservation; ImprovYield = Yield improvement; ImprovSoil = soil improvement; AdaptLand = adapted to land type; AdaptUsualFert = adapted to usual fertilizers; EasyAccess = easy access; LowReqTool = low tools requirement; ResistDrought = resistance to drought; KnowledgePract = knowledge about the practice; AdaptLocPract = Adaptation to local practices; AdaptClimat = adapted to climate; AdaptUserHerbi = Adapted to usual herbicides; ResistAniRoam = resistance to animal roaming; AbleEndCycle = early maturing crops; AdapLocVar = adapted to local variety; CompatBCR = compatibility with water collection basin; LowCost = low cost; GoodMarket = good market.

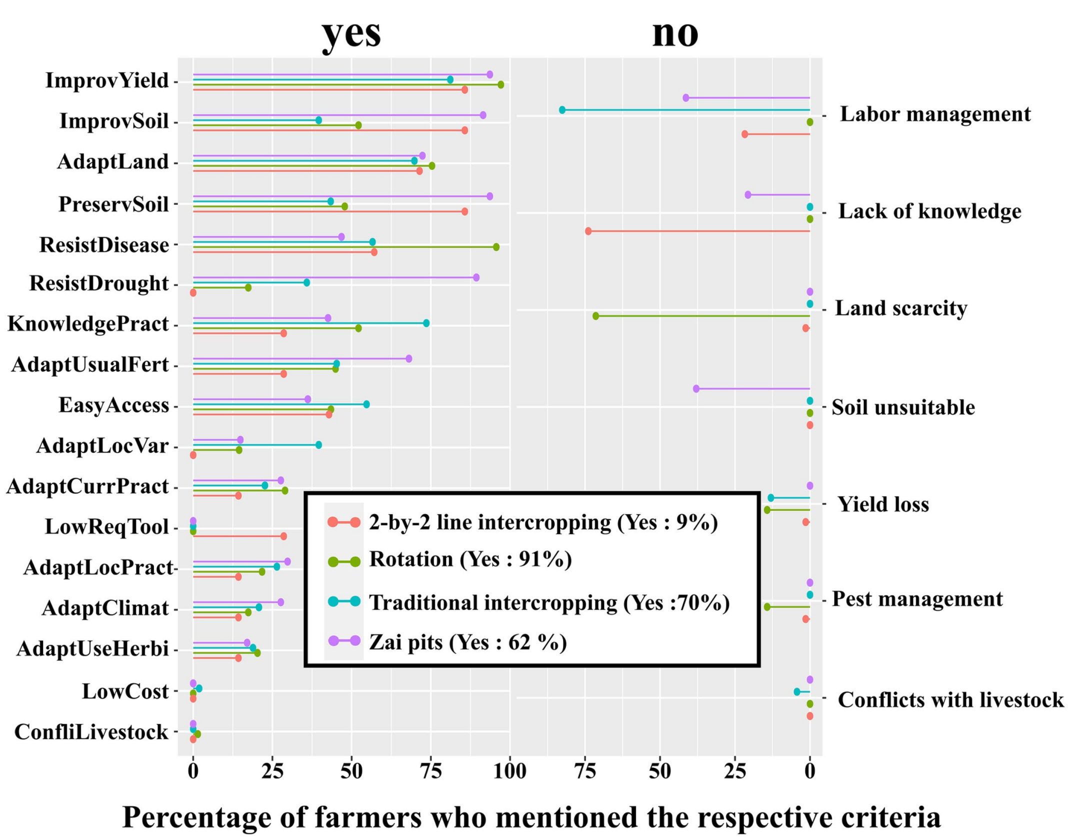

FIGURE 4
Implementation criteria (left, yes) and constraints (right, no) per practice. Refer to the caption of Figure 3 for the explanation of the abbreviations. X axis shows the percentage of farmers who implemented (left) or did not implement (right) the practice.

(Table 2), where it seemed less adapted to the geophysical context. Most soils in Nagreonkoudogo are dry, gravelly, and denuded while Tanvousse has a greater share of clay soils. Additionally, the presence of displaced people in Nagreonkoudogo due to the rise of terrorist activities probably influenced the extent of implementation. There, people worked as daily laborer for very low rates to earn income to feed their families. As such, labor was relatively cheap which helped to alleviate the labor constraint for implementing the practice. Because of similarities between villages for most practices, villages were analyzed together in the rest of the analysis.

Across farm types, some practices were widely practiced, while others were not. For example, both rotations and traditional intercropping were implemented by most farms (Figure 6). On the other hand, zai pits were most widely implemented by HRE farms (all of them), while the MRE farms had the lowest implementation rate. The 2-by-2 lines intercropping was only practiced by the MRE, except by the MRE and LRE_OFF farms (Figure 6). Based on the chi-square test, the implementation of the practices was not significantly different from one farm type to another for all the four practices.

3.2.4 Implementation of combined practices

The most widely implemented combination of practices was rotations, combined with traditional intercropping and zai pits (rotat_tradi_zai). Most of the farmers practicing this combination were in the LRE_OFF farm type. The second most implemented combination was rotation and traditional intercropping (rotat_tradi; Figure 7), mostly commonly practiced by the LRE_OFF farm type. The most popular combination for the MRE farms type was rotations, combined with 2-by-2 line intercropping, traditional intercropping and zai pits (rotat_inter_tradi_zai). The least implemented combined set was rotations and intercropping (rotat_inter), and rotations, combined with intercropping and zai pits (rotat_inter_zai; Figure 7).

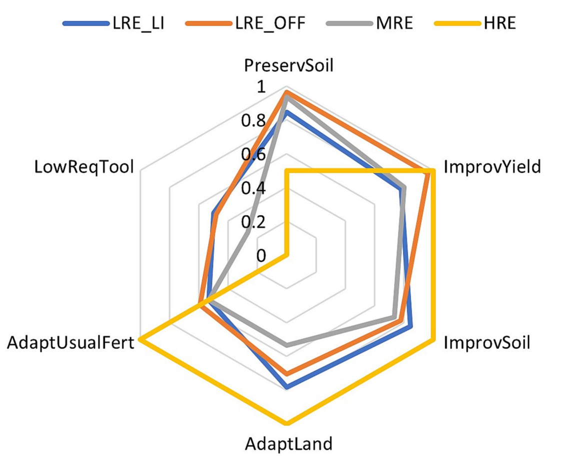

FIGURE 5
Percentage of farmers who considered the most important criteria by farm type. Most important criteria are the criteria considered by at least 40% of the farmers.

