RESEARCH ARTICLE

Assessing the role of fruit tree-based agroforestry in climate change adaptat on: A case study in Sofi district, Harari regional state, Ethiopia

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The article investigates the impact of climate change on agricultural productivity in the Sofi district of Harari regional state, Ethiopia, with a focus on smallholder farmers practicing agroforestry and monoculture. The study aims to understand smallholders' perceptions of climate change, identify climate change indicators, analyze observed climate trends, and explore adaptation strategies. The research employed a mixed-methods approach, combining focus group discussions, semi-structured surveys, key informant interviews, and meteorological data analysis. The study area, Sofi district, was described in terms of geography, climate, geology, soil, and land use. Results indicate that smallholders in Sofi district have observed rising temperatures, decreased rainfall, and increased drought frequency over the last three decades. Smallholder farmers practicing agroforestry are found to be more resilient to climate change impacts compared to monoculture practitioners. The study reveals that farmers perceive frequent droughts, erratic rainfall, shortness of rainy seasons, and temperature increases as significant indicators of climate change. Furthermore, respondents attribute climate change to anthropogenic factors such as deforestation, rapid population growth, and lack of soil and water conservation. Adaptation strategies employed by smallholders include crop diversification, adjusting planting dates, fruit tree-based agroforestry practices, reducing the number of animals kept, compost preparation, and improved animal feed production. Agroforestry practitioners exhibit significant differences in adaptation strategies compared to monoculture practitioners, emphasizing the importance of diverse coping mechanisms. Major constraints faced by farmers include pests and diseases, soil erosion, livestock deaths, crop loss, decreased farm income, and poor soil fertility. The study underscores the role of agroforestry in mitigating these challenges and enhancing smallholders' adaptive capacity. The findings suggest that agroforestry provides shade, fruit for income and consumption, reduces evapotranspiration, and minimizes soil erosion, making it a valuable approach for climate change adaptation. The research implies that promoting agroforestry practices can contribute to sustainable agricultural development and resilience in the face of climate change. Policymakers and agricultural stakeholders should consider supporting and implementing agroforestry initiatives to enhance the adaptive capacity of smallholder farmers in similar contexts.

Key Words: *Land use; Agroforestry; Agriculture; Smallholders livelihoods; Climate change; Adapation; Mitigation*

INTRODUCTION

Agricultural productivity is significantly impacted by climate, as the agricultural sector is both a contributor to and a victim of climate change. According to Khan et al., the agricultural sector is responsible for 16-27 percent of global greenhouse gas emissions and contributes to freshwater pollution, soil degradation, and loss of biodiversity. Climate change has resulted in rising challenges for the sector, including heat stress, water scarcity during crucial periods, and increased infections, all of which are linked to the continued strain on land, soils, and water supplies [1-2]. Without a technological transition, agronomic research predicts a significant decline in yields for most African crops [3]. Africa's reliance on rain-fed agriculture makes it particularly vulnerable to climate change, which is exacerbated by poverty and inadequate financial and systemic capacity.

This has led to a decrease in agricultural productivity and yields, putting food security at risk and increasing the likelihood of hunger [4]. Rural farmers in Sub-Saharan Africa are particularly vulnerable to the effects of climate change due to poverty, a lack of infrastructure and technology, and a heavy dependence on rainfed agriculture [5]. Rain-fed agriculture accounts for over 95 percent of agricultural production in Sub-Saharan Africa, and climate projections suggest that the continent will experience significant climate shifts [6]. Additionally, deforestation has made it more difficult for communities to access fruits, nuts, and other edible non-timber forest products that they once relied on to supplement their diets, with estimates suggesting that Africa loses 3.4 million hectares of forest each year [7]. Understanding climate change and variability is crucial for smallholder farmers, who are among the most vulnerable and marginalized groups in the world [8]. Climate change models predict that rain-fed farmers in the Third World, particularly small farmers, will be disproportionately affected, with yields from rain-fed agriculture potentially declining by up to 50 percent in some African nations by 2020 [9]. To effectively mitigate the adverse effects of climate change, a deeper understanding of the local aspects of climate change is necessary. Understanding the potential benefits of adaptation is crucial, particularly with respect to smallholder farmers' perceptions of climate change and its impact on local agriculture age, education level, livestock rearing, access to climate information, and extension services significantly influenced perception levels [10]. Ethiopia is highly vulnerable to climate change, experiencing droughts and floods, which are projected to have severe negative implications for the environment, water resources, crops and livestock, human health, and other farming livelihoods [11]. Ethiopia is a developing country with a high rate of food insecurity [12]. Agroforestry adoption depends on various management goals, drivers, and context variables. The primary drivers for agroforestry adoption are typically assets linked to ecosystem services and food security. However, agroforestry adoption has not been widespread in many parts of Ethiopia due to various reasons related to agro-ecological, socio-economic, and climate factors or farmers' awareness of planting multi-purpose trees on their farmland [13]. In the Harari region, unpredictable climate change factors, such as long droughts and severe flooding, lead to frequent total yield drops in crops, putting smallholder farmers at risk of food insecurity. Drought also causes livestock death, limiting the potential for other forms of resilience and increasing stress on fragile farming systems. Therefore, an adaptation strategy is critical to minimizing the impact of climate change on smallholder farmers. Smallholder farmers can interpret and adjust to climate change across social, economic, technical, and environmental trends.

