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Review Article

Challenges in adoption and wide use of agroforestry technologies in Africa and pathways for improvement: A systematic review

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ABSTRACT

In recent years, agroforestry technologies have emerged as promising alternative measures for addressing major environmental crises. However, their use in Africa remains below anticipated levels. Therefore, this systematic review aims to investigate the underlying reasons for the low adoption and limited use of such technologies in Africa. Employing the Preferred Reporting Items for Systematic reviews and Meta-analyses protocol (PRISMA), we conducted a comprehensive search for relevant scientific papers in databases such as Google Scholar, Scopus and Web of Science. A total of 351 articles were initially identified. Following the predefined inclusion and exclusion criteria, 36 articles were selected from which data were manually extracted for inclusion in this review. Descriptive statistics were employed to assess the farmers' perceptions of agroforestry technologies and the constraints they face when adopting them. Several constraints were identified, and the top five constraints were pests, problems of land access, lack of knowledge and skills, lack of capital and lack of seeds. To maximise the adoption of agroforestry technologies in Africa, it is imperative to introduce the technologies by considering the local context, the specific needs of farmers and the existing socio-economic dynamics. Such initiatives must include robust training and education programmes, accessible financing solutions, appropriate land tenure reforms and effective support mechanisms for access to seed and pest management. These factors could considerably improve the adoption and effectiveness of agroforestry technologies in Africa, thereby contributing to more sustainable and resilient agricultural practices.

1. Introduction

In response to the pressing environmental and climatic challenges, a plethora of solutions for sustainable agriculture has been proposed to ensure sustainable management of biodiversity, soil fertility and provision of adequate food for growing population. Among these solutions, agroforestry stands out as a promising approach that enhances agricultural production while promoting the sustainable management of natural resources, particularly soil and biodiversity (Muthee et al., 2022).

In Africa, numerous agroforestry technologies have been introduced. However, despite their potential benefits, their use in the region remains largely constrained (Chitakira and Torquebiau, 2010; Meijer et al., 2015; Mwase et al., 2015 Kiyani et al., 2017; Amare and Darr, 2023). Although numerous literature reviews have conducted a comprehensive analysis on the use of agroforestry technologies in Africa (Albrecht and Kandji, 2003; Asare, 2006; Kiptot and Franzel, 2012; Kaczan et al., 2013; Foster and Neufeldt, 2014; Agevi et al., 2017; Muthee et al., 2022; Amare and Darr, 2023; Ambele et al., 2023), a review that solely and thoroughly focuses on constraints is non-existent.

Moreover, identifying the specific obstacles to the adoption and widespread use of agroforestry technologies in Africa is crucial for developing effective solutions to improve their use and integration into existing agricultural practices within diverse African contexts. By gathering, and rigorously analysing existing evidence on the challenges of adopting agroforestry technologies in Africa, valuable guidance can be provided to policymakers, researchers and practitioners. This in-depth review aims to analyse potential obstacles and barriers in the widespread adoption and use of agroforestry technologies in Africa.

In this systematic review, we have used variations in socio-demographic and political realities across regions to analyse the

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constraints or obstacles hindering the adoption and wide use of agroforestry technologies in Africa. We have highlighted key factors that can be addressed and areas of action required to promote the uptake of the agroforestry technologies. This research, which aims at providing a checklist of bottlenecks that hinder or limit farmers' transition to more sustainable agricultural practices such as agroforestry in Africa, is a necessary step towards improving agroforestry technology use on the continent and enhancing agricultural landscape resilience.

2. Methods

2.1. Selection criteria

All articles were manually selected. Only primary studies, theses, reports or book chapters focusing on agroforestry technology adoption or use in Africa were included. Evaluations encompassed the impact of various factors or constraints on the adoption as well as wide and intensive use of agroforestry technology in the continent. The exclusion criteria were as follows: (i) non-original studies (editorials and reviews), (ii) studies conducted outside Africa and (iii) studies addressing technologies other than agroforestry.

2.2. Data collected

This systematic review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines for the composition and interpretation of systematic reviews (Page et al., 2021). A word chain was generated using subject keywords, with incorporation of PICOS model elements: population (agroforestry technologies or innovations), intervention (constraints or barriers), outcome (adoption) and study framework (all African countries). The following word chain was used in the search strategy: (agroforestry OR "modern agroforestry" OR "agroforestry practices" OR "agroforestry systems" OR "agroforestry technology" OR "new agroforestry technologies" OR "agroforestry innovations") AND (obstacles OR challenges OR "limiting factors" OR barriers OR constraints) AND (adoption OR use OR large use OR acceptance) AND (Africa). This guided our literature search across Scopus, Web of Science and Google Scholar databases from 2000 to 2023. To ensure a comprehensive coverage, a reference search of the included studies was conducted. The systematic review process, including database searches and reference review, is illustrated in the flow diagram (Fig. 1) following PRISMA guidelines. Initially, 351 articles were identified, with 20 duplicates automatically removed, resulting in 331 unique documents. After title screening, 203 documents were excluded, and subsequent abstract screening excluded additional 77 documents. Finally, 51 articles underwent full-text review, leading to the exclusion of 15 articles based on predefined criteria. A total of 36 articles met the inclusion criteria and were included in this review. Notably, article selection was performed independently by two reviewers following predefined inclusion and exclusion criteria.

