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Socio-Ecological Niche and Factors Affecting Agroforestry Practice Adoption in Different Agroecologies of Southern Tigray, Ethiopia

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Received: 15 June 2019; Accepted: 3 July 2019; Published: 8 July 2019

Abstract: This study was carried out in the southern zone of Tigray to identify and characterize traditional common agroforestry practices and understand the existing knowledge of farm households on the management of trees under different agroforestry in different agroecologies. We conducted reconnaissance and diagnostic surveys by systematically and randomly selecting 147 farming households in the three agroecologies of the study area. A logit regression model was employed to determine how these factors influence farmers' adoption decision. The findings indicate that a majority of the households (46.3%) were engaged in homestead agroforestry practices (AFP), followed by live fence (25.9%) and farmland or parkland (15%) agroforestry practices. The study identified *Carica papaya, Malus domestic, Persea americana, Mangifera indica, Ziziphus spina-christi*, and *Balanites aegyptiaca* as the most dominant fruit tree species found in the home garden agroforestry. In total, 68% of the households had some of these fruit trees around their home gardens. We also established the three most dominant agricultural production systems as: i) Agricultural production system, composed of fruit tree + cereal crops + *Ziziphus spina-christi* + *Balanites aegyptiaca* and/or *acacia* species; ii) agricultural production system, consisting of cash crops, like *Coffee arabica* and *Catha edulies* + fruit trees + *Cordia africana* + *Balanites aegyptiaca* and/or *acacia* species; and iii) agricultural production, composed of fruit trees + vegetables within a boundary of *Sesbania sesban* and other *acacia* species in the modern irrigated land. Furthermore, 90.16% of the households in the highlands reported a shortage of farmland for planting trees as the main constraint. About 34.44% farmers reported using leaves of *Cordia africana, Balanites aegyptiaca*, pods of *acacia* species, and crop residue as the main source of animal fodder. In total, 86.4% of the households also recognized the importance of multipurpose trees for soil fertility enhancement, control of runoff, microclimate amelioration, environmental protection, and dry season animal fodder. According to the logit model analysis, sex, family size, educational level, and landholding significantly ($p < 0.05$) influence the household's role in the adoption of agroforestry practices. Based on these findings, farmers used different adaptation strategies, such as planting of multi-purpose trees (34.7%), conservation tillage to minimize both erosion and runoff potentials as soil conservation strategies (27.2%), varying planting dates, use of drought tolerant crop varieties (16.3%), and others based on farmers' indigenous knowledge passed down from generation to generation. We conclude that agroforestry practices are important components of farming systems in Tigray, resulting in diversified products and ecological benefits that improve socio-ecological resilience. Therefore, we recommend that agroforestry practices are mainstreamed into development plans, especially in agriculture.

Keywords: agroforestry; cash crops; fruit trees; indigenous knowledge; home garden

1. Introduction

Land degradation implies a reduction or loss in arid, semiarid, and dry sub-humid areas of biological or economic productivity of land, usually resulting from land use cover change (LUCC) or processes arising from anthropogenic activities, such as soil erosion caused by long-term deterioration of natural vegetation [1]. The Ethiopian highlands constitute a large part of the Afromontane region, which is one of the biodiversity hotspots in Africa [2,3] and stretches from Cameroon to eastern Africa [2]. Human activities, such as overgrazing, large- and small-scale mining, deforestation, cultivation on steep slopes, rapid population growth, and clearing of vegetation, are playing increasingly important roles in changing environments, causing unprecedented land degradation and depletion of natural resources [1,3]. Such severe land degradation affects the livelihood of many farmers in the highlands and lowlands of northern Ethiopia [4–7]. An agroforestry and ecosystem-based approach to natural resource management presents itself as an effective strategy to resolve such a conflicting situation. By intercropping trees and woody perennials with crops on farms and rangelands, agroforestry diversifies and sustains production for increased socio-economic and environmental benefits for land users at all levels [8–11]. Consequently, agroforestry, therefore, offers proven potentials for increasing farm production and income [10,11] and as such are commonly used in poverty reduction strategies in the tropical east African countries [12]. Agroforestry is increasingly being used to reduce resources use conflicts between arable farming, livestock rearing, and forestry interests, especially in human-dominated landscapes with high population pressure [13]. Due to their socio-environmental benefits, a variety of agroforestry technologies are finding enormous application in the east and central African regions [12]. The application of appropriate agroforestry practices/systems is determined mainly by agroecological diversity [14].

In Ethiopia, there are location specific agroforestry practices, such as home garden, parkland and cash crop-based alley cropping agroforestry practice [14], and woodlots at the edge of crop fields. Furthermore, there are also fruit tree-based agroforestry practices [14]. In the drylands of northern Ethiopia, there are a number of indigenous agroforestry systems involving agri-silvi-cultural, silvo-pastoral, and agro-silvo-pastoral systems, which have trees, shrubs, agricultural crops (mainly cereals), and livestock as components in a mixed pattern [15].

Southern Tigray is characterized by high population pressure, scarcity of arable and grazing land, and low moisture [16]. High demand for land coupled with existing pressure on the available land is progressively narrowing farmers' agro-economic decisions and forcing part of them to encroach and cultivate on previously unused marginal or pastoral grazing lowland areas [17]. Farmers responded to this pressure by introducing high-value tree-based farming systems [18]. Despite its successes, including alleviating farm poverty, achieving environmental protection through reduced soil erosion, and mitigating climate change, very little research has been conducted specifically to ascertain the role of agroforestry practices in income diversification in southern Tigray.

Existing research efforts [19,20] center around agroforestry technology evaluation [19,20], and traditional agroforestry practices [21]; agroforestry and biodiversity conservation [22–24]; and others, like on farmers' perception and knowledge [25,26]. However, there are few or no studies that investigate the role of agroforestry in different agroecological systems (or zones) specifically to describe socio-ecological niche factors that affect agroforestry practices and income diversification in southern Tigray. Therefore, this research aimed to investigate the socio-ecological niche factors that affect agroforestry practices, and farm income diversification's role of this land use system in southern Tigray, Ethiopia. In particular, our study: Identifies and characterizes traditional agroforestry practices in the various agroecologies; assesses and compares the social, economic, and ecological roles of the major competing land uses within the agroforestry land use systems; identifies the factors affecting agroforestry practices by households in the area and examines the extent of adoption of agroforestry practices in the study area. The findings of our research are expected to generate policy recommendations to improve the existing agroforestry practices and reduce conflicts over resources use.