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Awareness of the adaptation process and factors that shape farmers' choice of adaptation strategies can enhance efforts to address the effects of climate change [14]. Therefore, in the selected district for this study, it is crucial to formulate adaptation strategies that can maximize productivity and resilience and minimize costs, leading to sustainable agricultural development (Figure 1).

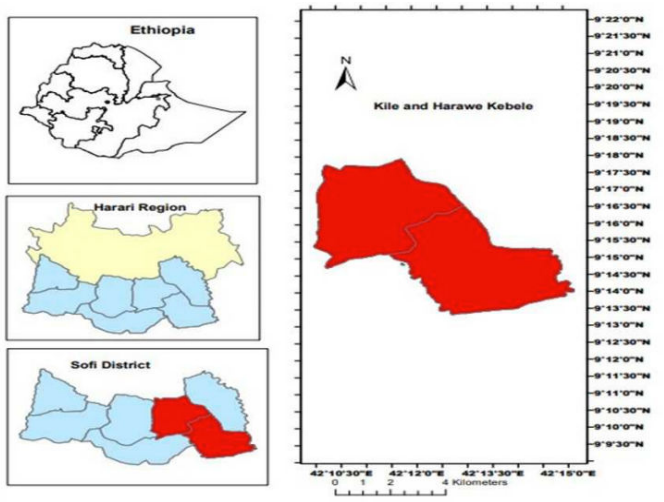

Figure1) *Location map of the study area in Sofi district*

MATERIALS AND METHODS

Description of the study area

Geographical location: This research was conducted in Sofi district of Harari regional state which is one of the upstream micro-watersheds of the Wabi Shebelle river basin [15]. Sofi district is located between 090 21'0" N to 090 9' 30" N and 420 11' 0" E to 420 15' 0" E, with an elevation range of 800–2920 meters above sea level (m.a.s.l). Sofi lies in the South-Western part of Harari regional state in the Southern edge of the South-Eastern plateau dividing the Great Rift Valley from the plains of the Ogaden lowlands.

Climate: The average annual temperature ranges from 10°C on high lands and 26°Con low lands. The mean annual maximum temperature of the area is 22°C in high land and 28°C in low land. In Sofi district, the rainfall ranges from 850 mm to 870 mm bi-modal with peaks in April and August [16].

Geology: According to the geological map of Ethiopia, first published in 1973 and edited in 1996 at a scale of 1:2000,000, the geology of the Harari region is dominantly covered by Adigrat formation constituted by sandstones and the Hamanlei formation that contains Oxfordian limestone and shale formed during the early Triassic to middle Jurassic periods [17]. The Harari highlands, on the other hand, appear to be built on the crystalline bedrock of the prehistoric Gondwana continent, which was later broken, according to Mohr. The geomorphology of the site is defined by a gently sloping landform at the western face of Abubekehre hill draining to the easterly direction. The site is relatively gently sloping to the north and covered with mango trees and shrubs [18].

Soil: The major soil types of the Harari region include Nitisols, Luvisols, Arnosols, Aerosols, and nitsols (distinguished by their shiny pad surface) occupy 2792.5 ha and luvisols (soils which have Cation Exchange Capacity (CEC) equal to or greater than 24 mol clay) occupy 2440 hectare. Regosols (medium and fine-textured) occupy 6,017.5 hectares and Aerosols (coarse-textured with weak pedo-genetic characteristics in the B-horizon) occupy 4575 hectares. The major soil types, which occur in Sofi, are the limestone plateau with limestone hills to the east, Vertisols on a plateau, and lithosols on hills. The site is covered with a reddish clay residual soil of thickness ranging from 2 to 4 meters above the weathered limestone, gypsum–marl interlaying Bezu et al.