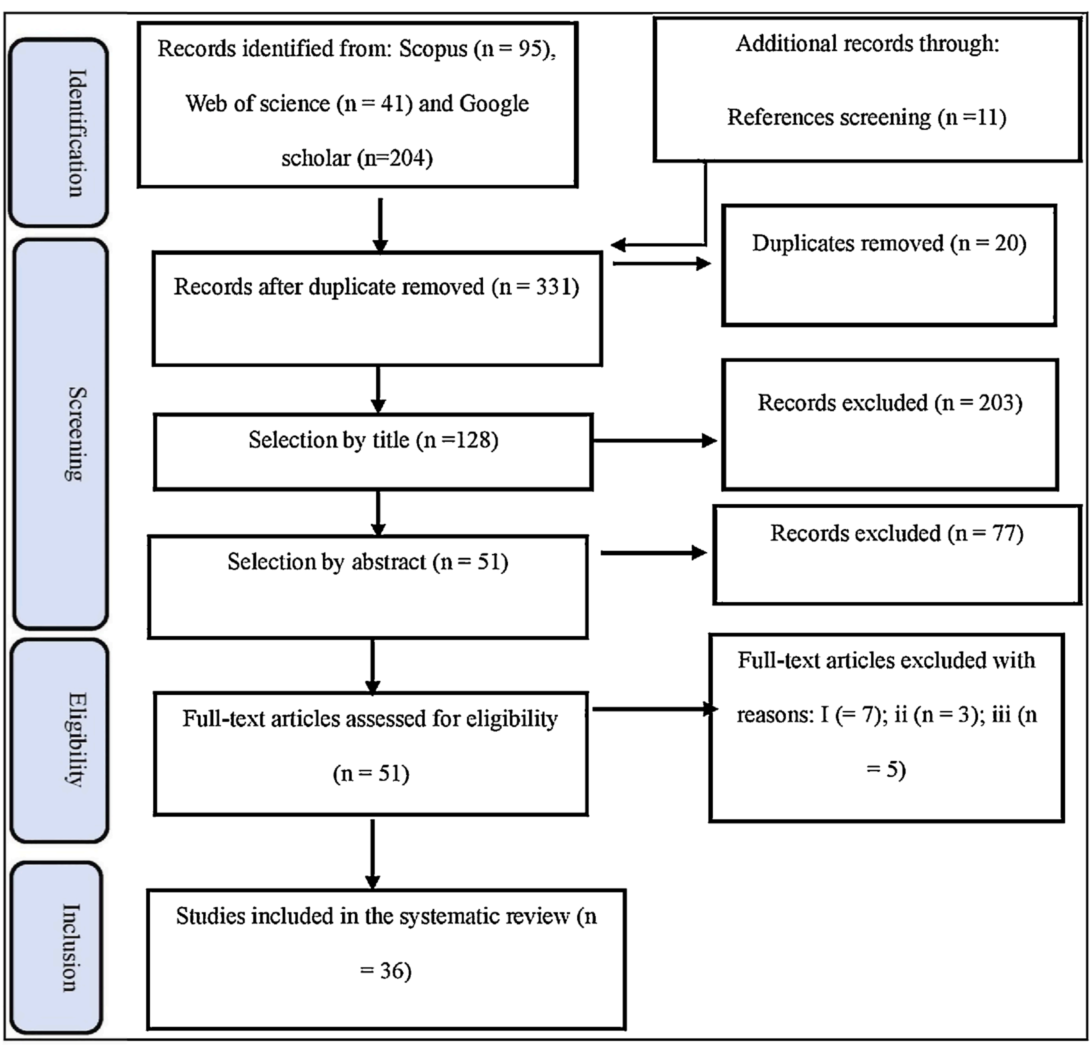

Fig. 1. Systematic review flow diagram including databases and other sources.

Subsequently, a consensus was reached through group discussions to finalise the selection, minimising potential selection bias inherent in single-reviewer assessments. Data collected during the review process included publication years, geographical and scientific contexts, author references, empirical methods, agroforestry technologies studied, use trends, factors influencing the use of agroforestry technologies (constraints or limitations), results and proposed solutions. Two independent reviewers extracted the data over a two-month period using a pre-developed and validated data collection form.

2.3. Data analysis

The extracted data were compiled into an Excel sheet, generating graphs that illustrate the technology adoption trends by country and the frequency of constraints.

The constraint prioritisation analysis was conducted using the ranking method based on ranks by assigning scores to each constraint based on the proportion of farmers having identified each constraint in each study. Thus, the scores were assigned as follows: 1 for constraints for which the proportion of farmers having identified it is between 0 % and 30 %, 2 for constraints for which the proportion of farmers having identified it is between 31 % and 50 %, 3 for constraints for which the proportion of farmers having identified it is between 51 % and 70 % and 4 for constraints for which the proportion of farmers having identified it is greater than 70 %. Initially, descriptive statistics were used to calculate average scores, facilitating the identification of constraints for which the highest scores were recorded. Next, a Kendall W test was applied to strengthen the results of descriptive statistical analysis.

However, a preliminary descriptive analysis (frequency calculation) was conducted to assess the empirical methodologies used and farmers' perception regarding the importance of trees in their fields. In addition, to assess the advantages of the different categories of agroforestry technologies listed in the studies, the proportion of works that identified each category of advantage was determined and compared according to the types of agroforestry technology. Moreover, the Sankey diagram was used to quickly and clearly visualise the advantages of each category of agroforestry technologies based on arrow thickness, which reflects intensity.

3. Result

3.1. Trends in research on agroforestry technology adoption in Africa and empirical methods used

3.1.1. Trends in research on agroforestry technology adoption in Africa

Studies examining concerns regarding the adoption and wide use of agroforestry technologies in Africa indicated a fluctuating trend between 2001 and 2020. However, interest in this topic increased after 2015, with the highest number of studies observed during the 2020–2021 period (Fig. 2).

3.1.2. Analysing the empirical methods used in previous studies

Based on the research objectives of each study, all the studies extending over the study period mentioned below are categorised into five groups (Table 1). Among the five groups, most studies were in Group 1 (53.73 %), comprising studies whose objective was to analyse and identify the factors or determinants of the adoption of agroforestry technologies and their associated constraints or challenges. These studies were mixed (descriptive and analytical; 59 %) or descriptive cross sectional (18 %), using qualitative and quantitative data collected via surveys and individual or household interviews (90.9 %) or selected essentially through random sampling (54.51 %). In this study, binary logistic regression (50 %), multivariate probit model and non-parametric chi-square statistical test (13.6 %) were the most commonly used statistical methods to assess the effect of socio-economic and demographic factors on the adoption of agroforestry technologies according to the study objectives of this study group. Following this group, the second group, representing 26.8 % of all the studies included in this review, aimed to assess the trend in the adoption of agroforestry technologies, over a defined period time. These studies were mixed (descriptive and analytical; 82 %) and longitudinal (18.1 %). They were based on qualitative or quantitative data collected over a period of time via interviews or surveys (90.92 %) and field observations (18.2 %) and used essentially random (90.92 %) and purposive (36.4 %) sampling. In these studies, descriptive statistics (100 %) such as the frequency and proportion of adoption and the binary logistic regression model (18.2 %) were more frequently used than others statistical analysis methods, to quantify the adoption rates and assess the effect of socio-demographic factors on the trend of agroforestry technology adoption over a specific period of time or after using an extension programme in a particular