2. Materials and Methods

2.1. Descriptions of the Study Area

The study was carried out in three woreda's of southern Tigray Ethiopia (Figure 1). The study area lies between latitude 39o 10′E to 40 o 02′ 34.08″ E and longitude 12°53′29.76″ N to 12°15′2.88″ N. The minimum mean annual temperature of the study area is 12 °C at Ofla and Endamohini woredas and 18 °C at Raya Azebo woreda. While the mean annual rainfall ranges between 350 mm at the low land of Raya Azebo and 1000 mm at the highland and midland of Endamohoni and Ofla woredas. The major agricultural activity in the area is a mixed farming system, which involves both the growing of crops and livestock raising. The dominant food crops grown in the study areas are teff (*Eragrostis tef*); sorghum (*Sorghum bicolor*); barley (*Hordeum vulgare*); wheat (*Triticum aestivum*); maize (*Zea mays*); millet (*eleusine coracana*, etc.); and pulses, such as pea (*Pisum sativum*) and chickpea (*Cicer arietinum*). While high-value tree crops, such as *Mangifera indica, Percea Americana, Papaya crack*, and *Psidium guajava* (Guava) in the lowland and *Malus pumila* (domestica apple) in the highlands of Endamohoni and Ofla woredas are produced in large quantities. Livestock keeping is an ancient tradition of the Ethiopian rural farming community. Major livestock reared in the zone include cattle, sheep, goats, and equines, such as donkeys, horses, mules, and camels. In Ethiopia, especially Southern Tigray, livestock is an essential component of the overall farming systems, serving as a source of draught power and forming an integrative linkage between crop and livestock production systems mainly in the highland regions. In addition, livestock supply farm families with milk, meat, manure, and serve as an immediate source of cash income of the farmers on the study area. The specific cattle breed in Southern Tigray are Sanga cattle. However, nowadays, specifically on the Southern Tigray, due to high human population growth, cereal production areas have encroached into pasture lands and range areas, frequent drought occurrence, deceased grazing land, and higher feed costs, have forced farmers to keep a smaller number of cattle in the area. Consequently, available grazing and fodder production areas have declined over the last two decades. Currently, in the highland and lowland farming systems, feed shortages both in quantity and quality become acute during the dry seasons. The available feeds do not meet the nutritional requirements (milk production, growth, and maintenance) of the milk producing animals. The cultivation of more productive fodder crops is not widely adopted, and commercial feed production is not well developed. Although the area was a potential of the Sanga cattle varieties, nowadays, farmers experience a lot of challenges to feeding their livestock and are forced to decrease the number of livestock. The major factors are the increased population pressure, increased deforestation rate for the expansion of agricultural land, and the frequent drought occurrence, which are some of the main reasons leading to the dramatically decreasing livestock population and number of households with a large number of cattle. As such, farmers suffer increased feed costs and decreased sale prices.

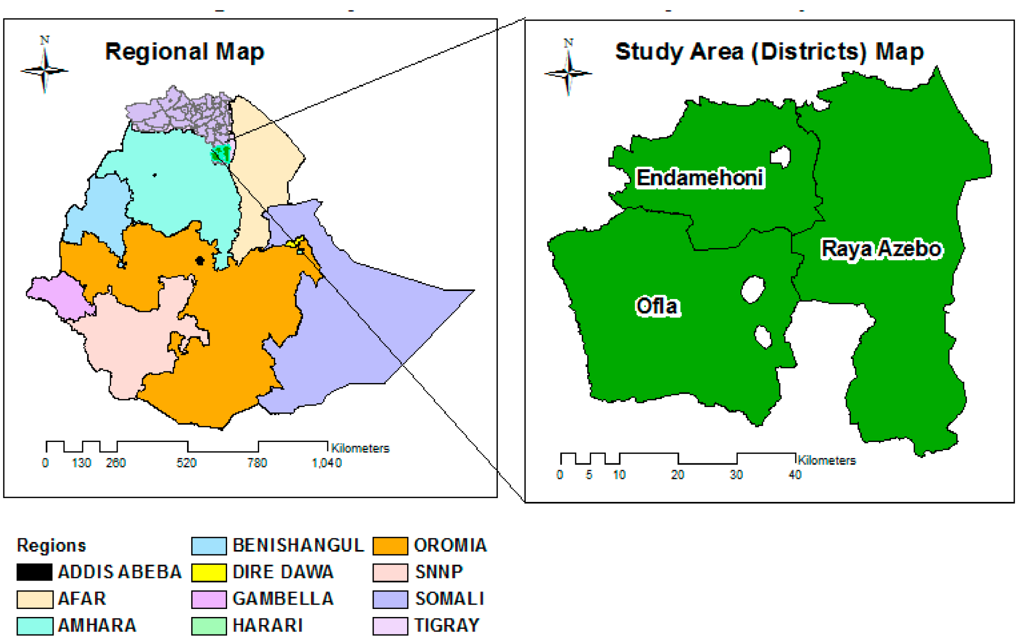


Figure 1. Study area map.

2.2. Methods

Indigenous agroforestry practices in the low, mid, and highlands of southern Tigray were studied using the following approaches. Secondary information was collected from reports, maps, censuses, theses, and other publications to gain an overall picture of the agroecologies. The specific sites for the study were identified in collaboration with a multidisciplinary research team, local people, and administrative bodies.

Reconnaissance and diagnostic surveys were undertaken to understand the actual ecosystem as well as estimate the inclusive practices in the selected districts. A total of 147 farm households were selected systematically from the three agroecologies of the study area. The households were selected randomly from the long-listed farmers of the three districts of the southern Tigray zone.

Informal surveys were conducted to gather qualitative information about traditional agroforestry practices, Agroforestry (AF) niches, and other related activities practiced by the farmers in their own land. Checklists were developed for the informal survey activities that generated information on: Niches for the practices, species composition, species arrangement, and management; components of the different practices (livestock, crop, vegetation, soils); benefits (social, economic, cultural, and environmental); laws and bylaws associated to the practices, resource management, and conservation systems; collective actions; complementarities between/among practices; innovations; changes/modifications of the components in the practices over time; and opportunities and constraints. A formal survey was carried out using a structured questionnaire to quantify and verify the informal survey findings. The formal survey involved direct field observations of the traditional agroforestry practices, discussions with individuals and group interviews, and key informant interviews, resource mapping, preference ranking, and other participatory rural appraisal techniques.

2.3. Model Selection

Logit regression analysis was carried out to analyze the factors influencing the adoption of agroforestry practices in the study area based on the prepared questionnaire. The questionnaire was designed to find out views concerning factors influencing the adoption of agro-forestry among smallholder farmers Therefore, a logit model was used in this study to determine the relationship between traditional agroforestry and affected factors in the study area.