3.2.5 Implementation of practices across farm structural variables

Farm structural variables such as household size, number of small ruminants, number of cows, crop income and livestock income were not significantly different for the farms which implemented the practices and those which did not. Farms which implemented the 2-by-2 line intercropping seemed to exhibit a larger average cultivated land area as compared to those which did not implement (Figure 8). However, the Kruskal-Wallis' rank sum test revealed that the observed difference was not significant.

4 Discussion

4.1 Diversity of criteria considered by farmers to implement agroecological practices

Farming practices implemented by farmers generally serve to meet their interest or reflect a lack of feasible alternatives. Our results showed that farmers considered several criteria in their decisions to implement agroecological practices at farm level. The most widely considered criteria include soil preservation, yield improvement, adaptation of the practice to local context (land and usual fertilizers), low tools requirement and easy access. These results agree with those reported in literature (Kapinga et al., 2009a; vom Brocke et al., 2010; Kondombo et al., 2016). In addition to yield, farmers are worried about preserving the soil. Indeed, they are aware that low-input agriculture is only sustainable on good soils (non-degraded soils). Many also indicated the importance of ease of access to the practice (Figure 3). This criterion was also identified in a study investigating farmers' decision making around pesticide use (Sharifzadeh et al., 2018). Farmers' criteria identified here align with the attributes of innovation adoption of Rogers (2003). In fact, soil preservation and yield improvement criteria refer to the relative advantage of the innovation, while both the adaptation to local context and current practices criteria refer to the compatibility attribute. Finally, the easy access criterion is related to the attribute describing the complexity of the innovation, among others.

The typology analysis based on resource endowment revealed that discriminating variables included livestock, land owned (Alvarez et al., 2018) and farm income. As different farms face different social and biophysical challenges, we hypothesized that their resource endowment may also explain differences in the implementation and considerations

TABLE 2 Percentage of the implementation of the practices across villages.

Village	Rotation	2-by-2 lines intercropping	Traditional intercropping	Zai pits
Tanvousse	90%	13%	64%	44%.
Nagreonkoudogo	92%	5%	76%	81%
p-value	1	0.47	0.39	0.0017

The *p*-value of the chi-square test is provided.

around agroecological practice implementation (Teixeira et al., 2018). A typology analysis can help in understanding farm diversity which is a useful first step in adapting farming options to farmers' context (Descheemaeker et al., 2019; Assogba et al., 2022). In addition to farm diversity, the typology revealed community differences as the two farms with the highest resource endowment and more farms with low resource endowment relying on off-farm income were located in Nagreonkoudogo and more farms with low resource endowment relying on livestock were located in Tanvousse. likely due to the accessibility and proximity of a permanent market in Nagreonkoudogo. Nevertheless, the typology as developed here could not explain the differences we observed in farmers' choices on whether to implement agroecological practices nor in the criteria they consider. Differences were expected, as criteria are assumed to depend on the socio-ecological context of the farms. That we found no differences in either implementation or criteria across farm types may point out the limit of the type of variables considered in creating the typology. For example, many of the farmers' criteria are related to the biophysical environmental factors which are largely shared by most of the farms in the study area, irrespective of their economic and social situation. In connecting farm household types to management strategies, Berre et al. (2022) found similar dissociated results. This finding underscores the difficulty in tailoring or recommending specific practices to a given farm type (Berre et al., 2022). Rather, it stresses the need to allow farmers to be able to choose and adapt from a basket of options, meeting their context-specific needs and considerations (Ronner et al., 2021).

Despite there being no differences across farm types, there was variation across individual farmers regarding the criteria considered in implementing agroecological practices at farm level. The results showed that farmers implemented rotations in their farms because of their perceived capacity to increase yield and help with striga management. Indeed, Bado (2002) found that sorghum in rotation with legumes such as cowpea could double yield in comparison to

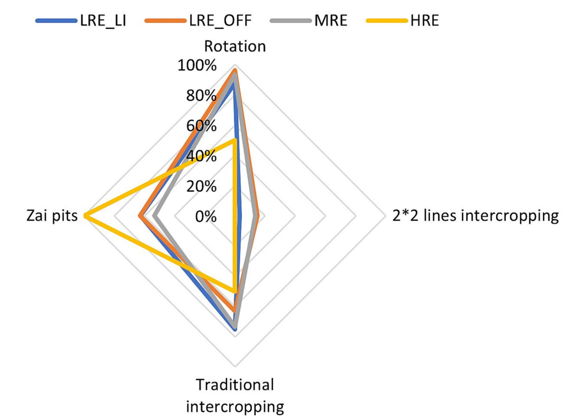

FIGURE 6
Implementation of agroecological practices in percentage by farm type, colors represent the different farm types, LRE_LI = low resource endowed farms relying on livestock, LRE_OFF = low resource endowed farms relying on off-farm income, MRE = medium resource endowed farms, HRE = high resource endowed farms.