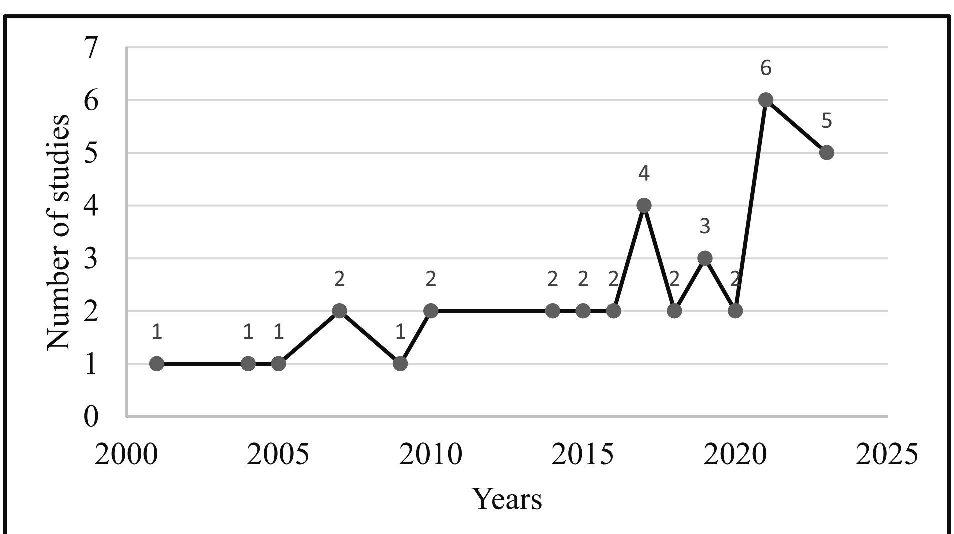

Fig. 2. Publications over time.
The number of articles published per year on the topic and included in this review. For instance, one article published on the topic in 2000 was included in this review.

Table 1
Empirical methods used in previous studies.

Groups	% of occurrence
1 (Analyse factors/determinants affecting farmers' technology adoption, adaption or intensification and investigate challenges or constraints faced)	53.70
Longitudinal study, diagnostic study, exploratory descriptive/analytics and impact study	4.53
Descriptive and analytical study	59
Descriptive cross-sectional study	18
Survey/interview	90.92
Focus group discussion	27.30
Literature review	9
Purposive	27.30
Random	54.51
Snowball, stratified, stratified random and systematic random	4.5
Chi-square	13.64
Binary logistic regression model	50
Heckman, linear regression model, econometric logit, double-hurdle model, average treatment effect estimation method, principal component analysis, interaction tests (mediation and moderation), collinearity tests and binary probit regression model	4.5
Multivariate probit model	13.63
2 (Investigate farmers' technology adoption and constraints or challenges faced)	26.80
Longitudinal study	18.10
Descriptive and analytical study	82
Survey/interview	90.91
Field observation	18.21
Focus group discussion and participant observation	9.10
Purposive	36.43
Random	90.91
Stratified random	18.2
Systematic random	9.10
Descriptive statistic	100
Binary logistic regression model and chi-square	18.21
Heckman, linear regression model, Pearson correlations, multivariate probit model, a five-point Likert-type scale, adoption index, principal component analysis, average treatment effect and estimation method	9.10
3 (Examine the socio-economic and environmental benefits of the agroforestry and constraints faced in its adoption)	12.23
Descriptive cross-sectional study	100
Survey/interview	100
Purposive, stratified random and gender stratification	20
Random	80
Descriptive statistic	100
Pearson correlations	40
t tests and five-point Likert-type scale	20
4 (Understand the motivation associated with the technology adoption or intensification and constraints faced)	5
Mixed studies (descriptive and analytic)	100
Survey/interview	100
Field observation	50
Purposive	100
Random	100
Descriptive statistic	100
Chi-square	50
Binary logistic regression model	50
Akaike information criterion (AIC)	50
5 (Explore the challenges of technology management and adoption)	2
Exploratory qualitative/quantitative	100
Survey/interview	100
Field observation	100
Focus group discussion	100
Stratified random	100
Descriptive statistic	100
Discourse analysis	100

% of occurrence is the proportion of the total number of appearances of a study in one of the five study groups from the total number of studies for the study groups, and the proportion of the total number of appearances of a methodology in a study group from the total number of methodologies in this group.

region over a specific period. This was followed by Groups 3 and 4, whose objectives were to investigate perceptions of the socio-economic and environmental benefits of agroforestry technologies (26.8 %) and understand farmers' motivations for adopting these agroforestry technologies and their associated challenges (12.2 %). These studies were 100 % descriptive and sometimes mixed (descriptive–analytical). Essentially using random sampling (80 % and 100 %) to select the population to be included, the data were collected mainly via qualitative or quantitative surveys (100 %) and field observations (50 %). In these study groups, descriptive statistics (100 %) were mainly used to assess farmers' perceptions of various ecosystem services, including the number of constraints mentioned and the proportion of farmers who mentioned them. Similarly, binary logistic regression was used by 50 % studies in this group, to assess the effect of motivation on the technology use adaptation and intensification. The last group of studies consisted of those intended solely to identify constraints or challenges in technology adoption without analysing them (2 %). This group consisted of exploratory studies (100 %). Several data collection methods (observation, focus group, survey and individual interview) were used to collect the data analysed using descriptive statistics and discourse analysis (100 %).

3.2. Agroforestry technologies involved in the adoption constraint analysis and their benefits

The constraints or challenges impacting the use or adoption of agroforestry technologies were studied across various categories of agroforestry technologies, with linear agroforestry being the most extensively studied (32.83 %), followed by sequential agroforestry (17.91 %), tree-covered cropping (16.41 %) and tree-covered livestock production (7.46 %) (Table 2). However, an important proportion of studies focused on agroforestry without specifying a particular technology (23.88 %).

The Sankey diagram presented in Fig. 3 illustrates the major benefits of agroforestry technologies, derived from a meticulous analysis of farmers' motivation for adopting the technologies in relevant studies.