According to Gujarati [27], the functional form of the logit model is presented as follows:

$$\begin{array}{c} pi = E\left(\frac{Yi}{Xi}\right) = \frac{1}{1+e^{-(\beta 0+\beta 1Xi)}} \\ pi = E\left(\frac{Yi}{Xi}\right) = \frac{1}{1+e^{-zi}}, \end{array} \quad (1)$$

where pi is a probability of using a given practice for the ith farmer and ranges from 0 to 1; zi is a functional form of m explanatory variables (X), which is expressed as:

$$Zi = \beta 0 \sum_{i=1}^{m} \beta iXi,\ i = 1, 2, 3 - - - - - m, \quad (2)$$

where $\beta 0$ is the intercept and β_{i} are the slope parameters in the model. The slope tells how the log-odds change as independent variables change. If p_i is the probability of using traditional agroforestry, then $1 - p_i$ indicates the probability of not using, which can be given as:

$$1 - pi = \frac{1}{1 + e^{zi}}. \quad (3)$$

Dividing Equation (1) by Equation (3) and simplifying gives:

$$e^{zi} = \frac{pi}{1 - pi} = \frac{1 + e^{zi}}{1 + e^{-zi}}. \quad (4)$$

Equation (4) indicates the odds ratio in favor of using traditional agroforestry. It is the ratio of the probability that a farmer will use agroforestry to the probability he will not use. Lastly, the logit model is obtained by taking the natural logarithm of Equation (4) as:

$$Li = \ln\left(\frac{pi}{1 - pi}\right) = \beta 0 + \beta 1X1, \quad (5)$$

where pi = the probability that Y = 1 (that the event occurs or probability of using);
1 − Pi = the probability that Y = 0 (that using does not occur);
L = the natural log of the odds ratio or logit;
βi = the slope, measures the change in L (logit) for a unit change in the explanatory variables (X);
$\beta 0$ = the intercept. It is the value of the log odd ratio;
$\frac{pi}{1+pi}$ when X or the explanatory variable is zero.
Thus, if the stochastic disturbance term (Ui) is taken into consideration, the logit model becomes:

$$Li = \beta 0 + \beta 1Xi + \cup i. \quad (6)$$

2.4. Data Analysis

Finally, the collected information was entered into spreadsheets and analyzed by using SPSS version 25 and Stata 12 software for various parametric and non-parametric tests. Data obtained were analyzed using descriptive statistics that include the use of frequency distributions, means, and percentages. Chi-square (χ^2) was used to test for the presence of associations in the variables obtained. Student t-test was used to verify the presence of significant differences between respondents' age, gender, family size, level of education, landholding, farming experience, livestock holding, etc., the proportion of those aware of agroforestry practices, and those not aware. The logit model developed by Gujarati [27] was used to analyze the agroforestry adopters and no adopters.

3. Results and Discussion

3.1. Demographic Features of the Households

Descriptive statistics were run to observe the distribution of the independent variables. The factors socio-economic and institutional characteristics of the respondents, such as age, gender, family size, level of education, landholding, farming experience, livestock holding, etc., of agro-forestry users and non- users were analyzed. The descriptive analysis employed tools, such as the mean, standard deviation, percentage, and frequency distribution. In addition, *t*-test and chi-square statistics were employed with respect to some explanatory variables.

The demographic features of the household in the study area are presented in Table 1. The age of the household head is an important characteristic that is useful to describe households and provide an indication about the age structure of the sample and the population as a whole. The age of the sampled household heads ranged from 20 to 71 years. Age of farmers adopting agroforestry is considered an important aspect and this study revealed that most adopters averaged an age of about 43.6 years, with about 49% of the adopters falling within the age of 20 to 40 years This might imply that the younger farmers have potential for the adoption and implementation of agricultural activities due to their invreased exposure to information and dissemination of agricultural extension compared to old farmers. Similar to this finding, Muneer [28] verified that young farmers have been found to be more innovative than older farmers. Contrary to our finding, Bannister and Nair [29] specified that older heads are more experienced and efficient in planting and managing more tree species in home garden agroforestry than youth. Though, the results showed that there are no significant variations in the adoption of agroforestry technology among other age groups, thus those farmers aged 41 to 50 years contributed 17.5%. Likewise, those aged 51 to 60 years had 15.5%, while those aged 61 to 70 years and greater than 70 years contributed 10.5% and 7.5%, respectively. An independent-sample *t*-test was conducted to test if there is a significant difference in the mean age of agroforestry users and non-users. The result of the *t*-test confirmed that the age difference between agroforestry users and non-users is not statistically significant (t = 0.165, $p = 0.870$).

The family size of the respondent in this study is considered as the number of individuals who resides in the household on a full-time basis. The family size ranged from 2 to 10, with an average family size of 6 persons per household. Most of the time, the large family size was assumed as an indicator of labor availability in the family to use integrated agroforestry practices. Past studies in Western Kenyan [30] and Mexico [31] also confirmed that more people in the family may provide more labor for home gardening could result in more stems and species in home garden agroforestry practices. This finding also showed that the mean difference in family sizes of the agro-forestry users and non-users was statistically significant (t = 2.273, $p = 0.02$ *). This may be because agroforestry practices require intensive labor and those households with a large family size have an advantage in a source of farm labor to adopt agroforestry practices and technologies easily. Similar to this, the past studies of Salam [32] and Kabir [33] in Bangladesh also assured that more family members contributes more labor for home gardening and results in more diverse and income-oriented adoption of home garden agroforestry.

In total 73% of the households were male-headed while 27 households were female-headed (Table 1). This indicates the majority of the residents are male dominant households. Further disaggregation by gender for agroforestry users showed males as the dominant head of households (87%) compared to females (13%). A chi-square test to detect an association between male-headed and female-headed households and the adoption of agroforestry practices was insignificant.

Education is very important for farmers to understand and interpret the agricultural information coming to them from any direction. A better-educated farmer is proven to better understand and interpret the information transferred to them by development agents and any other bodies [34]. Of the 147 respondents, 46.3%, 20.4%, 21.1%, and 12.2% were illiterate, able to read and write, above grade 4, and respondents >5 grade, respectively. In general, the significant relationship between the level of education and adoption implies that educated farmers more easily adopt than the less or non-educated ones. This is because education enhances the ability to derive, decode, and evaluate useful information for agricultural production.