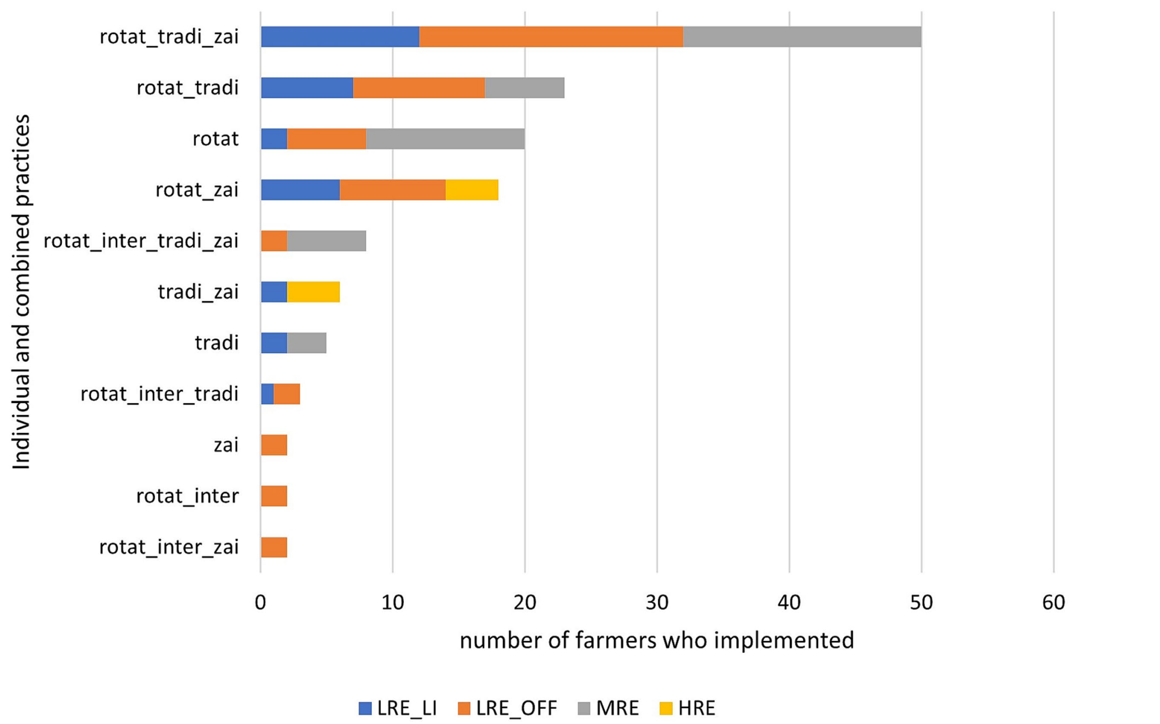

FIGURE 7
Individual and combined set of practices as implemented across farm types (n = 76), colors represent farm types, Blue = low resource endowed farms relying on livestock, Orange = low resource endowed farms relying on off-farm income, Gray = medium resource endowed farms, Gold = high resource endowed farms. Rotat = rotation, tradi = traditional intercropping, zai = zai pits, inter = 2-by-2 lines intercropping.

FIGURE 8
Implementation of selected agroecological practices (mentioned in the panel title). Land size is the sum of all field areas with or without the practice.

a continuous sorghum. They further mentioned that sorghum preceded by cowpea benefits from additional N which is estimated at 25 kg N/ha. Farmers are generally aware of the advantages of rotations. During a group discussion, they mentioned that "as we are practicing low-input agriculture, rotations remain an option to avoid mining the soil as it improves soil fertility." Those who did not implement rotations mentioned land scarcity as a main constraint, as in previous studies (Rosenberg et al., 2022; Rohit et al., 2023). However, our results (Figure 8) suggested that farm size was not significantly related to the implementation of rotations. Farmers who did not implement rotations did not have significantly smaller farm size as compared to those who implemented them. In fact, the farm size effect regarding the implementation of crop rotations should be carefully analyzed by considering the household size. For instance, a farmer with a 3.5 ha farm (average farm size) may still find it difficult to implement rotations if the household size is large. If a farmer currently grows only cereals each year on all land, adding legumes in rotation will reduce the cereal land area and production, challenging efforts to reach food demand through own production for large families.

The results showed that farmers considered yield increase, relatively good knowledge and knowhow when deciding whether to implement traditional intercropping (Figure 4). Some evidence suggests that traditional intercropping allows farmers to stabilize yield and deal with climate hazards (Ganeme et al., 2021). This practice is easily accessed by farmers as they use seeds from their own production. Unlike 2-by-2 line intercropping which has been introduced by researchers, farmers have been practicing traditional intercropping for a long time. This is reflected by their statements that they have good knowledge and knowhow about the practice. Farmers who did not implement the traditional intercropping mentioned the high labor demand as a main constraint. In fact, with traditional intercropping farmers cannot do weeding with draft animals as there is not enough space in between plant rows. Instead, farmers weed using hoes or by hand. In addition to weeding, harvesting is also difficult for farmers with this cropping system. The legume crop matures before the cereals and farmers must harvest the legumes under the tall cereal crop. Farmers implemented the zai pits technique mainly because of its adaptation to their land (degraded land), its capacity to improve soil fertility and attenuate climate shocks such as short dry spells and its capacity to increase grain yield. Scientific studies support this view (Zougmoré et al., 2014; Schuler et al., 2016). Zai practice appeared to be village dependent as it was practiced significantly more in Nagreonkoudogo as compared to Tanvousse. Some farmers did not implement zai pits due to labor shortage, unsuitable soils (lowland) and a lack of knowledge and knowhow for preparing the zai pits. Indeed lowland fields are not adapted to zai practice (Slingerland and Stork, 2000). During the group discussion, a male farmer in the age of 50 mentioned that to dig zai pits, "I must go with the whole family and be present to supervise as my wives and kids will not be able to do the work in my absence because they do not know how to do it properly." Matching new innovations to the main criteria mentioned by the farmers is likely to increase their implementation rate but is not a guarantee as the village location may also influence the practice implementation rate. In general, farmers rarely implement only one practice, they rather implement a combined set of practices (Zampaligré and Fuchs, 2019) and our results confirm this.

4.2 2-by-2 line intercropping: from on-station performance to farmers' constraints

The results indicated that the main reasons farmers implemented sorghum cowpea intercropping included its association with good yields, soil improvement and soil preservation. The farmers' reasons mirrored the benefits of the system found in the literature (Jahel et al., 2015). Indeed, intercropping sorghum and cowpea has been shown to improve soil fertility through nitrogen fixation (Giller, 2001; Kermah et al., 2018). In the study area, farmers practice traditional intercropping that they have inherited from their ancestors. According to farmers, constraints linked to this practice are labor management (HUSSON et al., 2010), yield losses and pest management (Coulibaly et al., 2011). To reduce these constraints, researchers and projects have proposed various row intercropping systems (Ganeme, 2022), one of which is the 2-by-2 line intercropping of sorghum and cowpea. Unlike the traditional intercropping system where sorghum and cowpea are not sowed in rows, the rows in the 2-by-2 line intercropping make weeding easier through allowing the use of hand tools such as hoes in a steady motion along a straight line, as well as, allow individual pest management for cowpea and sorghum.