The farmers motivation for adopting these agroforestry technologies was primarily associated with tangible ecosystem services such as improved soil fertility, weed control and crop destruction by wind, increased agricultural yield and diversification of crops and livestock. These reasons were most frequently associated with farmers using agroforestry technologies in the category "linear agroforestry", crops under tree cover, sequential agroforestry and agroforestry in general (Fig. 3). Moreover, according to the same data collected on the reasons for adopting the agroforestry technologies in the studies, the livelihood support provided by these agroforestry technologies through the supply of medicinal products, food for humans and animals (fruit, leaves, flowers, etc.), shade for resting during fieldwork and for animals, wood, improved access to fuel and fodder for animals and improved income through the sale of forest products and associated agricultural production were the most cited reasons. Farmers in the studies associated these more with the agroforestry technologies "crops under tree cover", "linear agroforestry", "Livestock production under tree cover", home gardens and agroforestry in general (Fig. 3).

3.3. Agroforestry technologies uptake in Africa

3.3.1. Trends in the adoption of agroforestry technologies in Africa

The majority of studies identified on the subject were conducted in four African regions (Table 3), with the East African region accounting for the largest proportion (47.22 %), followed by the West African region (27.8 %), South Africa (16.7 %) and finally the Central African region (8.33 %).

For all studies consulted for this review, 58.33 % calculated the adoption rate during the statistical analysis after data collection, 13.88 % included adopters and non-adopters in their base sample and 25 % did

Table 2
Categories of agroforestry technologies covered in the studies.

Categories	Mention number	Mention percentage (%)	Definition
Linear agroforestry techniques (windbreaks, alley cropping, living hedges, boundary, hedge row, woodlot, border planting, shelterbelts, fodder trees and scattered trees)	12	32.83	In this form of land use, trees appear in alignment in plots, farms or rural landscapes in association with annual crops. Sometimes they are border plantations, defining land boundaries or enclosing land (Torquebiau, 2022).
Agroforestry (unspecified)	9	23.88	Land-use practices permanently or sequentially associating trees in borders or in fields with annual crops or animals to obtain useful products or services for living organisms (Torquebiau, 2022).
Sequential agroforestry techniques (improved tree fallow, taungya)	9	17.91	In this category of agroforestry techniques, trees and crops do not grow at the same time but follow one another over time, either totally or partially (Torquebiau, 2022).
Crops under tree cover (Shaded coffee, cocoa agroforestry and natural regeneration assisted)	8	16.41	A land-use system where scattered or ordered tall trees above crops cover the upper stratum (Torquebiau, 2022).
Livestock production under tree cover (grazing under scattered trees, breeding under tree cover and apisilviculture)	3	7.46	This involves an association between trees and animals or fodder production on an agricultural land for animal feed (Torquebiau, 2022).
Total	41	100	

not report this rate. For the 58.33 % of studies that calculated the adoption rate after data collection, the non-adoption rate ranged from 5.3 % to 82.2 % (Table 3). Meanwhile, 8.33 % of the studies were longitudinal, which examined the dynamics of adoption over a period of time and sometimes mentioned the non-adoption and dropout rates. Of these studies, 33.33 % reported both rates (non-adoption and dropout), 33.33 % reported only the dropout rate and 33.33 % did not clearly report either rate. For all studies that reported the dropout rate, the rate varied between 39 % and 46.81 % (Table 3).

With respect to the aforementioned rates, the most frequently documented rate in the studies conducted in Central and South Africa was the rate of non-adoption of the technologies. In the Central African region, all of the studies reported non-adoption rates ranging from 42.2 % to 15 %. In South Africa, 50 % of the studies reported non-adoption rates ranging from 33.7 % to 25 %. Conversely, 52.94 % of East African studies reported non-adoption rates ranging from 72.7 % to 18 %, whereas a single study (representing 5.88 % of the total) reported a dropout rate of 39 %. Finally, the majority of studies conducted in West Africa (50 %) also reported non-adoptions, with rates varying from 57.2 % to 5.3 %. Only one study in this region documented a dropout rate of 46.8 % (Table 3).

3.3.2. Factors driving the adoption of agroforestry technologies

Various trends were noted from the factors identified by the authors as the causes of abandonment or withdrawal of the use of agroforestry technologies by farmers (Fig. 4). At the top of the list, the most frequently cited constraint is the 'lack of knowledge and skills', accounting for a high proportion of 18.20 %. Second, 'land access challenges' and 'lack of seeds' are mentioned in 13.64 % of studies, respectively.

Third, the 'lack of capital' is identified in 9.10 % of the studies, followed by 'low productivity' and 'drought' in 4.54 % of cases each. Finally, constraints such as 'expensive technologies', 'high labor demand' and 'insufficient or missing infrastructure' are identified in a lower proportion of 4.54 % each.

3.3.3. Prioritisation of constraints

The hierarchical analysis of the main constraints or reasons for abandoning the use of agroforestry technologies provides valuable insights into the challenges faced by farmers (Table 4). The value of the median score, which represents the median of the scores given by farmers to the various constraints in the literature consulted, when ranked in ascending order, provides a useful indication of the relative position of each constraint in terms of priority (Table 4). The 'lack of knowledge and skills' appears as the most important constraint, ranking first with a score of 0.39. Subsequently, the 'lack of capital' is identified as a significant barrier with a score of 0.32. In third place, 'land access challenges' are identified as major obstacles, with a score of 0.29.

Continuing in the analysis, we observe that constraints such as the 'lack of seeds', 'pest species' and 'low resource capacity of farmers' are in the fourth position, indicating a similar prevalence in the studies analysed. In addition to these different barriers, constraints such as 'market inaccessibility', 'low productivity' and 'limited access to credit' are in the 11th position.

Finally, constraints such as the 'tree use permit procedure lengthy and time consuming', 'inadequate equipment and practices', 'low levels of education' and 'roaming animals' are the least mentioned. In addition, the categorisation of constraints groups the previously prioritised constraints into four categories (Table 4). These are socio-demographic constraints, which refer to the specific characteristics of farmers and social and geographical factors; the institutional/organisational constraints, which include the higher authorities and the organisation of society, including economic and governance policies and norms; the economic constraints, which include the economic power of farmers, existing economic policies to support farmers and the specific economic aspects of each technology; and the agricultural constraints, which refer to agricultural production factors in agroforestry systems and the specific productivity of the different technologies, such as their impacts on understory products.