With regard to marital status, from the total sample, 31% were single while the rest (69%) were married. The proportion of married respondents was much larger than the remaining marriage categories.

The majority of the households (40.1%) live in the middle land agroecology, followed by highland (32.7%) and lowland (27.2%) (Table 1).

Land is the main asset of farmers in the study areas. Land size was thought to be a good proxy indicator of wealth, which is an important resource for any economic activity in the rural and agricultural sector. Hence, the availability of enough land per household is assumed as an indicator for agro-forestry. According to the sampled survey data, only 22 farmers own more than 1 ha of land while the remaining 125 farmers own less than 1 ha of land.

Of the households adopting agroforestry (86.4%), 74% were male-headed and 26% were female-headed.

Overall, respondents perceived that agroforestry farms are slightly more important than conventional farms in producing ecological benefits. What differentiates agroforestry from other land uses is the deliberate inclusion of woody perennials on farms, which usually leads to significant economic and/or ecological interactions between woody and non-woody system components.

Table 1. Socio-demographic profile of respondents.

Socio-Demographic Profile of Respondents		**Frequency**	**Percent**
Educational Status	Illiterate	68	46.3
	Read and write	30	20.4
	Grade 4	31	21.1
	>5	18	12.2
Sex	Male	108	73.5
	Female	39	26.5
Marital status	Single	46	31.3
	Married	101	68.7
Family size	1–4	36	24.5
	5–8	100	68
	>8	11	7.5
Landholding	<0.5 ha	78	53.06
	0.5–1 ha	47	31.97
	>1 ha	22	14.97
Agroecology	highland(>2300)	48	32.7
	Midland (1500–2300)	59	40.1
	lowland (<1500)	40	27.2
HH source income based on	Cereal crop production	12	8.2
	Livestock rearing	5	3.4
	Cereal production with livestock production	33	22.4
	Agroforestry system(cereal + animal +tree)	64	43.5
	Cereal production + livestock + others daily laborer	15	10.2
	Cereal crop production + forest products (selling of AF fruits, timber, lumber, fuelwood and charcoal)	18	12.2
	Total	147	100.0

3.2. Logit Model Analysis

The logit model analysis of gender indicates that male-headed households are expected to adopt introduced agroforestry practices and land management practices better than female-headed households (Table 2). Therefore, maleness is hypothesized to positively correlate with decisions to adopt different inputs and it significantly influences ($p > 0.05$) the adoption of agroforestry practices in the study area. This finding also shows that although women are as actively involved in agroforestry for fruit and fodder production, woodlot technology, and soil fertility improvement as their male counterparts, their level of participation is low, as reflected in the number of shrubs/trees they plant relative to men. This finding is similar to Kebede et al. [35] in the Ofla district of Sothern Tigray, Ethiopia and Kiptot et al.'s findings [36] in Africa also indicate that lesser involvement reflects women's lack of resources, particularly land and labour, their heavy workload, and perhaps also their greater aversion to risk.

Table 2. Logit model of the respondents.

Variable	Coef.	Odds Ratio	St.E	Sig.	Z
Age	−0.003	0.024	0.019	0.892	0.997
Sex	1.142	0.778	2.151	0.021 *	3.132
Marital	0.995	0.779	1.634	0.201	2.705
Family size	0.367	0.148	6.185	0.013 *	1.444
Educational level	0.036	0.246	0.021	0.009 *	1.037
landholding	−0.214	0.367	0.338	0.002 **	0.808
Constant	−6.877	2.912	5.576	0.018	0.001

* indicates a significant difference at $p < 0.05$.

According to the logit model analysis, sex, family size, educational level, and landholding significantly ($p < 0.05$) influence the household's role in the adoption of agroforestry practices, while age and marital status tested as non-significant. This implies that households with large family sizes are willing to adopt agroforestry compared to smaller families (as they can get information from different sources). A large family size means a high availability of labor. This finding has confirmed the findings of Blanckaert et al. [31] in Mexico and a small family size means lesser availability of labor and the other literature also agreed with this finding [37–40].

3.2.1. Ranking of Fruit and Fodder Species Based on Their Use and Availability in North Ethiopia

There are different plant species that are selected by farmers for different purposes (Table 3). For instance, *Opuntia ficus-indica, Ziziphus spina-christi, Balanites aegyptiaca*, etc. are preferable species as wild edible fruit trees while *Faidherbia albida, Acacia nilotica*, and *Becium grandiflorum* are preferable as fodder trees.

Table 3. Species ranking for fruit and fodder purpose in the study area.

Ranking	Priority Fruit Species	Ranking	Priority Fodder Species
1.	*Opuntia ficus-indica*	1.	*Faidherbia albida (Acacia albida)*
2.	*Ziziphus spina-christi*	2.	*Acacia nilotica*
3.	*Mimusops kummel*	3.	*Ziziphus spina-christi*
4.	*Prunuspersica*	4.	*Becium grandiflorum*
5.	*Balanites aegyptiaca*	5.	*Acacia seyal*
6.	*Ximenia americana*	6.	*Grewia bicolor*
7.	*Cordia africana*	7.	*Balanites aegyptiaca*
8.	*Balanites aegyptiaca*	8.	*Acacia tortilis*

3.2.2. Factors Limiting Tree Planting in the Study Area

The planting of multipurpose trees, such as *Faidherbia albida, Acacia nilotica, Cordia Africana*, etc., play an important role in the rehabilitation of an environment stressed by biomass shortage, water scarcity, erosion, and land degradation, such as northern Ethiopia. These multi-purpose trees are critical for rural livelihoods in the study area, providing significant economic and ecological benefits (Table 3). Tree planting supplies households with wood products for their own consumption, as well as for sale, and decreases soil degradation. The respondents indicated a lack of water or moisture (34.7%), shortage of land (27.2%), low income, slow growth rate of the species (10.9%), and lack of fruit tree seedlings (10.9%), as some of the major factors constraining tree planting and water retention (Figure 2). However, there is good awareness of the importance of agroforestry practices; these factors and other related problems are hindrances for the adoption of agroforestry practice in the study areas. Respondents also suggested planting trees as an alternative livelihood strategy to minimize existing constraints. This is because, in the study area, the occurrence of frequent droughts coupled with land degradation is decreasing soil fertility. Similar findings were reported by Gebreegziabher et al. and Jagger and Pender [41–43] in rural Ethiopia.