The 2-by-2 line intercropping has been included in the experimental trial of the central field with the aim to improve its dissemination among farmers. However, the present study revealed that the 2-by-2 line intercropping was only implemented by a few farmers (9%). Farmers who did not implement it stated the lack of knowledge about the practice and labor management as key reasons. Svensson (2023) found a positive relation between farmers' self-reported knowledge about intercropping and its adoption. Indeed, putting in place the 2-by-2 line intercropping requires knowledge, labor and farming tools. In Nagreongo, where farmers lack many farming tools, the labor requirement for the formation of rows is pronounced. Farmers can use draft animals for this, but for those without draft animals, ropes are used to guide seeding along rows and this requires more labor. Furthermore, sowing in this system should be alternating with different seeds between rows, as compared to traditional intercropping where the two seeds are mixed during sowing. In addition to labor management, the lack of knowledge was also mentioned by farmers who did not implement it, probably because it has been recommended by research and its dissemination remains low.

Like the other practices, the 2-by-2 line intercropping was not influenced by farm structural variables. However, during a group discussion farmers mentioned that when comparing the 2-by-2 line intercropping to traditional intercropping, the 2-by-2 system forces them to reduce plant density as the spaces between rows are empty. Farmers with a small farm size, particularly poorer farmers who rent or borrow land, cannot afford losses due to lower plant density. According to the farmers, the proposed spacing of 80 cm between rows is too large and as such non-optimal for grain yield, similar to other results (Ganeme et al., 2021). Further study comparing row spacing alternatives for intercropping may provide a good co-learning opportunity for farmers and scientists in support of co-designing intercropping systems. From the farmers' perspective, the 2-by-2 line intercropping is not feasible with small farm size implying that for the innovation to be successful it should focus on incremental adaptations of the traditional intercropping practice. In this regard, the co-design process in this project will be a useful approach to further explore the implementation constraints, farmers' objectives and the possibility of combining and adapting different practices to achieve them.

4.3 Linkages between criteria, practice implementation and farm typology

The study identified a diversity of agroecological practices implemented by farmers in the region. It also explored the criteria farmers consider in implementing them. Contrary to our initial hypothesis, the practices and the associated criteria did not vary between the structural farm types. This can possibly be explained by the fact that the structural typology was constructed at farm level while criteria were collected at the individual level (household head). Other data were explored to explain agroecological practices and criteria, such as gender and age of the farmers but they were also not significant. This limits us in making recommendations on agroecological practices beyond our sample (e.g., tailor a given practice to a particular farm type in the study area). Several reasons could explain the observed lack of significance between farm types and the implementation of agroecological practices. Firstly, many of the benefits and constraints stated by the farmers were shared due to the natural environment conditions, irrespective of economic and social situation. In other words, even though the farming system diversity was high in the study region, the strength of the constraints at village scale (climate, market access, access to inputs, etc.) was larger and masked potential distinguishing factors between farms. The non-consideration of intra-farm household diversity could also explain the mismatch between a given level of implementation of agroecological practices and a farm type. Probably the results would have been different if we would have considered spouses or young household members managing their own fields, as their criteria might be different from those of the household heads. Agroecology is known to potentially change the labor burden and income, and their repartition among the members of the household (women, men, children) is certainly a key point in understanding agroecological transition drivers. Criteria considered by farmers to implement agroecological practices were diverse and went beyond economic criteria. They were in line with the "relative advantage," "compatibility" and "complexity" attributes of innovations, proposed by Rogers (2003). A new practice or innovation which meets those attributes is likely to be implemented by farmers.

4.4 Limitations

A potential limitation related to the serious game method is its small sample size, which may cause validity problems. However, by integrating the criteria identified through the game in the complementary household survey, we were able to effectively triangulate this information. The survey form was initially designed in French and then translated into the local language for the farmers to understand. Some degree of information loss can be expected due to translation. However, to reduce this, the enumerators were trained and the survey questionnaire was pre-tested. The sample size may have also impacted statistical results as a larger sample size would have led to stronger statistical power and therefore more robust results. A particular limitation is that the study was not able to consider the dynamic aspect of the criteria and/or implementation across years and weather conditions. Rather it provided a snapshot of the state of implementation and the reasons. Follow-up research could investigate how both the criteria and implementation develop over time, controlling for how they are influenced by weather and market conditions. Also, the cost of the practice was not explicitly considered by the farmers when articulating criteria, yet it was found to be an important criteria for practice implementation (Bagagnan et al., 2019; Kernecker et al., 2021). Since the TAKIT game was played in the framework of the project, participants were expecting to get the discussed practices for free, therefore they did not consider the cost.

5 Conclusion

This study identified criteria considered by farmers to implement selected agroecological practices at farm level, and evaluated the level of implementation of agroecological practices in the study area. It also assessed farm diversity. Several criteria in line with the innovation adoption attributes of Rogers (2003) were considered by farmers for farm-level implementation of agroecological practices, among which yield increase, capacity for soil conservation and soil fertility improvement were considered by at least 80% of the farmers. Crop rotation was found to be the most implemented practice while the 2-by-2 lines intercropping was the least implemented. The combination of rotation with traditional intercropping and zai pits was revealed as the most common combination of practices. Farm-level implementation of agroecological practices was not significantly different across farm types. Only the implementation of zai pits was significantly influenced by village location. Consequently, the uptake of agroecological practices in the North-Sudanian Burkina Faso, can be fostered by addressing farmers' criteria related to soil improvement and preservation, yield improvement and adaptation to site-specific conditions. Furthermore, labor constraints can be lifted by redesigning traditional intercropping system to allow plowing with animals and introducing mechanized zai pits. As the zai practice appeared to be village dependent, its promotion needs to take into account the geophysical context. The studied practices were adapted to the region as they were co-designed locally with the farmers. Nonetheless, they may be relevant for the entire North-Sudanian agroecological zone facing the same levels of soil infertility, climate variability and poor access to inputs and mechanization. These findings contribute to our understanding of the complexity of an agroecological transition in sub-Saharan Africa, where farming systems are diverse and decisions to implement a practice are influenced by a variety of criteria.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