In addition, this categorisation has a mixed aspect of certain constraints: inaccessibility to the market for the sale of forest products resulting from these agroforestry practices, limited access to land, limited access to credit, the lack of seeds and animal transhumance, which involve organisational and socio-geographical factors affecting farmers' willingness to engage in this practice on a long-term basis. The mixed nature of most constraints indicates the crucial importance of cooperation between various actors, from the technology development phase to the implementation of diffusion and monitoring strategies.

However, considering the four categories of constraints, the institutional/organisational category has the highest number of constraints (eight constraints), followed by the socio-demographic and economic categories (five constraints) and the agronomic category (four constraints).

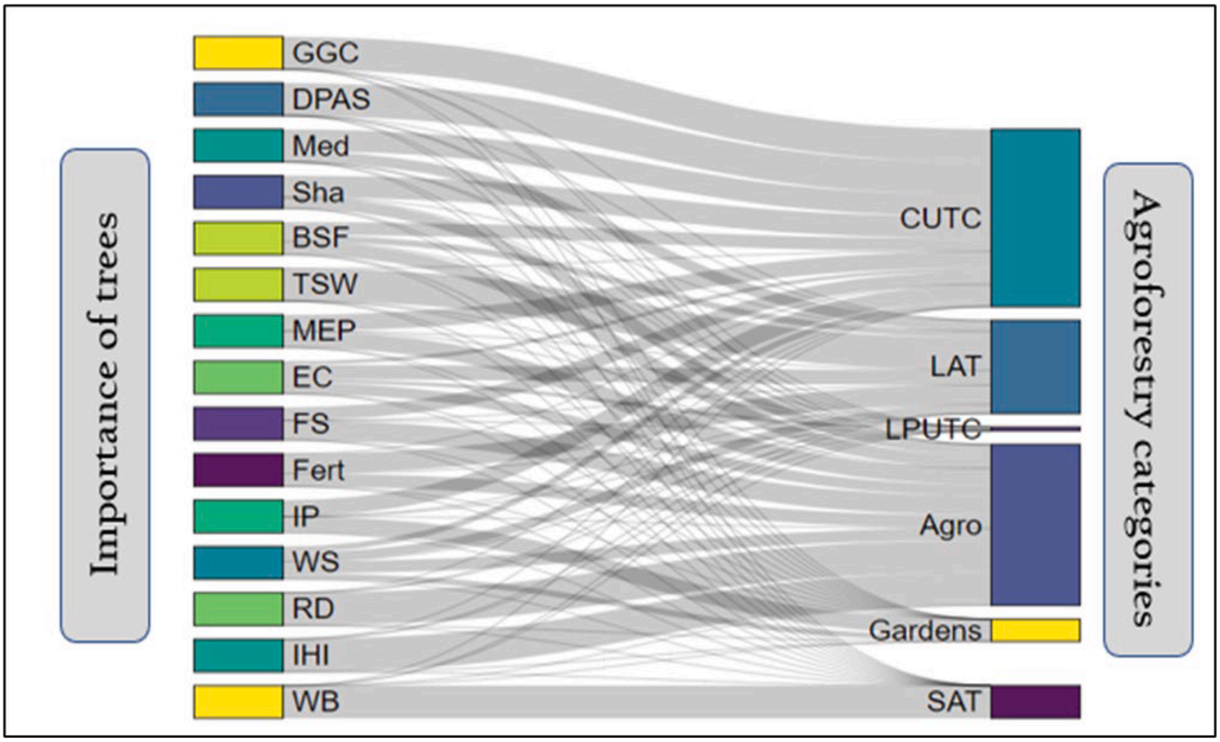

Fig. 3. Categorisation of the agroforestry technologies studied and their importance according to the farmers in each study.
GGC = Good growth of crops; DPAS = diversification of plant and animal species; Med = medicinal; Sha = shading; BSF = biomass as source of fodder; TSW = trees smother weeds; MEP = minimize environmental pollution; EC = erosion control; FS = food source; Fert = fertilizer; IP = improve productivity; WS = wood supply"; RD = reduction of deforestation; IHI = increase household income; WB = wind break; CUTC = crops under tree cover; LAT = linear agroforestry techniques; LPUTO = livestock production under tree cover; Agro = agroforestry; Gardens = home gardens; SAT = sequential agroforestry techniques.

3.4. Strategies for promoting large-scale adoption of agroforestry technologies in Africa

For each of the priority constraints identified above, the studies consulted for this review identified several approaches specific to each constraint (Table 5). These approaches highlight the need for key actors in agroforestry sector, such as policy makers and agricultural extension agents and researchers, to review their strategies for developing and promoting the technologies.

4. Discussion

In recent years, the search for solutions to sustainable agriculture has globally led to an explosion in the development and diffusion of agroforestry technologies, especially in Africa. However, trends in the adoption and use of these technologies in Africa are not necessarily commensurate with the efforts made to develop and diffuse them. Through literature analysis, this study aimed to examine the reasons for the limited and non-intensified use of agroforestry technologies in Africa.

The spatial-temporal trend of publications on the adoption of agroforestry technologies in Africa reveals a renewed interest of scientists in this field between 2020 and 2022. This reflects a progressive awareness of environmental, social and economic challenges in conventional agricultural practices specifically during this period (Tilman et al., 2011; Norfolk et al., 2013). Agroforestry technologies, as an integrated and sustainable approach (Borges et al., 2020; Gomes et al., 2020; Sabino et al., 2022), have generated growing interest from leaders and key stakeholders in the agricultural and sustainable development sectors as a potential solution to these challenges. A regional analysis of the extent of publication on the African continent reveals a dominance of studies in four African regions, with a particularly large concentration of studies in East Africa, followed by the West Africa, South Africa and finally Central Africa. The geographical distribution of studies may reflect regional priorities and local needs. Regions where agroforestry technology adoption is seen as a strategic priority or where agroforestry technologies face particular agricultural challenges may be more active in research on this topic. This may explain the large number of studies in the East African region, which is one of the regions most exposed to agricultural land scarcity and food insecurity(Mazzucato and Niemeijer, 2001; Chirwa, 2014). In addition, it is important to highlight that the lack of studies in certain regions or countries does not necessarily mean that there are no constraints and barriers to the adoption of agroforestry technologies in these regions. Thus, may be simply due to the differences in research priorities or because some regions have not yet recognised the importance of agroforestry technologies or identified these practices as potential solutions to their agricultural challenges. Similarly, it is possible that some regions where the said technologies are present and even experiencing difficulties with adoption face research capacity constraints, including limited resources, restricted access to funding or the lack of expertise in agroforestry technologies. This may contribute to the lack of research in these regions. Moreover, restrictive agricultural policies or inappropriate regulations may hinder agroforestry research in certain areas.

