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Determinants of the Adoption of Forest Zaï and Prospects for Promoting the Technology in Yaadga (Burkina Faso)

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Abstract: This study analysed the factors leading to the adoption of forested "zaï" technology and how to take advantage of its outcomes in the local environment. Socio-economic data were collected from a sample of 130 producers although data related to the tree distribution in fields and fallows were collected in 40 sampling plots in 4 villages of the Yaadga Province. Descriptive analyses were performed on the importance of trees for the local sahelian populations and logit model to characterize the determinants of the adoption of the forested "zaï" technology. The results showed that trees were maintained for both men and animals, and in the restoration of degraded land. The use of forested "zaï" technology to restore soils, the number of hoes, the number of small ruminants, the source of care and producers network affected the adoption of the technology. Taking into account those variables can contribute to improving natural resources management.

Key words: Burkina Faso, degraded soils, econometric, forested zaï, logit model.

1. Introduction

Burkina Faso is a Sudano-Sahelian country with an agropastoral economy and limited natural resources [1]. With an area of 274,200 km², its population was estimated at 20,505,155 [2]. The country's economic and social development relies primarily on rain-fed agriculture. The primary sector employs over 80% of the active population and contributes 16.3% to the gross domestic product [2].

For several decades, the northern part of the country has faced serious problems of natural resource degradation. In extreme cases, this degradation results in the appearance of land devoid of all vegetation and severely eroded soils [3]. These bare, crusted lands,

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called *zipellés* in the Mooré language (“white spaces”), represent the final stage of the degradation process. The Yaadga region is thus considered one of the most degraded areas of Burkina Faso [4].

To address this situation, rural populations have developed local techniques for soil and water conservation and land restoration, among which zaï plays a central role [5, 6]. This technique has demonstrated a positive impact on soil recovery and vegetation regeneration [7].

Zaï, derived from the Mooré word *zaïegré* (“to hasten to prepare one’s land”), consists of digging pits in crusted soils to concentrate runoff water and organic matter. These pits become micro-spaces of fertility where crops are sown [5]. This technique was improved by innovative farmers, notably Sawadogo Yacouba in Gourga in the Yaadga region, who initiated a particular form of this practice known as forest zaï. Today, two variants are distinguished: agricultural zaï and forest zaï. The effectiveness of agricultural zaï on cereal yields has been widely demonstrated [5, 8].

Forest zaï relies on the regeneration and protection of woody species in restored plots. By selecting and protecting seedlings grown from seeds contained in the zaï (a type of seed-based preparation) or intentionally introduced, farmers gradually transform the zaï into agroforestry areas or forests [5, 9]. This practice contributes to ecological restoration, as well as to the production of timber, fodder, food, and medicinal products, thus strengthening the livelihoods of rural households [10].

However, despite its recognized ecological and socio-economic benefits, the forest zaï technique is not uniformly adopted by all producers in Yaadga. Some producers have integrated it permanently into their practices, while others use it little or not at all. This heterogeneity suggests the existence of social, economic, technical, and land-related constraints and factors that influence producers’ commitment to this technology. Several studies have analyzed the adoption of water and soil conservation techniques [11-13], but few have specifically focused on forest zaï as a particular form of agroforestry management. The objective of this study was therefore to identify the determinants of the adoption of forest zaï and to analyze the potential for adding value to its products in a farming community. More specifically, it aimed to: (i) identify the main tree species present in forest zaï plots and their uses and (ii) analyze the factors that influence the likelihood of adopting this technology. The main hypotheses of this study were: (H1) producers retain on their plots woody species with high soil fertilization capacities and (H2) land tenure influences the producer’s behavior in adopting forest zaï technology. This research article presents the mains findings.

2. Materiel and Methods

2.1 Presentation of the Study Area

The study was conducted in the Yaadga region of northern Burkina Faso. It covers an area of 7,026.8 km² with a population of 1,840,537 [2]. The most dominant soil type is ferruginous soil, characterized by a deficiency in organic matter, phosphate, and nitrogen [14]. The climate is Sudano-Sahelian. Temperatures range from 15 °C (in February) for the minimum to 45 °C (in April) for the maximum. Rainfall is scarce and irregular in both time and space. The vegetation consists of wooded savanna dominated by *Acacia albida, Khaya senegalensis, Tamarindus indica, Lannea microcarpa, Parkia biglobosa, Sclerocarya birrea, Vitellaria paradoxa*, *Adansonia digitata,* etc. The villages studied were: Gourga, Ziga, Oula, and Sonh. These villages were located along a transect drawn on a topographic map of the area (Fig. 1). They were selected based on population size, their distance from the city of Ouahigouya, and the presence of a Zaï group.