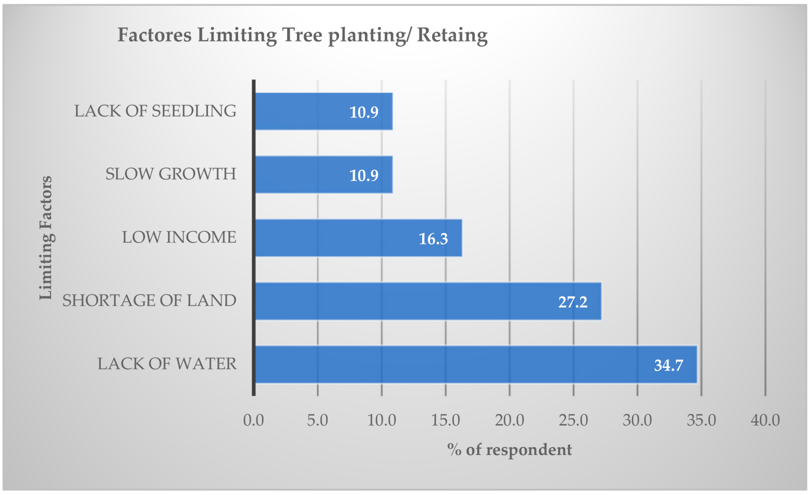


Figure 2. Factors that affect tree planting by farmers in drylands of South Tigray, north Ethiopia.

3.3. *Characterization of Agroforestry Practices (AFPs) in Southern Tigray, Ethiopia*

The major agroforestry practices practiced in the study area are a homestead, live fence, and niche AFPs (Table 4). Homestead AFP indicated a significant difference at ($p < 0.05$) with the highland and midland than that of the lowland agroecology in the study area. This indicates that homestead AFP is more preferable by the respondent farmers than that of the other agroforestry practices in the study area.

Table 4. Agroecological-based niche cross-tabulation.

Agroecology * Niches		Niches						Total
		Farm Land	Homestead	Live Fence	Farm Boundary	Grazing Land	Farmland and Homestead	
Agroecology	highland (>2300)	5 ^{a}	27 ^{a}	11 ^{a}	1 ^{a}	3 ^{a}	1 ^{a}	48
	Midland (1500–2300)	6 ^{a}	29 ^{a}	17 ^{a}	4 ^{a}	0 ^{a}	3 ^{a}	59
	low land (<1500)	11 ^{a}	12 ^{b}	10 ^{a,b}	3 ^{a,b}	0 ^{a,b}	4 ^{a,b}	40
Total		22	68	38	8	3	8	147
				Value	df	Asymp. Sig. (2-sided)		
Pearson Chi-Square				19.793a	10	0.031		
N of Valid Cases				147				

Each superscript letter denotes a subset of niche categories whose column proportions do not differ significantly from each other at the 0.05 level.

3.3.1. Dominant Agroforestry Niches Practiced

Home gardens AFP: In total, 46.3% of the respondents practiced home garden agroforestry practices. Home gardens are characterized by high species diversity and usually three to four vertical canopy strata using MPTs, fruit trees, vegetables, root crops, and tuber crops. Based on agroecology, the most dominant agroforestry practices in the study area are: Home garden, on farm, live fence, farm boundary, and grazing land.

Species interactions and their agroforestry niches practiced by the local farmers in the study area include:

(1) Wild fruit trees found in home garden, live fencing, and farm boundary: *Ziziphus spina-christi*, *Balanites aegyptiaca*, *Tamarindus indica*, *Carissa edulis*, *Cordia africana*, *Diospyro smespiliformis*, *Dovyalis abyssinica*, *Vernonia amygdalina Del.*, *Ficus sur*, *Ficus vasta*, *Xmenia americana*, *Zyzygium guineense*, *Grewia ferruginea*, *Grewia villosa*, *Mimusops kummel*, *Rhus natalensis*, *Opuntia ficus-indica*, and *Prunus persica*.

(2) Live fences: Lines of trees or shrubs planted in close spacings on farm boundaries or on the borders of agricultural fields. Trees species used as live fences are *Acacia tortilis*, *A. seyal*, *A. sieberiana*, *A. etbaica*, *A.*, *abyssinica*, *Ziziphus spina-christi*, *Balanites aegyptiaca*, and *Opuntia ficus-indica* (L.) Mill.

(3) Scattered trees in croplands (parkland AFP): Common tree species are *Acacia tortoils, acacia absynica, Cordia africana, Ziziphus spina-christi*, and *Balanites aegyptiaca*. The crops grown in association with parkland AFP are teff, sorghum, maize, wheat, barley, and pulses, such as chickpeas, beans, and lentils.

(4) Trees on rangelands—silvopastoral systems: The dominant tree species are *Acacia seyal*, *A. tortilis*, *A. sieberiana*, *A. abyssinica*, *A. etbaica*, *A. bussei*, *Balanites aegyptiaca*, and *Ziziphusspina-christi*.

(5) Boundary Trees for Soil Conservation: Trees are planted for soil conservation works (grass strips, bunds, risers, and terraces) to stabalize the structure and make productive use of the land they occupy, e.g., *Faidherbia albida*, *Balanites aegyptiaca*, *Ziziphus spina-christi Eucalyptus camaldulensis*, *E. globulus*, *Grevillea robusta*, and *Acacia* species.

(6) Woodlots: Woodlots are established on underutilized or degraded lands for the purpose of supplying fuelwood or fodder, with trees, such as *Eucalyptus camaldulensis, E. globulus, Grevillea robusta*, and *Acacia* species.

3.3.2. Agroecology Difference and Agroforestry System (AFS) in Southern Tigray

Form the sampled households of the study area, the agro-silvo-pastoral system (ASPS) was statistically significant different at $p < 0.05$ than that of agri-silvi-culture and silvo-pastoral with the lowland than that of the highland and midland agroecology in the study area. This indicates that the agro-silvo-pastoral system was better practiced by the respondent farmers than that of other types of the agroforestry system in the lowland areas.

The major agroforestry systems experienced in the study area was agri-silvi-culture (59.18%) followed by agro-silvo-pasture (28.57%) and silvo-pastoral (12.25%) systems (Tables 5 and 6). Based on their agroecological niches, agri-silviculture is dominantly practiced in the midlands and highlands and least practiced in the lowlands. The silvo-pastoral system was more popular in the midlands followed by the lowlands. Agro-silvopasture is more common in the lowlands and its popularity decreased in the midlands and highlands.

Table 5. Niches of agroforestry systems (AFSs) based on different agroecology in southern Tigray.