An analysis of the empirical methods used in studies reveals a wide range of empirical methods employed in different studies, depending on the research objectives and contexts. Most studies (53.7 %) focused on identifying the factors and challenges associated with technology adoption using mixed methods and advanced statistical techniques such as binary logistic regression. However, 26.8 % of the studies assessed adoption trends, mainly using descriptive statistics and modelling with longitudinal data. Further, 26.8 % and 12.2 % of the studies examined farmers' perceptions of socio-economic benefits and motivations using descriptive and mixed methods. Finally, the last group of studies were

Table 3
Percentage of no adoption/abandoned.

Country	Regions	Authors	Proportion of no adoption%	Proportion of abandoned%
Ghana	West Africa	Kaba et al., 2020	57.17	NA
Ethiopia	East Africa	Urgessa Waktola and Fekadu, 2021	32.50	NA
Senegal	West Africa	Camara et al., 2021	77	NA
Ethiopia	East Africa	Tafere and Nigussie, 2018	50	NA
Congo	Central Africa	Etshekape et al., 2018	16.10	NA
Ethiopia	East Africa	Beyene et al., 2019	72.68	NA
Nigeria	West Africa	Adesina and Chianu, 2002	NA	46.80
Tanzania	East Africa	Matata et al., 2010	45	NA
Tanzania	East Africa	Kiyani et al., 2017	Included intentionally in the sample	NA
Zimbabwe	South Africa	Chitakira and Torquebiau, 2010	NA	NA
Nigeria	West Africa	Owombo and Idumah, 2017	32	NA
Southern Africa	South Africa	Mwase et al., 2015	33.72	NA
Cameroon	Central Africa	Alemagi et al., 2015	15	NA
Zambia	South Africa	Keil et al., 2005	25	NA
Mali	West Africa	Ouédraogo et al., 2019	16	NA
Malawi	East Africa	Ajayi, 2007	Included intentionally in the sample	NA
Senegal	West Africa	Karambiri et al., 2023	NA	NA
Ethiopia	East Africa	Sisay et al., 2023	54	NA
Cote d'Ivoire	West Africa	Kouassi et al., 2021	5.31	NA
Kenya	East Africa	Kinyili et al., 2021	18	NA
Malawi	East Africa	Toth et al., 2017b	NA	NA
Ghana	West Africa	Acheampong et al., 2016	NA	NA
Malawi	East Africa	Toth et al., 2017a	NA	NA
Uganda	East Africa	Ntakimanye et al., 2021	Included intentionally in the sample	NA
Kenya	East Africa	Kiptot et al., 2007	35	39
Nigeria	West Africa	Saliu et al., 2015	NA	NA
Kenya	East Africa	Pello et al., 2021	Included intentionally in the sample	NA
South Africa	South Africa	Zaca et al., 2023	NA	NA
Cameroon	Central Africa	Nkamleu and Manyong, 2005	42.22	NA
South Africa	South Africa	Zerihun et al., 2014	28	NA
Rwanda	East Africa	Kiyani et al., 2017	41.50	NA
Rwanda	East Africa	Umuhoza et al., 2023	NA	NA
Ethiopia	East Africa	Horamo et al., 2020	69	NA
Zambia	South Africa	Kabwe et al., 2009	NA	NA
Rwanda	East Africa	Mukundente et al., 2019	Included intentionally in the sample	NA
Nigeria	West Africa	(Alabi et al., 2023)	NA	NA

NA = Not mentioned.

exploratory studies that identified adoption barriers using various qualitative data collection and analysis methods. This review highlights different but complementary approaches to understanding agroforestry technology adoption and emphasises the importance of mixed methods and robust statistical analysis. Thus, the results obtained in the studies using these empirical methods generally indicate a negative trend in the adoption and widespread use of agroforestry technologies in Africa, dominated by a high proportion of abandoned or not adopted technologies in most regions, whatever the technology concerned. This highlights the existing socio-demographic and cultural, financial, institutional and organisational as well as agronomic constraints. However, regional analysis of adoption trends reveals some peculiarities. For example, in addition to non-adoption rates, only the studies conducted in East and West African regions reported dropout rates. This seems to indicate that technology adoption trends vary according to socio-demographic, environmental, economic and political factors in each specific region.

The analysis of the reasons for adoption reveals that farmers were willing to use these technologies because of the tangible benefits linked to the ecosystem services that could be derive directly from these technologies. This seems to reflect the fragile socio-economic situation of most farmers in rural Africa and their constant search for ways to improve their living conditions (Horamo et al., 2020; Zaca et al., 2023). However, the analysis of adoption conditions through constraints shows that farmers have less willingness in using these technologies. Indeed, the analysis of constraints indicates that several constraints of socio-demographic, institutional/organisational, economic and agronomic origin hinder farmers' efforts in adopting these technologies. The ranking of these constraints shows that constraints such as the lack of knowledge and skills, lack of capital, land access problems, lack of seeds and pests were the top five highest rated constraints, with the lack of knowledge and skills at the top of the list. This indicates the importance of the factors associated with these constraints when adopting these technologies. The fact that the lack of knowledge and skills constraint is ranked first is explained by the fact that the acquisition of theoretical and, more importantly, practical knowledge of these technologies by farmers is essential to facilitate their adoption and use. Similarly, these technologies often involve complex interactions between trees, crops, animals and specific ecological dynamics, making it difficult for farmers to understand and manage these interactions, particularly in contexts with limited access to formal education, as is often the case in Africa (Kiyani et al., 2017; Kaba et al., 2020). Farmers' access to clear information about sustainable practices, potential yields, environmental impacts and other benefits and technical skills that allow them to be independent in technology implementation are essential to persuade them for adoption. Therefore, it is necessary to develop policies and measures to facilitate and deepen farmers' knowledge and skills in these technologies. For instance, some studies (Keil et al., 2005;Matata et al., 2010; Alemagi et al., 2015; Beyene et al., 2019; Kaba et al., 2020; Camara et al., 2021; Kinyili et al., 2021;Urgessa Waktola and Fekadu, 2021) recommended raising awareness, educating and training farmers on the technologies and their benefits, improving promotion and extension services, providing technical support, focusing extension efforts specifically on 'very poor' and 'poor' farmers, establishing