2.2 Sampling

The 136 groups belonging to the Association of Zaï Groups for the Development of the Sahel served as the sampling frame for the surveys in the four villages studied. One hundred and thirty farmers, 70 of whom practice forest zaï and 60 of whom do not, were randomly selected from the four villages.

Following the surveys, we randomly selected 10 plots belonging to the interviewed farmers in each village (one plot per farmer, for a total of 40 plots across the four villages) for a systematic inventory. This data provided not only a broad overview of the woody plants present in the fields and fallow land of the area but also allowed us to verify the accuracy of the survey data.

Within each plot, we delineated a transect 100 meters long by 20 meters wide. We then proceeded to sample the transect in 5 sections of 20 m × 20 m, i.e., 400 m^2 (Fig. 2).

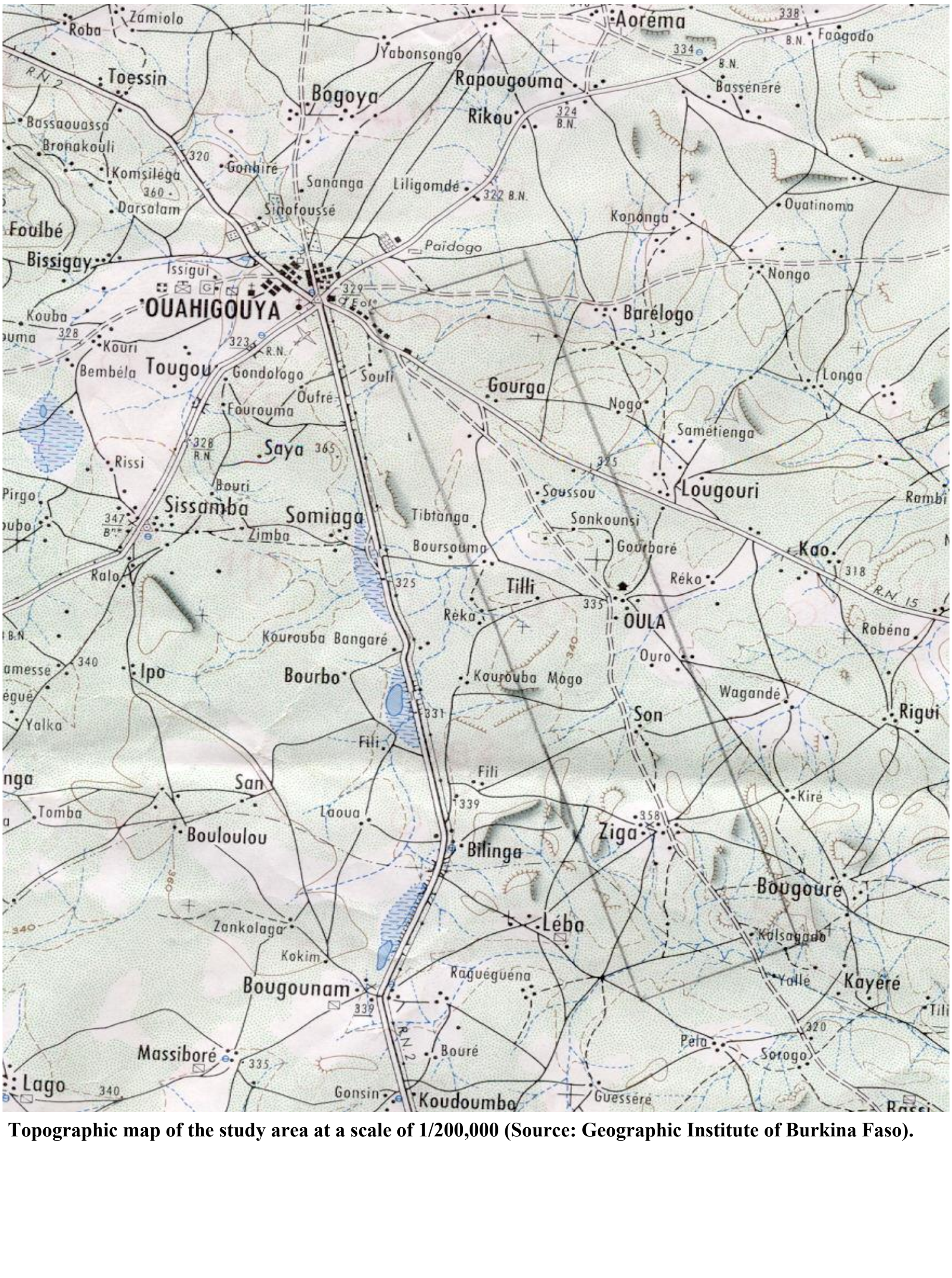

Fig. 1 Topographic map of the study area at a scale of 1/200,000 (Source: Geographic Institute of Burkina Faso).