Land use: Agriculture is a fundamental practice in providing adequate food to the needy Harari. Land uses of Sofi are intensive rain-fed crop cultivation, small farm forestry, and extensive grazing on hills [19]. The major staple food crops include sorghum, maize, horticultural crops, etc. There is no specialization in the production of specific crops [20].

Sampling design and research design

Collection of data on smallholder perceptions of climate change: To gather data on smallholders' perceptions of climate change, two representative kebeles and cluster villages were purposively selected based on their intensity and potential for fruit tree-based agroforestry practices and adjacent monoculture. The households were then categorized as either agroforestry practitioners or non-practitioners, and further classified as poor, medium, or better-off wealthy class using KA and KI. Key informants were selected using a snowball approach and given a wealth ranking by smallholders. A random sample of 15 percent of households from each class was selected for qualitative data collection, with 52 monoculture smallholders and 50 agroforestry smallholders participating. Focus group discussions and semi-structured surveys were used to collect data on smallholders' perceptions of climate change. Six focus group discussions were conducted on members of different age, gender, and educational levels, with the main focus on understanding respondents' long-term observations of climate-related characteristics. Structured interviews were also conducted to gather information on household histories, resources, expenditures, and incomes. Key informant interviews were done to triangulate with smallholders' views on fruit tree-based agroforestry and monoculture agricultural practices for climate adaptations. Additionally, six focus group discussions led by a skilled moderator were conducted with randomly selected members from the Kebele administrative, elders, women, different age groups, smallholders, and development agents, with discussions initiated by questions about farmers' livelihood assets identified during household and key informant interviews. The focus group discussions were led by a skilled moderator and involved members of different age, gender, and educational levels. The discussions covered topics such as farmers' livelihood assets and perceptions of long-term shifts in climate-related characteristics. Farmers' comprehension of climate change was defined as their aggregated knowledge of climate patterns, such as rainfall and temperature. The main objective of the study was to understand smallholders' perceptions of climate change and their adoption of fruit tree-based agroforestry as a climate adaptation strategy. Therefore, the interviews and focus group discussions were designed to elicit information on farmers' personal histories, household resources, major expenditures, and main source of annual incomes.

Overall, the methodology used in this study aimed to gather qualitative data from a diverse group of smallholders and key informants to gain a comprehensive understanding of their perceptions and practices related to climate change adaptation.

RESULTS AND DISCUSSION

On-farm tree management in Sofi district

In the Sof district, the agroforestry and monoculture systems included a variety of species such as *Citrus limon, Catha edulis, Mangifera indica, Moringa oleifera, Caricia papaya, Cajanus cajan, Ficus vasta, Grevillea robusta, Pennisetum purpureum, Psidium guajava, Ziziphus mauritiana, Arachis hypogaea, Sesamum indicum*, and *Zea mays*. A total of 15 tree and crop species were found in both systems. *Mangifera indica* (173 individuals) was the most common tree species, followed by *Carica papaya* (112 individuals) and *Psidium guajava* (78 individuals). This dominance of certain species can be attributed to the preference of households for high-value fruit tree species. In a similar study conducted in the Dale District of Sidama region, *Musa acuminata*, *Mangifera indica*, and Persea Americana were the most frequently recorded fruit tree species compared to other fruit tree species. The least common tree species recorded in the study were *Ficus vasta* Forssk. (6 individuals) and *Ziziphus mauritiana* Lam. Indian jujube (12 individuals). Compared to an earlier report by Lengkeek et al., from Meru, Kenya, where the average number of species per farm was 54, ranging from 7 to 24, the current study's result showed a lower value.

Trends in climate change at Sofi district

Perceived trend in climate change: In the last three decades, most farmers in Sofi District have observed a prolonged dry spell and recurrent drought, along with rising temperatures and decreasing rainfall. A staggering 93 percent of respondents agreed that temperature has increased, while 94 percent perceived a decline in rainfall with unpredictable patterns (Figure 2). This aligns with the global concern of climate change. Smallholders in Sofi district have received ample climate information, and their product and productivity have been influenced by the changing climate, leading to their perception of climate change. Difficulties like heat stress, water scarcity, and diseases have had an adverse impact on agriculture and forestry, as noted by Legesse and Drake, Hernandez-Morcillo et al.