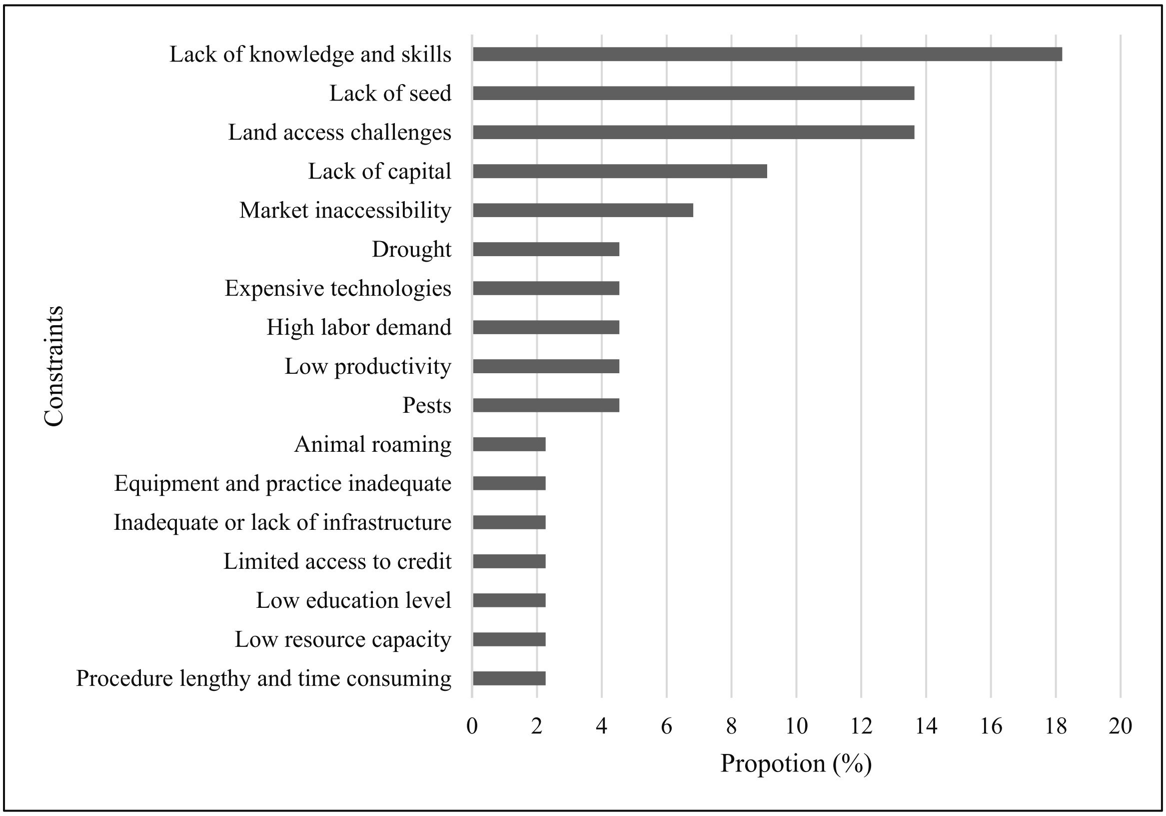

Fig. 4. Main factors of agroforestry technology non-adoption.

agroforestry extension services for small farmers, capacity building and educating farmers on appropriate agroforestry practices. In addition, the 'land access challenges' appear in the top five priority challenges. Without clear property rights and adequate land access, farmers cannot establish and maintain agroforestry systems. Furthermore, in many African countries, land ownership rights are typically the preserve of men, which is an obstacle to the adoption of agroforestry technologies by farmers and women. This constraint is exacerbated by the fact that the benefits of investment often flow back to landowners, discouraging the adoption of agroforestry technologies by those who have access to land through loans or rents (Etshekape et al., 2018). Therefore, improving agricultural tenancy laws, providing land tenure security for agroforestry farmers, introducing other technologies that do not require long-term land and tree rights to female farmers, lobbying for the provision of more secure title deeds or leases and addressing the issue of land tenure and tree ownership are measures that can help to alleviate land-related constraints to the wider adoption of these technologies (Adesina and Chianu, 2002; Beyene et al., 2019; Kaba et al., 2020). With respect to agronomic constraints impeding technology adoption, crop destruction by plant pests is the most cited constraint. Incorrect crop–-tree associations may facilitate the spread of diseases or pest invasions, leading to reduced productivity. Most agroforestry technologies involve planting of different tree species, depending on the technology and context of use. Therefore, access to the seeds or seedlings of these species is a necessary requirement for continued use of these technologies. Moreover, the lack of access or limited access to these seeds, as indicated in priority constraints, is a major obstacle to the abandonment or limited use of these technologies. For example, provision of seedlings, establishment of household nurseries, procurement of seeds from stakeholder institutions and establishment of community satellite nurseries are necessary to facilitate farmers' access to these plant materials and thus wider adoption of these technologies(Etshekape et al., 2018; Ntakimanye et al., 2021). Finally, some agroforestry technologies require significant initial investment in seeds, trees or additional equipment, which is a financial barrier for farmers with limited incomes. As discussed in the main constraints, the lack of capital and resources was a major barrier to the adoption and long-term use of these technologies. Therefore, farmers may choose to continue with traditional farming practices that require low investment costs for agricultural production. Economic policies aimed specifically at providing financial support to farmers using these practices are therefore needed to encourage farmers to continue using these technologies (Kiyani et al., 2017).