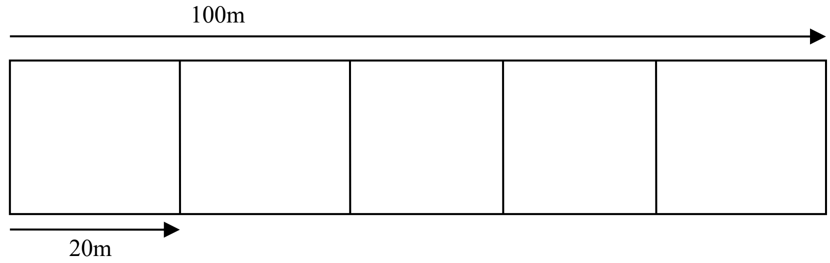

Fig. 2 Experimental protocol for sampling woody plants.

3. Data Collection and Analysis

Data collection was carried out through direct interaction with the farmer using a questionnaire, followed by observations on the selected plots. The survey questionnaire gathered information on the socio-economic characteristics of the farm manager, general information on the practice of forest zaï, and the potential for adding value to forest zaï products.

The work on the plots required: two 20-meter measuring tapes, 12 stakes to delineate the plots and sub-plots, a compass to determine the orientation of the transects, a GPS (global position system) for locating the plots, and a flexible measuring tape for the circumferences of the tree trunks. In each section of the transect, we inventoried and measured the circumference at the base of all woody species encountered. A general observation was made regarding the condition of the trees (disease, dead, cut, stripped of bark, etc.), and the geographic coordinates of the plot were recorded. Descriptive analyses were performed using Excel, and an econometric analysis was carried out with EViews Version 3.

4. Theoretical Framework of the Econometric Model

The issue of technology adoption in environmental management is increasingly becoming a priority for some researchers and natural resource users [15]. Several definitions of the concept of "adoption" exist, and therefore several methods for measuring it [11, 12, 16]. The adoption of a new technology can be defined as the complete application of the technology [11]. Producers abandon their old practices and adopt others that they consider rational for their production systems [17]. Adoption is defined as a producer's openness to a technology about which they have sufficient information regarding its potential after a certain period [12]. Adoption is seen here as a real need for the producer to intensify their production by applying the technology [13]. A producer has adopted the forest zaï technology if they have a fallow area on a plot previously used for zaï or if they have voluntarily retained at least 12 woody species per hectare of *"zipépellé"* managed as zaï from the first year of operation [5].

Logit and probit models are commonly used in studies of agricultural technology adoption by producers [13, 17-19]. These statistical methods link the probability of a dichotomous outcome to a set of explanatory variables assumed to influence it [20]. They allow for the analysis of the probability of technology adoption. To analyze producer behavior regarding the forest zaï technology by identifying the factors influencing its adoption, we opted for a logit econometric model. The choice of the logit model is motivated by the ease of manipulating the results [21]. Indeed, two properties make the logistic distribution function particularly useful in modeling discrete choices. These are its interval, which is limited to [0, 1], and the possibility of linearizing it through a logarithmic transformation.

In the logit model, the unobservable latent variable y^* is defined as follows:

$$y_i = \alpha + X_i\beta + \varepsilon_i \tag{1}$$

with yi^* the benefit or utility derived from the producer's engagement in the practice of forest zaï; x_i is a vector of exogenous variables; the model parameters; and i the random perturbation. Since the variable yi^* is not observable, it seems necessary to generate an observable variable expressing the producers' practice of forest zaï.

By asking:

$$y_i = \begin{cases} 1 \text{ if adoption} \\ 0 \text{ if not} \end{cases}$$
$$y = \begin{cases} 1 \text{ si } y^* > 0 \\ 0 \text{ si } y^* \leq 0 \end{cases} \quad (2)$$

The regression of the logit model characterizing adoption by a sample of producers is specified as follows [21]:

$$p_i = E(y_i) = F(\alpha + X_i\beta) = \frac{1}{[1 + e^{-(\alpha + X_i\beta)}]}$$

where:

i denotes the i^{th} observation in the sample.

P_i is the probability that an individual makes a given choice y_i.

e is the base of the natural logarithm.

x_i is a vector of exogenous variables.