BR: Conceptualization, Data curation, Investigation, Methodology, Software, Writing – original draft. DB: Conceptualization, Methodology, Software, Supervision, Validation, Writing – review & editing. HW: Conceptualization, Methodology, Software, Supervision, Validation, Writing – review & editing. JL: Conceptualization, Methodology, Writing – review & editing. HS: Conceptualization, Supervision, Writing – review & editing. KD: Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Validation, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2024.1386143/full#supplementary-material

References

Altieri, M. A. (2002). Agroecology: the science of natural resource management for poor farmers in marginal environments. *Agric. Ecosyst. Environ.* 93, 1–24. doi: 10.1016/S0167-8809(02)00085-3

Altieri, M. A., and Toledo, V. M. (2011). The agroecological revolution in Latin America: rescuing nature, ensuring food sovereignty and empowering peasants. *J. Peasant Stud.* 38, 587–612. doi: 10.1080/03066150.2011.582947

Alvarez, S., Timler, C. J., Michalscheck, M., Paas, W., Descheemaeker, K., Tittonell, P., et al. (2018). Capturing farm diversity with hypothesis-based typologies: an innovative methodological framework for farming system typology development. *PLoS One* 13:e0194757. doi: 10.1371/journal.pone.0194757

Anderson, C. R., Maughan, C., and Pimbert, M. P. (2022). Transformative agroecology learning in Europe: building consciousness, skills and collective capacity for food sovereignty. *Agric. Hum. Values*, 36, 531–547. doi: 10.1007/s10460-018-9894-0

Anley, Y., Bogale, A., and Haile-Gabriel, A. (2007). Adoption decision and use intensity of soil and water conservation measures by smallholder subsistence farmers in Dedo District, Western Ethiopia. *Land Degrad. Dev.* 18, 289–302. doi: 10.1002/ldr.775

Assogba, G. G., Adam, M., Berre, D., and Descheemaeker, K. (2022). Managing biomass in semi-arid Burkina Faso: strategies and levers for better crop and livestock production in contrasted farm systems. *Agric. Syst.* 201:103458. doi: 10.1016/j.agsy.2022.103458

Baafi, E., Akom, M., Agyeman, A., Darko, C., and Carey, T. (2020). Breeding farmer and consumer preferred sweetpotatoes using accelerated breeding scheme and mother–baby trials. *Open Agricul.* 5, 548–557. doi: 10.1515/opag-2020-0055

Bado, B. V. (2002). Rôle des légumineuses sur la fertilité des sols ferrugineux tropicaux des zones guinéenne et soudanienne du Burkina Faso. Université Laval Québec.

Bado, B., and Cescas, M. (2006). Assessment of cowpea and groundnut contributions to soil fertility and succeeding sorghum yields in the Guinean savannah zone of Burkina Faso (West Africa). *Biol. Fertil. Soils* 43, 171–176. doi: 10.1007/s00374-006-0076-7

Bagagnan, A. R., Ouedraogo, I., Fonta, W. M., Sowe, M., and Wallis, A. (2019). Can protection motivation theory explain farmers' adaptation to climate change decision making in the Gambia? *Climate* 7:13. doi: 10.3390/cli7010013

Berre, D., Adam, M., Koffi, C. K., Vigne, M., and Gautier, D. (2022). Tailoring management practices to the structure of smallholder households in Sudano-Sahelian Burkina Faso: evidence from current practices. *Agric. Syst.* 198:103369. doi: 10.1016/j.agsy.2022.103369

Bonaudo, T., Bendahan, A. B., Sabatier, R., Ryschawy, J., Bellon, S., Leger, F., et al. (2014). Agroecological principles for the redesign of integrated crop–livestock systems. *Eur. J. Agron.* 57, 43–51. doi: 10.1016/j.eja.2013.09.010

Coulibaly, K., Vall, E., Autfray, P., and Sedogo, M. P. (2011). Performance technico-économique des associations maïs/niébé et maïs/mucuna en situation réelle de culture au Burkina Faso: potentiels et contraintes. CIRAD.

Damiba, L., Doumounia, A., Casey, V., Bounkoungou, A., and Zougmoré, F. (2020). Analysis of rainfall variability on the groundwater levels of wells in the Nouaho Basin in east-Central Burkina Faso. *Inter. J. Environm Monit and Analysis*, 8, 27–32. doi: 10.11648/j.ijema.20200802.12

Danso-Abbeam, G., Dagunga, G., and Ehiakpor, D. S. (2019). Adoption of Zai technology for soil fertility management: evidence from upper east region, Ghana. *J. Econ. Structures* 8:32. doi: 10.1186/s40008-019-0163-1

Debray, V., Wezel, A., Lambert-Derkimba, A., Roesch, K., Lieblein, G., and Francis, C. A. (2019). Agroecological practices for climate change adaptation in semiarid and subhumid Africa. *Agroecol. Sustain. Food Syst.* 43, 429–456. doi: 10.1080/21683565.2018.1509166

Descheemaeker, K., Ronner, E., Ollenburger, M., Franke, A. C., Klapwijk, C. J., Falconnier, G. N., et al. (2019). Which options fit best? Operationalizing the socio-ecological niche concept. *Exp. Agric.* 55, 169–190. doi: 10.1017/S001447971600048X

Duru, M., Therond, O., and Fares, M. H. (2015). Designing agroecological transitions; a review. *Agron. Sustain. Dev.* 35, 1237–1257. doi: 10.1007/s13593-015-0318-x

Elisabeth, T. M., and Martin, S. (2022). Farmers' perceptions and adoption of agroecological practices in the central-north region of Burkina Faso. *African Scientific J.* 3:407. doi: 10.5281/zenodo.7528396