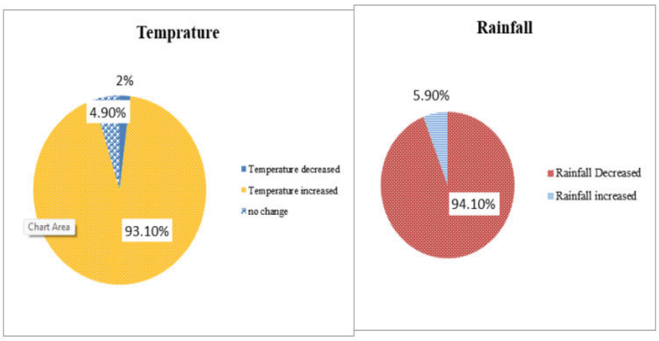

Figure 2) *Perceptions of respondents on the trend of temperature and rainfall change at Sofi district over the last three decades (1991-2020)*

Observed trend in climate change: Meteorological data collected from Sofi district over the last 30 years showed variations in average rainfall, with inadequate averages in 1994 (621 mm) and 2012 (613 mm) and sufficient averages in 1996 (1147.8 mm) and 2018 (1089 mm). The coldest years were 2015 (26.84°C) and 2016 (27.3°C), while the hottest years were 2019 (30.0° C) and 1998 (29.45°C) (Figure 3). The farmers' perception of climate change over the previous three decades aligned with the historical patterns in meteorological data, with year-to-year variances suggesting unpredictability in rainfall or drought. The average air temperature increased by 0.40°C (Figure 4) over the last three decades, indicating significant change while Asare-Nuamah and Botchway revealed no significant relationship between farmers' perceptions and climate data for rainfall showed that rural farmers' perceptions of climate change and variability were consistent with climatic trend analyses. However, this study found that temperature trends were consistent, while the rainfall average was not also noted that smallholders' perceptions were not entirely supported by meteorological data, indicating fluctuations in rainfall onset or offset. Conversely, rainfall was consistent with the perceptions of Simelton et al., Asare-Nuamah and Botchway, Batisani and Yarnal, Akinyemi.

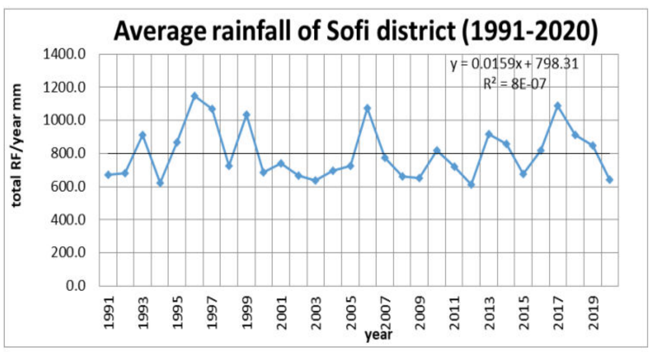

Figure 3) *Average yearly received rainfall (mm) at Sofi district (1991-2020)*

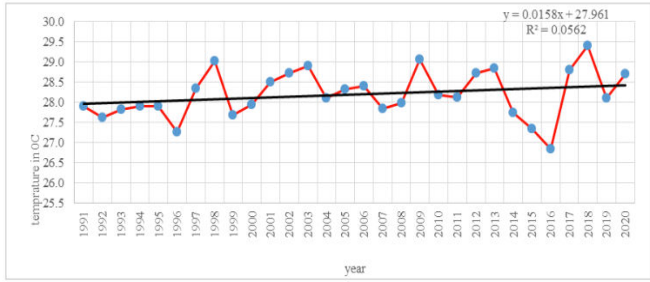

Figure 4) *Observed average annual air temperature (1991-2020) at Sofi district*

Perception of smallholders on climate change at Sofi district

Respondent's perception on indicators: Smallholders in Sofi district have relied on their own observations and experiences to identify the indicators of climate change. The majority of respondents (93.9 percent) perceived frequent droughts as the most common indicator of climate change in the area over the last three decades. Other common indicators include erratic rainfall (98 percent), shortness of rainfall (92.1 percent), shortness of rainy season (65.7percent), and increase in temperature (70.6 percent) (Figure 5). These findings are consistent with similar studies by Asare-Nuamah and Botchway, which found that smallholders identified excessive lightning, changes in rainfall season length, and frequent droughts as the most common indicators of climate change.