Agroforestry system * Agroecology		**Agroforestry System**			**Total**
		Agri-Silviculture (59.18%)	**Silvo-Pastoral (12.25%)**	**Agro-Silvo-Pasture (28.57%)**	
Agroecology	high land(>2300)	35	4	9	48
	Midland (1500–2300)	36	8	15	59
	low land (<1500)	16	6	18	40
Total		87	18	42	147
Chi-Square Tests		Value	df	Asymp. Sig. (2-sided)	
Pearson Chi-Square		10.585a	4	0.03*	
N of Valid Cases		147			

Table 6. Agroecology and agroforestry systems with their frequency distribution.

Agroecology * AF System Cross Tabulation						
Agroecology * Agroforestry system			Agroforestry system			Total
			Agri silviculture	Silvo-pastoral	Agro-silvo-pasture	
Agroecology	High land (>2300)	Count	35 [a]	4 [a]	9 [a]	48
		%within Agroecology	72.9%	8.3%	18.8%	100%
		% within AFS	40.2%	22.2%	21.4%	32.7%
	Midland (1500–2300)	Count	36 [a]	8 [a]	15 [a]	59
		%within Agroecology	61.0%	13.6%	25.4%	100%
		% within AFS	41.4%	44.4%	35.7%	40.1%
	low land (<1500)	Count	16 [a]	6 [a,b]	18 [b]	40
		%within Agroecology	40%	15%	45%	100%
		% within AFS	18.4%	33.3%	42.9%	27.2%
Total		Count	87	18	42	147
		%within Agroecology	59.2%	12.2%	28.6%	100%
		% within AFS	100%	100%	100%	100%
		% of Total	59.2%	12.2%	28.6%	100%

Each superscript letter denotes a subset of AF system categories whose column proportions do not differ significantly from each other at the 0.05 level.

3.4. Farmers Adaptation Strategies Based on Agroforestry Systems and Practices

The results indicate that 74.1% of the surveyed farmers have observed increasing temperatures over the past 30 years. In total, 61.9% of the respondents observed a decreasing intensity and duration of rainfall over the past three decades (Table 7). The household farmers (71.4%) experienced the highest incidences of drought and also observed that the frequency of occurrence is shorter than the last decades. Similar to this study, Eze [44] in Nigeria also proved that the occurrence of drought has increased in the past decades. Additionally, these farmers who claimed to have observed changes in the climate over the past 30 years were subsequently asked if they had responded through adaptation to counteract the impact of climate change. Accordingly, those who responded that they had adapted to climate change indicated that different adaptation strategies were practiced in the study area. Some of the practices included planting trees, soil conservation, use of different crop varieties, changing planting dates, and irrigation (Figure 3a–d). From the total interviewed households, 72.16% identified moisture stress as the top challenge facing the adoption of agroforestry followed by open grazing (16.4%) and shallow soil depth (11.44%). This may be due to the fact that some households rely on traditional cultivation systems, like plowing methods. Therefore, to enhance the productivity of available rainwater within the present land use, different in-situ moisture conservation methods through tillage practices and increased moisture availability to the agricultural crops, and agroforestry practices are necessary to adopt in-situ moisture conservation techniques in addition to the large-scale soil and moisture conservation and water harvesting structures in the watershed. The use of different soil and water conservation measures, planting trees, and use of diversified crop varieties are the major adaptation methods identified in the southern Tigray of northern Ethiopia. Greater use of different crop varieties as an adaptation method could be associated with the lower costs and ease of access by farmers, while the limited use of irrigation could be attributed to the need for more capital and low potential for irrigation.

Climate change is one of the leading challenges affecting the performance of agriculture practices and the livelihoods of local farmers in the study area. Farmers have to continuously respond to the frequent climatic variations (Table 7). The survey results from the focus group discussions and semi-structured questionnaires are presented in Table A1 and Figure 3, which indicates a decrease in precipitation by 61.9%, increase in temperature by 74.1%, and an increase in the frequency of drought occurrence in the past three decades of the dry Afromontane ecosystem of southern Tigray, Ethiopia. In line with this finding, Bishaw and Abdelkadir [14] in east African and Meijer et al. [25] also proved that agroforestry innovations among smallholder farmers in sub-Saharan African are an option to tackle climate change. The comprehensive survey of households across the three different agroecologies of southern Tigray districts indicates that homestead or home garden agroforestry practices are the most dominant practices in the midland (29%) and highland (27%) of the total respondents. This means that farmers perceived agroforestry practices as a win-win strategy to adapt to the changing climate in the Southern Tigray zone.

Table 7. Farmers' perceptions of long-term temperature, precipitation changes, and drought conditions.

Variables		Frequency	Percent
Precipitation	Decreased	91	61.9
	Increased	56	38.1
	Total	147	100
Temperature	Increased	109	74.1
	Decreased	22	15
	No change	16	10.9
	Total	147	100
Drought occurrence	Frequency increased	105	71.4
	Frequency decrease	27	18.4
	No occurrence	15	10.2
	Total	147	100

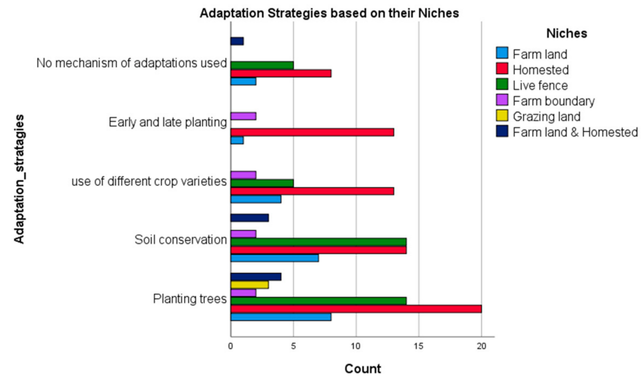
These adaptation measures are similar to the other findings in the climate change adaptation literature [45–49]. Moreover, farmers who did not adapt have given many reasons for their failures to adapt, which include lack of information, lack of money, shortage of labor, shortage of land, and poor potential for irrigation.

The household survey results show that farmers adopted a range of practices in response to perceived climate change (Figure 3a,d). The most common responses included changing and using a different crop variety (16.3%) and early and late planting or changing planting dates (10.9%). Other responses included planting trees (34.7%), crop rotation, cover crops, and conservation tillage to minimize both erosion and runoff potentials (27.2%). While the number of farmers who did not adjust their farming practices in response to perceived climate change (10.9%) may seem high, this figure is relatively low compared to similar data collected from other parts of Ethiopia and south Africa, where 37% and 62% of farm households, respectively, did not adapt [38,50,51].