Falconnier, G. N., Descheemaeker, K., Van Mourik, T. A., Sanogo, O. M., and Giller, K. E. (2015). Understanding farm trajectories and development pathways: two decades of change in southern Mali. *Agric. Syst.* 139, 210–222. doi: 10.1016/j.agsy.2015.07.005

Fanchone, A., Alexandre, G., Chia, E., Diman, J.-L., Ozier-Lafontaine, H., and Angeon, V. (2020). A typology to understand the diversity of strategies of implementation of agroecological practices in the French West Indies. *Eur. J. Agron.* 117:126058. doi: 10.1016/j.eja.2020.126058

Faye, B., Webber, H., Naab, J. B., MacCarthy, D. S., Adam, M., Ewert, F., et al. (2018). Impacts of 1.5 versus 2.0 C on cereal yields in the West African Sudan savanna. *Environ. Res. Lett.* 13:034014. doi: 10.1088/1748-9326/aaab40

Ganeme, A. (2022). Performances agronomiques et modélisation des associations sorgho-niébé en zone Soudano-sahélienne du Burkina Faso: Université Joseph Ki-Zerbo.

Ganeme, A., Douzet, J.-M., Traore, S., Dusserre, J., and Kabore, R., (2021). L'association sorgho/niébé au poquet, une pratique traditionnelle en zone soudano-sahélienne à faible rendement: état des lieux et pistes d'amélioration. *International Journal of Innovation and Applied Studies*. 3, 836–848.

Giller, K. E. (2001). Nitrogen fixation in tropical cropping systems. *CabinetMaker*. doi: 10.1079/9780851994178.0000

Giller, K. E., Tittonell, P., Rufino, M. C., van Wijk, M. T., Zingore, S., Mapfumo, P., et al. (2011). Communicating complexity: integrated assessment of trade-offs concerning soil fertility management within African farming systems to support innovation and development. *Agric. Syst.* 104, 191–203. doi: 10.1016/j.agsy.2010.07.002

Girard, P., and Dugué, P. (2009). Analyse de la durabilité des systèmes de production à l'UGCPA – BM et proposition d'un plan d'action agro-environnemental, Farm, UGCPA/BM. 61.

Gliessman, S. R. (2007). Agroecology: The ecology of sustainable food systems. FL: CRC Press.

Gliessman, S., and Montenegro, M. W. (2021). Agroecology at the UN food systems summit. *Agroecol. Sustain. Food Syst.* 10, 1417–1421. doi: 10.1080/21683565.2021.1976474

Haggar, J., Nelson, V., Lamboll, R., and Rodenburg, J. (2021). Understanding and informing decisions on sustainable agricultural intensification in sub-Saharan Africa, vol. 19: Taylor & Francis, 349–358. doi: 10.1080/14735903.2020.1818483

Han, L., Shen, P., Yan, J., Huang, Y., Ba, X., Lin, W., et al. (2021). Exploring the clinical characteristics of COVID-19 clusters identified using factor analysis of mixed data-based cluster analysis. *Front. Med.* 8:644724. doi: 10.3389/fmed.2021.644724

Huet, E., Adam, M., Giller, K. E., and Descheemaeker, K. (2020). Diversity in perception and management of farming risks in southern Mali. *Agric. Syst.* 184:102905. doi: 10.1016/j.agsy.2020.102905

Husson, O., Charpentier, H., Razanamparany, C., Moussa, N., and Michellon, R. (2010). Mais ou sorgho associe aune legumineuse alimentaire volubile (Dolique, Niebe ouVigna umbellata). Manuel Pratique du Semis Direct A Madagascar, Volume V. CIRAD, Antananarivo, pp. 20.

Ingram, K., Roncoli, M., and Kirshen, P. (2002). Opportunities and constraints for farmers of West Africa to use seasonal precipitation forecasts with Burkina Faso as a case study. *Agric. Syst.* 74, 331–349. doi: 10.1016/S0308-521X(02)00044-6

INSD (2019). "Cinquième Recensement Général de la Population et de l'Habitation du Burkina Faso" in Ministère de l'Economie, des Finances et du Développement (Ouagadougou, Burkina Faso: Institut National de la Statistique et de la Demographie).

Iyabano, A., Klerkx, L., Faure, G., and Toillier, A. (2022). Farmers' organizations as innovation intermediaries for agroecological innovations in Burkina Faso. *Int. J. Agric. Sustain.* 20, 857–873. doi: 10.1080/14735903.2021.2002089

Iyabano, A., Klerkx, L., and Leeuwis, C. (2023). Why and how do farmers' organizations get involved in the promotion of agroecological techniques? Insights from Burkina Faso. *Agroecol. Sustain. Food Syst.* 47, 493–519. doi: 10.1080/21683565.2023.2164881

Jahel, C., Baron, C., Vall, E., Bégué, A., Coulibaly, K., Karambiri, M., et al. (2015). Land pressure and agrarian mutation, spatial modelling of farming systems evolution from plot to regional scale in West Burkina Faso. in: FSD5 Proceedings: Multi-functional farming systems in a changing world. Gritti Emmanuel S (ed.), Wery Jacques. ESA, Agropolis International. Montpellier: European Society of Agronomy-Agropolis International, pp. 239–240.

Kanjanja, S. M., Mosha, D. B., and Haule, S. C. (2022). Determinants of the implementation of Agroecological practices among smallholder farmers in Singida District, Tanzania. *European J. Agricul. Food Sci.* 4, 152–159. doi: 10.24018/ejfood.2022.4.5.571

Kapinga, R., Lemaga, B., Nsumba, J., Tumwegamire, S., Yencho, C. G. (2009a). Naspot 7", "Naspt 8", "Naspot 9 O", "Naspot 10 O" and "Dimbuka-Bukulula" Sweetpotato. *HortScience*, 44, 828–832.

Kassambara, A. (2017). Practical guide to principal component methods in R. STHDA, 2, 1–170. CreateSpace Independent Publishing Platform.