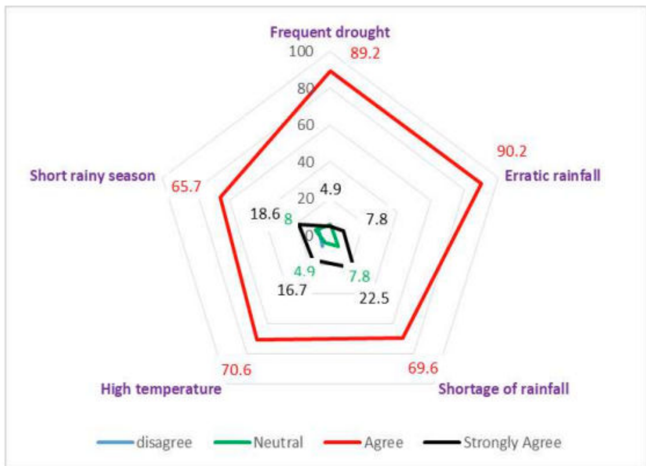

Figure 5) *Percent of respondents and their perception on climate change indicators at Sofi district*

Respondent's perception on causes of climate change: The reasons for climate change identified by the farmers were dominated by anthropogenic factors. The majority of respondents agreed that increased deforestation, rapid population growth, invasive species, and lack of soil and water conservation were the major causes of climate change, with agreement levels ranging from 82.4 percent to 88.2 percent. Other reasons cited included reduced livestock production, decrease in forest resources, income decline, and high food costs, increased flooding, and decline in crop yield. These reasons are most likely due to the fact that smallholders in the area rely on rain-fed agriculture, and even small changes in weather patterns can greatly impact their production systems. This finding is consistent with a similar study by Tesfahunegn et al., in which Ethiopian farmers also identified deforestation and soil degradation as major causes of climate change.

The perception of climate change impacts among smallholders in Sofi district: Smallholder farmers in Sofi district perceive the impacts of climate change differently, and their adaptation tactics also vary. Farmers who practice monoculture agriculture reported that climate change has had a significant influence on their production system (78.8 percent), while farmers who practice agroforestry reported that the impacts are manageable (70.6 percent) or have multiple effects (54.3 percent) (Figure 6). The majority of smallholders in Sofi district rely on rain-fed agriculture, and they tend to cite the negative effects of climate change more than the opportunities it presents. Even minor deviations from normal weather patterns can have a direct impact on their livelihoods, affecting their agricultural products and productivity. The *Chi-square* test was used to examine the relationship between the effects of climate change on smallholders practicing agroforestry and those practicing monoculture. The results revealed a significant relationship between agroforestry and monoculture and the level of effects from climate change (extreme effects, manageable effects, and multiple effects). The findings showed that monoculture smallholders are significantly more affected by climate change than agroforestry smallholders, while agroforestry smallholders are only moderately affected. Most farmers perceive floods as devastating, but a small percentage harvest floodwaters to use for irrigation during the dry season. According to the respondents, 40 percent of them collect floodwater for irrigation, while only 8.8 percent believe that floods improve groundwater. Additionally, only 2 percent of farmers believe that storms increase water production.

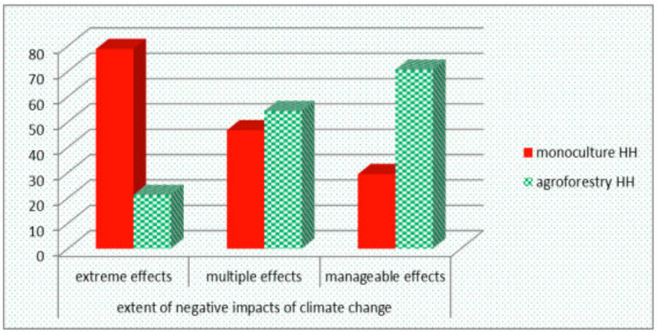

Figure 6) *Main negative effects of climate change*

Adaptation strategies of Sofi district smallholder farmers

Strategies crop diversification (82.2 percent) and reducing the number of animals (87.1 percent) were found to be common adaptation practices among farmers of both land uses. In addition, compost preparation (68.3 percent), improved animal feeds (61.4 percent), and fruit tree-based agroforestry (49.5 percent) were identified as the primary coping mechanisms specifically used by agroforestry practitioners. Smallholder farmers employed a variety of approaches simultaneously to enhance their resilience to climate change, and these strategies varied by region and system. According to Cooper, adopting various coping mechanisms is necessary for farmers to remain resilient in the face of present climate change. Similarly, Koohafkan et al. suggested that agroforestry is a sustainable way to intensify farming practices to improve food security through socially and cost-effective management techniques.