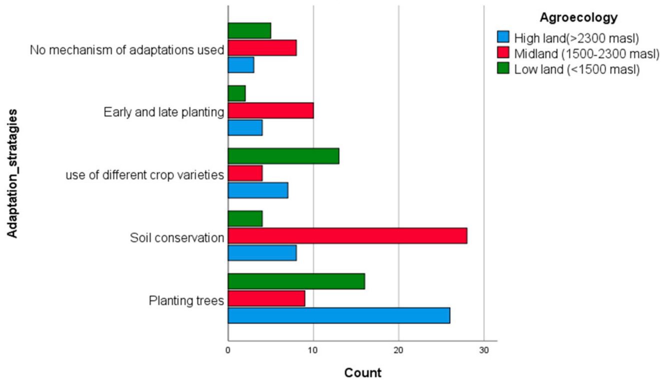
Knowledge of the respondent on the adoption of agroforestry at the farm level is crucial to the promotion of agroforestry practices, such as the major adaptation measure for the changing climate that farmers adopt across agroecological zones of southern Tigray. Farmers in the study area also suggest afforestation for communal land to reclaim degraded lands. Farmers use different soil and water conservation techniques to prevent soil degradation and build organic matter. For mitigation of the current changing climate, farmers design different mechanisms, such as the farming practices, including crop rotation, reduced tillage, mulching, cover cropping and cross-slope farming, changing planting time decisions. Choosing a new crop or crop variety and early and late planting dates were the key adaptation measures in all agroecological zones of southern Tigray as well as in most common parties of Ethiopia.

3.5. Socioeconomic Benefits Obtained from Agroforestry Practices and Systems

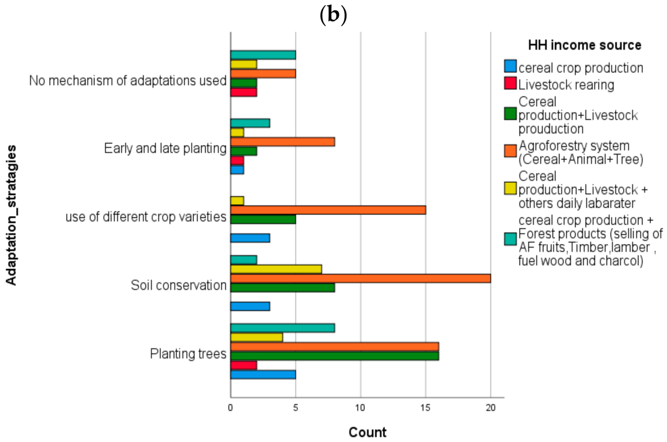
Agroforestry practices diversify the socio-economic benefits of the livelihood (Table 1) and provide an opportunity for exploiting the potential soil ameliorative attributes of trees to enhance crop production. The majority of the respondents (86.4%) expressed indifference towards the attitude statements related to agroforestry regarding how people can improve their socioeconomic conditions by adopting innovative agroforestry practices with their specific niches. Agroforestry is successful in meeting the social, cultural, religious, and recreational needs of the people. Farmers' attitudes towards the tangible benefits of agroforestry were highly promising whereas farmers' perceptions towards the tangible benefits were very low or apathetic. The interviewed households expressed a higher preference for fuelwood, fodder, vegetable, fruit, household (HH) consumption, cash income, and timber while moderate or low preferences were observed for medicine, industry/handicrafts, and employment opportunities for a jobless group, etc. Agriculture was the main source of income for about 83% of the households in the study area. Although socio-economic considerations are often found to play an important role in the adoption process of agroforestry, a wide range of other variables affects the decision to plant trees. The respondents indicated that variables, such as family size, landholding, adaptation strategies, agroforestry niches, and marital status, had a significantly positive ($p < 0.000$) effect on adoption as well as having an influence on the adoption of agroforestry practices and socio-economic benefits obtained from the traditional agroforestry practices. In general, the provision of direct economic benefits in the study resulting from agroforestry has been mentioned as a key factor in determining the adoption potential, as shown in Appendix A.



(**a**)

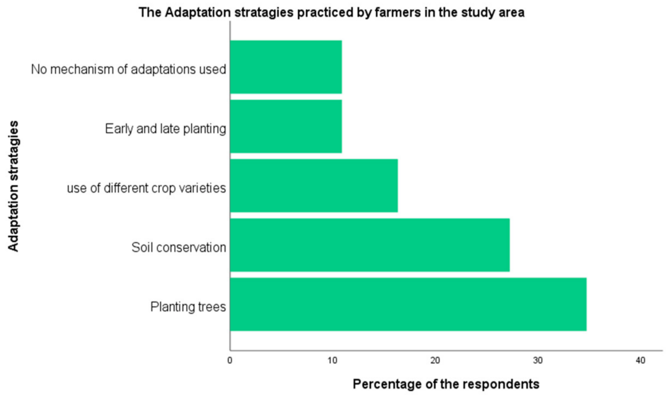


(**b**)



(**c**)

Figure 3. *Cont.*



(**d**)

Figure 3. (**a**–**d**) Different adaptation strategies based on their ecological niches and agroecology.

This study is in line with the study in India [25,52–54], which showed agroforestry as an important livelihood strategy of the rural peoples.

4. Conclusions and Recommendation

The study findings confirm that agroforestry help alleviate livelihood issues of farmers through better access to fuelwood, fodder, timber, and other non-timber forest products, employment, and income opportunities, thus improving their resilience. Further, agroforestry has decreased the incidence of natural hazards and flood, minimized soil erosion as well as ameliorated the microclimate and reduced the migration of rural people to urban areas for their livelihood.

Most of the respondents noticed an increase in the frequency of late onset and early cessation of the rain and a decrease of the amount of rain in a specific study area. Furthermore, farmers experienced a moisture deficit and frequent occurrence of drought conditions in the last decades. Our findings confirm global trends in increasing temperatures, drought, and erratic rainfall [40,50]. Households in the study area reported increased changes in land cover and agricultural practices due to increasing temperature and drought accompanied by erratic rainfall. Farmers in the study area should be aware of the climatic conditions to adapt to the changes, and have resorted to modifications of their farming practices, such as changing planting times, using improved drought-resistant crop varieties, and soil and water conservation by government and agricultural extensions. Agroforestry, although effective in alleviating climate-related stresses, continues to face multiple challenges, including pre- and post-planting management, lack of suitable land, poor access to the improved variety of saplings, and inadequate extension support. A majority of the households (72.16%) identified moisture stress as the top challenge facing the adoption of agroforestry followed by open grazing and shallow soil depth.