Kermah, M., Franke, A., Adjei-Nsiah, S., Ahiabor, B., Abaidoo, R. C., and Giller, K. (2018). N2-fixation and N contribution by grain legumes under different soil fertility status and cropping systems in the Guinea savanna of northern Ghana. *Agric. Ecosyst. Environ.* 261, 201–210. doi: 10.1016/j.agee.2017.08.028

Kernecker, M., Seufert, V., and Chapman, M. (2021). Farmer-centered ecological intensification: using innovation characteristics to identify barriers and opportunities for a transition of agroecosystems towards sustainability. *Agric. Syst.* 191:103142. doi: 10.1016/j.agsy.2021.103142

Kondombo, C. P., Deu, M., Chantereau, J., Martin, G., Chapuis, E., Letourmy, P., et al. (2016). Patterns of genetic structure and phenotypic diversity in sorghum landraces in relation to farmers' management in Burkina Faso. *Int. J. Biol. Chem. Sci.* 10, 1747–1764. doi: 10.4314/ijbcs.v10i4.24

Kuivanen, K., Michalscheck, M., Descheemaeker, K., Adjei-Nsiah, S., Mellon-Bedi, S., Groot, J. C., et al. (2016). A comparison of statistical and participatory clustering of smallholder farming systems–a case study in northern Ghana. *J. Rural. Stud.* 45, 184–198. doi: 10.1016/j.jrurstud.2016.03.015

Lairez, J., Lopez-Ridaura, S., Jourdain, D., Falconnier, G. N., Lienhard, P., Striffler, B., et al. (2020). Context matters: agronomic field monitoring and participatory research to identify criteria of farming system sustainability in South-East Asia. *Agric. Syst.* 182:102830. doi: 10.1016/j.agsy.2020.102830

Lancelloti, G. F. F. L. (2019). Slash-and-mulch: Exploring the role of shrub-based agroforestry systems for smallholder farmers in the Sahel: Wageningen University and Research.

Lê, S., Josse, J., and Husson, F. (2008). FactoMineR: an R package for multivariate analysis. *J. Stat. Softw.* 25, 1–18. doi: 10.18637/jss.v025.i01

Michalscheck, M., Groot, J. C. J., Kotu, B., Hoeschle-Zeledon, I., Kuivanen, K., Descheemaeker, K., et al. (2018). Model results versus farmer realities. Operationalizing diversity within and among smallholder farm systems for a nuanced impact assessment of technology packages. *Agric. Syst.* 162, 164–178. doi: 10.1016/j.agsy.2018.01.028

Mier y Terán Giménez Cacho, M., Giraldo, O. F., Aldasoro, M., Morales, H., Ferguson, B. G., Rosset, P., et al. (2018). Bringing agroecology to scale: key drivers and emblematic cases. *Agroecol. Sustain. Food Syst.* 42, 637–665. doi: 10.1080/21683565.2018.1443313

Niang, I., Ruppel, O., Abdrabo, M., Essel, A., Lennard, C., and Padgham, J. (2014). Africa. Climate change. eds. V. R. Barros, C. B. Field, D. J. Dokken, M. D. Mastrandrea, K. J. Mach and T. E. Biliret al Climate change 2014: impacts, adaptation, and vulnerability. Part B: regional aspects. Contribution of working group II to the fifth assessment report of the intergovernmental panel of climate change. Cambridge: Cambridge University Press (2014). 1199–265.

Nicholls, C., and Altieri, M. (2016). Agroecology: principles for the conversion and redesign of farming systems. *J. Ecosystem and Ecography* 1. doi: 10.4172/2157-7625.S5-010

Ochola, D., Jogo, W., Ocimati, W., Rietveld, A., Tinzaara, W., Karamura, D., et al. (2013). Farmers' awareness and perceived benefits of agro-ecological intensification practices in banana systems in Uganda. *Afr. J. Biotech10.5897/AJB12.2868*, 4603–4613. doi: 10.5897/AJB12.2868

Ollenburger, M., Crane, T., Descheemaeker, K., and Giller, K. E. (2019). Are farmers searching for an african green revolution? exploring the solution space for agricultural intensification in Southern Mali. *Exp. Agric.* 55, 288–310. doi: 10.1017/S0014479718000169

Ornetsmüller, C., Castella, J.-C., and Verburg, P. H. (2018). A multiscale gaming approach to understand farmer's decision making in the boom of maize cultivation in Laos. *Ecol. Soc.* 23:25. doi: 10.5751/ES-10104-230235

Pereira, N. (2019). Factor analysis of mixed data (FAMD) and multiple linear regression in R. Dissertations., p 212. https://arrow.tudublin.ie/scschcomdis/212

Périnelle, A., Meynard, J.-M., and Scopel, E. (2021). Combining on-farm innovation tracking and participatory prototyping trials to develop legume-based cropping systems in West Africa. *Agric. Syst.* 187:102978. doi: 10.1016/j.agsy.2020.102978

Ripoche, A., Crétenet, M., Corbeels, M., Affholder, F., Naudin, K., Sissoko, F., et al. (2015). Cotton as an entry point for soil fertility maintenance and food crop productivity in savannah agroecosystems–evidence from a long-term experiment in southern Mali. *Field Crop Res.* 177, 37–48. doi: 10.1016/j.fcr.2015.02.013

Rodenburg, J., Büchi, L., and Haggar, J. (2021). Adoption by adaptation: moving from conservation agriculture to conservation practices. *Int. J. Agric. Sustain.* 19, 437–455. doi: 10.1080/14735903.2020.1785734

Rogers, E. M. (2003). Diffusion of innovations. New-York: Free Press.