5. Conclusion

This review has highlighted numerous modern agroforestry technologies deployed across Africa, accompanied by many constraints categorised into socio-demographic, economic, institutional/organisational and agronomic factors. Among these, significant constraints include pests, the lack of knowledge and skills, lack of capital, challenges in land access and lack of seed. To achieve widespread adoption of agroforestry technologies in Africa, concerted efforts are required, emphasising a participatory approach involving farmers throughout the technology conception and scaling-up stages while considering their specific socio-demographic factors. Developing markets and value chains for non-wood forest products, along with implementing market access policies accessible to all social strata, are imperative. Furthermore, new approaches in agroforestry research should focus on developing appropriate scaling-up and training methods that cater to farmers' specific needs. Given the patriarchal system of Africa, gender sensitivity plays a pivotal role in technology adoption success. Hence, initiatives for scaling-up and developing technology must target women to facilitate access and adoption. Facilitating access to quality seeds and seedlings, credit and land as well as promoting species diversification are vital for the broad adoption of agroforestry technologies in Africa. In conclusion, addressing these constraints and implementing the suggested strategies will be instrumental in fostering the widespread adoption of agroforestry technologies across Africa, contributing to sustainable agricultural

Table 4
Prioritisation of constraints according to each study.

Main constraints or reasons for no adoption/abandonment agroforestry technologies	Categories	Median score	Rank
Lack of knowledge and skills	Socio-demographic and institutional/ organisational	0.39	1
Lack of capital	Socio-demographic	0.32	2
Land access challenges	Socio-demographic and institutional/ organisational	0.29	3
Lack of seed	Institutional/ organisational and agronomics	0.27	4
Pests	Agronomics	0.15	5
Low resource capacity	Economics	0.09	6
Drought	Agronomics	0.09	6
Expensive technologies	Economics	0.09	6
High labour demand	Economics	0.09	6
The lack of or inadequate infrastructure	Institutional/ organisational	0.09	6
Market inaccessibility	Socio-demographic, institutional/ organisational and economics	0.07	11
Low productivity	Agronomics Institutional/ organisational	0.07	11
Limited access to credit	Institutional/ organisational	0.07	11
Lengthy and time-consuming tree use permit procedure	Institutional/ organisational	0.04	14
Equipment and practices inadequate	Institutional/ organisational	0.04	14
Low education levels	Socio-demographic	0.02	16
Animal roaming	Institutional/ organisational and agronomics	0.02	16
N		140	
W de Kendall		0.00678	
Chi-square		4.77***	

*= Significant at the 5 % level.
W de Kendall= The Kendall test associated with the Chi-square test provides an indication of the coherence in the classification of constraints by farmers.
N= total number of constraints.

practices and addressing pressing environmental, social and economic challenges on the continent.

While this study provides important information on the current state of agroforestry technology adoption and associated constraints in Africa, it is important to recognise that it may bear possible limitations. Such limitations can be derived from the use of a string of words and the Boolean operator to structure the search queries, limiting the number of already available original studies that could have broadened the scope of knowledge and subsequent conclusions and suggestions.

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CRediT authorship contribution statement

Marie Reine Jésugnon Houndjo Kpoviwanou: Writing – original draft, Methodology, Formal analysis, Conceptualization. **Bienvenue Nawan Kuiga Sourou:** Writing – review & editing, Visualization, Data curation. **Christine A.I. Nougbodé Ouinsavi:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization.

Table 5
Solutions proposed to address some constraints listed in this review.

Constraints	Solutions	Studies
Lack of knowledge and skills	Sensitisation, education and training for farmers on technologies and their benefits; improving promotion and extension services, technical support and a great share of extension efforts should thus be directed towards 'very poor' and 'poor' farmers, agroforestry extension services for the smallholder farmers, capacity building and education of farmers on the appropriate agroforestry practices	Alemagi et al., 2015; Beyene et al., 2019; Camara et al., 2021; Kaba et al., 2020; Keil et al., 2005; Kinyili et al., 2021; Kouassi et al., 2021; Matata et al., 2010; Ntakimanye et al., 2021; Urgessa Waktola and Fekadu, 2021
Land access challenges	Improved agricultural tenancy law; grant land security, introducing to female farmers other technologies that do not require secure long-term land and tree rights, lobby for the provision of more secure title deeds or leases, addressing the issue of land tenure and tree ownership	Adesina and Chianu, 2002; Beyene et al., 2019; Chitakira and Torquebiau, 2010; Kaba et al., 2020)
Lack of seed	Seedling supply, establishment of household nurseries, procurement of seeds from stakeholder institutions, establishment of community satellite nurseries, establishment of tree planting bylaws, facilitation of access to improved tree materials, availability of agroforestry species	Chitakira and Torquebiau, 2010; Etshekape et al., 2018; Kouassi et al., 2021; Ntakimanye et al., 2021)
Pests	Form buying clubs with fellow farmers to procure pesticides at low cost, seek external support	Chitakira and Torquebiau, 2010b
Low resource capacity/lack of capital	Financial support	Kiyani et al., 2017
Drought	Research is needed for detailed coffee production under irrigation systems	Urgessa Waktola and Kidist Fekadu,20,121
Expensive technologies	Giving cash transfer as incentives in agroforestry adoption, providing incentives, giving subsidies to farmers	Mwase et al., 2015; Tafere and Nigussie.,2018; Etshekape et al.,2018; Kiyani et al.,2017
High labour demand	Research should emphasise methods for reducing labour use	Keil et al.,2004
Market inaccessibility	Improvement of market accessibility, farmers' access to relevant market information, improvement of market accessibility	Kiyani et al., 2017; Alemagi et al.,2014
Low productivity	There should be shade trees that do not grow too big to destroy our cocoa plants when harvesting or felling	Alemagi et al.,2014
Limited access to credit	Improving farmers' access to agricultural credit	Alemagi et al.2014; Chitakira and Torquebiau, 2010; Kinyili et al.,2021; Pello et al., 2021; Sisay et al., 2023

(*continued on next page*)

Table 5 (*continued*)

Constraints	Solutions	Studies
Equipment and practices inadequate	Adapting these technologies to local traditional practices and local agroecology, early rewards from multipurpose tree species	Tafere and Nigussie,2018; Mwase et al.,2015
Low education levels	Researchers should facilitate the process of farmer learning	Adesina and Chianu,2001
Animal roaming	Adopt effective grazing management policies	Camara et al.,2021; Tafere and Nigussie, 2018
Lengthy and time-consuming tree use permit procedure	Simplify and shorten the procedures for making the permit available at the local level, lift all fees related to pruning and felling of FMNR trees, and reduce the distances by increasing the number and distribution of forestry units	Karambiri et al.,2023

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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Data availability

Data will be made available on request.

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