The adoption of agroforestry needs to be sensitive not only to the characteristics of the technology and biophysical environment but also to the socioeconomic conditions, which is often not given due attention. The promotion of agroforestry in the study area is constrained by numerous factors, including small landholdings, lack of adequate financial and technical support, poor soil, and incidences of drought exacerbated by climate change. Another important factor influencing the adoption of agroforestry practices is the nature of the innovation itself. Tree growing is a long-term investment and without substantial support from the government or other non-governmental organiztions (NGOs), subsistence farmers may not be able to afford it. Such support could be in the form of monetary aid (subsidies or loans) or the provision of servicse (technical support, market linkages, and price support). Furthermore, land ownership and a small piece of land are crucial to undertaking agroforestry practices effective in the study area. Since most of the household, 53.06%, have small landholdings that are <0.5 ha of land per household, the promotion of agroforestry among rural communities is difficult. Regarding public lands, areas of degraded forest lands are available that are being distributed to landless youth and households. Poor households do not have adequate resources to undertake tree growing other than at the scale of home gardens.. To address this constraint, we recommend for the government and other NGOs to reclaim degraded land and provide them to rural people who are interested in adopting agroforestry techniques.

As agroforestry is effective at improving socio-economic conditions and environmental health, we highly recommend the intercropping of fruit and fodder trees with farming on a pocket of land, such as farm boundary and hedgerow in cropland. Policy measures or interventions that enhance the security of existing land tenure and support greater education of the household head would, at the same time, enhance the awareness for the household of adoption and tree planting.

We recommend research on the nutritional value, propagation, and interaction of fruit and fodder tree species with annual crops, and an economic analysis of the individual agroforestry practices involving fruit and fodder species as priority research areas for the drylands of Northern Ethiopia. In addition, we recommend further research to understand hydrometeorology and farmers' perception on climate change and its impact on the socio-economics of the rural people on the dry Afromontane.

The following policy measures and interventions are recommended:

- ➢ This study highlighted certain factors that policies aiming to inspire or encourage household agroforestry adoption and tree planting should focus on or strategize to be targeted.
- ➢ Policy measures or interventions that enhance the security of existing land tenure and support greater education of the household head would, at the same time, enhance the awareness of the household on adoption and tree planting. In addition, these research results are relevant to forestry policy because they identify the agroforestry niches that may be more important, for example, to address the species interactions problem or enhance soil and water conservation.
- ➢ Improving access to climate information is an important first step to improve the livelihood of people in such sensitive or variable climate conditions. Complementary efforts must be made to ensure that the farmers understand the information and can modify their agricultural activities.

Author Contributions: The lead author B.M.G. was the principal investigator for the research and took the study from inception, through to fieldwork, data management/analysis, drafting, and proofing of the manuscript. S.W.W. provided technical inputs into cross interpretation, editing, and proofing of the manuscript, S.K. reviewing and editing, and W.K.L. provided expert input into data interpretation and proofing of the manuscript.

Funding: This research received funding from **Environmental GIS/RS Center** of Korea University and National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. 2018R1A2B6005682).

Acknowledgments: The authors would like to thank the support from the agriculture officials and farmers who participated in the study; **Environmental GIS/RS Center** of Korea University, National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. 2018R1A2B6005682) and Mekelle Environment and Forestry Research center for their technical and financial support in analysis and writing of this article. Finally the Author would to acknowledge the staffs of MEFRC Specially, Tewelde Girmay, Birhanu Biruk, Ashenafi Manaye, Dereje Egeta, and Berihu Tesfamaryam for their support during field data collection.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Farmers' Agroforestry Adoption Correlation Coefficients.

Spearman's rho		Family Size	landholding	HH Income Source	SE AFP	TAFP	Educational	Sex	Age	Marital	Adaptation Strategies	Agroecology	AFP	Niches
Family size	Coefficient	1.000												
	Sig. (2-tailed)													
landholding	Coefficient	0.198 *	1.000											
	Sig. (2-tailed)	0.016												
HH income source	Coefficient	0.086	0.134	1.000										
	Sig. (2-tailed)	0.301	0.105											
SE AFP	Coefficient	0.081	0.252 **	0.333 **	1.000									
	Sig. (2-tailed)	0.327	0.002	0.000										
TAFP	Coefficient	0.184 *	0.002	0.173 *	0.193 *	1.000								
	Sig. (2-tailed)	0.026	0.980	0.036	0.019									
educational	Coefficient	0.100	−0.079	−0.058	−0.112	0.009	1.000							
	Sig. (2-tailed)	0.229	0.343	0.486	0.176	0.917								
sex	Coefficient	−0.196 *	−0.181 *	−0.069	−0.214 **	0.031	−0.222 **	1.000						
	Sig. (2-tailed)	0.017	0.028	0.404	0.009	0.708	0.007							
Age	Coefficient	0.128	0.110	−0.193 *	−0.107	−0.030	0.140	−0.063	1.000					
	Sig. (2-tailed)	0.123	0.186	0.019	0.199	0.717	0.090	0.452						
marital	Coefficient	0.072	0.207 *	0.106	0.310 **	0.054	0.200 *	−0.591 **	−0.075	1.000				
	Sig. (2-tailed)	0.385	0.012	0.201	0.000	0.517	0.015	0.000	0.364					
Adaptation strategies	Coefficient	−0.208 *	−0.082	0.113	0.042	−0.024	−0.014	0.049	0.010	0.088	1.000			
	Sig. (2-tailed)	0.012	0.322	0.173	0.613	0.775	0.868	0.556	0.900	0.291				
Agroecology	Coefficient	−0.025	−0.006	0.115	−0.017	−0.052	−0.156	0.142	0.081	−0.065	0.155	1.000		
	Sig. (2-tailed)	0.767	0.940	0.165	0.837	0.531	0.058	0.086	0.331	0.431	0.060			
AFP	Coefficient	−0.036	−0.274 **	−0.265 **	−0.495 **	−0.056	0.080	0.202 *	0.166 *	−0.320 **	−0.084	0.256 **	1.000	
	Sig. (2-tailed)	0.665	0.001	0.001	0.000	0.500	0.335	0.014	0.044	0.000	0.313	0.002		
Niches	Coefficient	0.208 *	0.073	0.017	0.097	0.184 *	−0.046	−0.014	0.070	−0.070	−0.112	−0.002	0.073	1.000
	Sig. (2-tailed)	0.012	0.379	0.841	0.242	0.026	0.577	0.863	0.399	0.398	0.179	0.983	0.381	
	N	147	147	147	147	147	147	147	147	147	147	147	147	147

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).

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