Rohit, P. S., Singh, H. C., and Asha, K. (2023). Constraints faced by the farmers in the adoption of crop rotation in Ayodhya District. *Age* 25:39. doi: 10.54986/irjee/2023/apr_jun/120-124

Ronner, E., Sumberg, J., Glover, D., Descheemaeker, K., Almekinders, C., Haussmann, B., et al. (2021). Basket of options: unpacking the concept. *Outlook on Agricul.* 50, 116–124. doi: 10.1177/00307270211019427

Rosenberg, S., Crump, A., Brim-DeForest, W., Linquist, B., Espino, L., Al-Khatib, K., et al. (2022). Crop rotations in California rice systems: assessment of barriers and opportunities. *Front. Agronomy* 4:806572. doi: 10.3389/fagro.2022.806572

Ryschawy, J., Grillot, M., Charmeau, A., Pelletier, A., Moraine, M., and Martin, G. (2022). A participatory approach based on the serious game Dynamix to co-design scenarios of crop-livestock integration among farms. *Agric. Syst.* 201:103414. doi: 10.1016/j.agsy.2022.103414

Sawadogo, H. (2011). Using soil and water conservation techniques to rehabilitate degraded lands in northwestern Burkina Faso. *Sustain. Intensification* 9, 120–128. doi: 10.3763/ijas.2010.0552

Schuler, J., Voss, A. K., Ndah, H. T., Traore, K., and de Graaff, J. (2016). A socioeconomic analysis of the zaï farming practice in northern Burkina Faso. *Agroecol. Sustain. Food Syst.* 40, 988–1007. doi: 10.1080/21683565.2016.1221018

Sharifzadeh, M. S., Abdollahzadeh, G., Damalas, C. A., and Rezaei, R. (2018). Farmers' criteria for pesticide selection and use in the pest control process. *Agriculture* 8:24. doi: 10.3390/agriculture8020024

Signorelli, S. (2016). Typology characterization of farmers in Ghana. https://africa-rising.wikispaces.com/file/view/Typology+Characterization+Ghana_Final.pdf

Sissoko, K., van Keulen, H., Verhagen, J., Tekken, V., and Battaglini, A. (2011). Agriculture, livelihoods and climate change in the West African Sahel. *Reg. Environ. Chang.* 11, 119–125. doi: 10.1007/s10113-010-0164-y

Slingerland, M., and Stork, V. (2000). Determinants of the practice of Zai and mulching in North Burkina Faso. *J. Sustain. Agric.* 16, 53–76. doi: 10.1300/J064v16n02_06

Speelman, E., García-Barrios, L., Groot, J., and Tittonell, P. (2014). Gaming for smallholder participation in the design of more sustainable agricultural landscapes. *Agric. Syst.* 126, 62–75. doi: 10.1016/j.agsy.2013.09.002

Svensson, F. (2023). The effect of knowledge on farmers' intercropping adoption decisions. Uppsala.

Tan, S. F., Guèye, B., Telly, B., Oulagelem, A., and Sangala, B. (2005). Portraits of family farming in West Africa. London: IIED Dryland Programme.

Tanveer, A., Ikram, R. M., and Ali, H. H. (2019). Crop rotation: principles and practices. *Agronomic Crops* 2, 1–12. doi: 10.1007/978-981-32-9783-8_1

Teixeira, H. M., Van den Berg, L., Cardoso, I. M., Vermue, A. J., Bianchi, F. J., Peña-Claros, M., et al. (2018). Understanding farm diversity to promote agroecological transitions. *Sustain. For.* 10:4737. doi: 10.3390/su10124337

Toillier, A., Bancé, S., and Faure, G. (2021). Emergence et cloisonnement de sous-systèmes de conseil pour l'intensification écologique de l'agriculture au Burkina Faso. In: Gasselin P, Lardon S, Cerdan C, Loudiyi S, Sautier S (eds). Coexistence et confrontation des modèles agricoles et alimentaires: un nouveau paradigme du développement territorial. Versailles (France): Editions Quae pp. 133–150.

Tumuhimbise, R., Melis, R., Shanahan, P., and Kawuki, R. (2012). Farmers' perceptions on early storage root bulking in cassava (*Manihot esculenta* Crantz) in east and Central Uganda and their implication for cassava breeding. *World J. Agricul. Sci.* 8, 403–408. doi: 10.5829/idosi.wjas.2012.8.4.1667

Visbal-Cadavid, D., Mendoza-Mendoza, A., and De La Hoz-Dominguez, E. (2020). Use of factorial analysis of mixed data (FAMD) and hierarchical cluster analysis on principal component (HCPC) for multivariate analysis of academic performance of industrial engineering programs. *J. Southwest Jiaotong University* 55. doi: 10.35741/issn.0258-2724.55.5.34

vom Brocke, K., Trouche, G., Weltzien, E., Barro-Kondombo, C. P., Gozé, E., and Chantereau, J. (2010). Participatory variety development for sorghum in Burkina Faso: farmers' selection and farmers' criteria. *Field Crop Res.* 119, 183–194. doi: 10.1016/j.fcr.2010.07.005

Weltin, M., Zasada, I., Franke, C., Piorr, A., Raggi, M., and Viaggi, D. (2017). Analysing behavioural differences of farm households: an example of income diversification strategies based on European farm survey data. *Land Use Policy* 62, 172–184. doi: 10.1016/j.landusepol.2016.11.041

West, C. T., Roncoli, C., and Ouattara, F. (2008). Local perceptions and regional climate trends on the central plateau of Burkina Faso. *Land Degrad. Dev.* 19, 289–304. doi: 10.1002/ldr.842

Wezel, A., Casagrande, M., Celette, F., Vian, J.-F., Ferrer, A., and Peigné, J. (2014). Agroecological practices for sustainable agriculture. A review. *Agronomy Sustain. Develop.* 34, 1–20. doi: 10.1007/s13593-013-0180-7

Zampaligré, N., and Fuchs, L. E. (2019). Determinants of adoption of multiple climate-smart adaptation practices in Sudano-Sahelian pastoral and agro-pastoral production systems. *Sustain. For.* 11:4831. doi: 10.3390/su11184831

Zorom, M., Barbier, B., Mertz, O., and Servat, E. (2013). Diversification and adaptation strategies to climate variability: a farm typology for the Sahel. *Agric. Syst.* 116, 7–15. doi: 10.1016/j.agsy.2012.11.004

Zougmoré, R., Jalloh, A., and Tioro, A. (2014). Climate-smart soil water and nutrient management options in semiarid West Africa: a review of evidence and analysis of stone bunds and zaï techniques. *Agric. Food Secur.* 3, 1–8. doi: 10.1186/2048-7010-3-16