A *Chi-square* analysis indicated a significant difference in the adaptation strategies used by agroforestry practicing smallholder farmers, such as planting trees, livestock diversification, planting high-value fruit trees, and improved animal feed production, compared to monoculture-practicing smallholder farmers who mostly apply drought tolerant crop varieties. However, no significant difference was found in other practices such as crop diversification, adjusting planting dates, reducing the number of animals kept, and compost preparation, which was commonly, used strategies by both agroforestry and monoculture-practicing smallholder farmers.

Major constraints facing farmers

Farmers in the Sofi district encounter various constraints, with pests and diseases being the most prevalent for both agroforestry and monoculture smallholders. Monoculture farmers face additional challenges such as soil erosion, livestock deaths from drought, crop loss from drought, decreased farm income, and poor soil fertility. Agroforestry farmers are better equipped to deal with these constraints. Figure 7 highlights other significant constraints that farmers in Sofi district face besides climate change-related issues. Agroforestry has been proven to enhance livelihoods, boost production, reduce malnutrition, and adapt to anthropogenic climate change, as evidenced in studies such as Udawatta et al., Carsan et al. Agroforestry has shown to minimize soil water content during critical periods, produce fruit and building materials, and adjust to anthropogenic climate change.

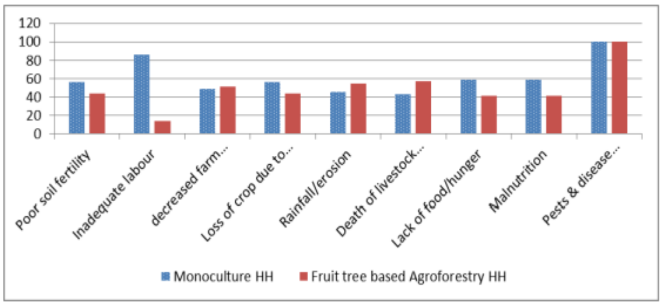

Figure 7) *Major constraints other than climate change-related to farmers in Sofi district*

The *Chi-square* test examined the relationship between agricultural practices (agroforestry and monoculture) and the constraints faced by smallholder farmers due to climate change. The test indicated a connection between agricultural practice and smallholder farmers experiencing challenges such as soil erosion, livestock deaths due to drought, crop loss due to drought, decreased farm income, and poor soil fertility.

Perception of respondents on drought and erosion management: The survey asked the respondents about their perception of changes in flood and drought frequency and severity over the past 30 years to understand the relationship between agroforestry and these natural disasters. The top benefits of agroforestry during both drought and floods were shade, fruit for income and household consumption, reducing evapotranspiration from farms, and reducing soil erosion disaster. The respondents identified *Mangifera indica*, *Carica papaya*, and other fruit trees as the most important tree species during drought, as they provide a wide range of benefits, including most sources of income and food. Agroforestry played an essential role in reducing the risk during drought and high erosion events by improving environmental conditions and increasing adaptive capacity by providing tree products and financial benefits. It allows smallholder farmers to diversify their production methods while also improving sustainability. Studies by Thorlakson and Neufeldt in western Kenya and Paudel et al., in Nepal reported similar findings, where agroforestry reduced food insecurity by 25 percent and was rated as very important during drought, respectively (Figure 8).

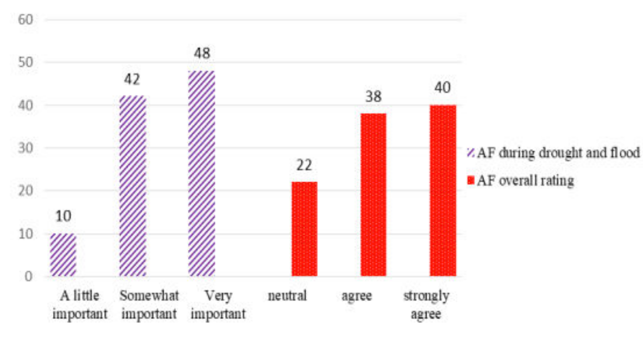

Figure 8) *Respondents' evaluation and rating of agroforestry by sofi smallholders*

CONCLUSION

During floods and droughts, the majority of respondents evaluated agroforestry as extremely significant, while 42 percent ranked it as somewhat important, showing that agroforestry approaches are rated higher than monoculture practices for climate change adaptation. Around 40 percent of smallholders believed that agroforestry systems provide excellent shade during climate change extremes, and 38 percent agreed that agroforestry is an important component during these extreme events.

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