α is a constant.

and β_i are coefficients associated with each explanatory variable X_i to be estimated.

It is important to note that the estimated coefficients do not directly indicate the effect of changes in the corresponding explanatory variables on the probability (p) of the occurrence of the results. A positive coefficient means that the probability increases with an increase in the corresponding independent variable [20]. The coefficients in the logistic regression are estimated using the maximum likelihood method. Several variables were assumed to influence a producer's adoption of a technology. A distinction is generally made between the socio-economic characteristics of the farm manager and those of their environment (Table 1).

5. Results and Discussion

5.1 The Role of Trees in Agricultural Systems

Producers are motivated to keep trees in the fields for personal reasons. The tree is important to the producer and receives special attention from them (Table 2). A selection process takes place during weeding operations from the first year of cultivation of the plot under the zaï agricultural system.

In Oula and Ziga, trees are kept in the fields primarily for their fertilizing role. In these two villages, the proportion of producers motivated for this reason is 51% and 49%, respectively. In contrast, 32% of producers in Gourga and 42% of those in Sonh preserve trees mainly for food, wood, and fodder.

Useful tree species are selected by farmers during weeding according to individual criteria. A tree's ability to meet food needs is a key factor in its selection for 41.66% of farmers in Sonh and 37% of those in Ziga.

Table 1 Definition of all variables used in the model.

Variables	Description	Variable type and possible sign
ADEPTEZF	Dependent variable: 1 if there is adoption and 0 otherwise.	Qualitative
Socio-economic factors		
Educational level (NIVINSTRUCT)	Farm manager's instruction: 1 if the producer is educated (can read and write), 0 otherwise	Qualitative +
Means of travel (NBVELO)	The total number of bicycles on the farm	Quantitative +
Agricultural equipment (NBHOUE)	The total number of hoes on the farm	Quantitative -
Perception of fallow land (PJACH)	If the farmer considers fallow land as a way to reclaim his land, 1 if he considers it and 0 otherwise.	Qualitative +
Number of small ruminants (NBPETITRUM)	The total number of sheep and goats on the farm	Quantitative +/-

Table 1 to be continued

Environmental factors		
Available areas (SUPERDISPO)	Unexploited areas	Quantitative +
Quantity of organic matter (QMO)	The average amount of organic matter mobilized per year	Quantitative +
Duration of plot use (DUREEXPLOIT)	The number of years a field has been cultivated before the main fallow period	Quantitative -
Source of care from the producer (SS)	The producer's main source of healthcare: 1 if they primarily use traditional medicine and 0 otherwise	Qualitative +
Loan of work equipment (PRETMAT)	The producer's willingness to borrow work equipment from colleagues during the rainy season: 1 if they lend it, and 0 otherwise	Qualitative +

Table 2 Importance of trees for producers and selection criteria per village.

		Gourga	Oula	Sonh	Ziga
Reasons to keep the tree in the field (%)	Stop desertification	7.31	5.40	0	10.63
	Operational requirements	31.70	18.91	42.10	17.02
	Windbreak	12.19	10.81	7.89	4.25
	Soil fertilizer	26.82	51.35	31.57	48.93
	Field humidification	4.87	5.40	10.52	10.63
	Positive effect on rainfall	7.31	2.70	5.26	8.51
	Tree protection	9.75	5.40	2.63	0
Selection criteria (%)	Trees for human consumption	11.62	25.64	41.66	37.17
	Fodder trees	13.95	12.82	5.55	17.14
	Medicinal Trees	18.60	12.82	8.33	2.85
	Need wood	27.90	28.2	13.88	14.28
	Trees with fertilizing properties	0	12.82	25	8.57
	Trees with extensive foliage	11.62	2.56	0	0
	Other criteria	6.97	0	5.55	17.14
	Abstention	9.30	5.12	0	2.85

In contrast, for 28% of farmers in Gourga and Oula, more attention is paid to tree species that provide timber. Trees improve soil structure, promote infiltration, and reduce runoff. They provide products (fruit, leaves, wood) and services (shade, etc.) to farmers who protect and respect them [22].

5.2 Species Density

The practice of zaï has encouraged the colonization of fields by woody plants (Table 3). It is up to the farmers to control and protect them. The average adult density is 957.7 individuals/ha in fallow land and 257.79 individuals/ha in fields. However, in fields, there was a very high number of stumps (148.91 individuals/ha compared to 58.33 for fallow land). This situation was explained by the fact that farmers cut branches from field trees for fodder. Some of these trees were no longer able to survive due to the area's unpredictable climate (low rainfall). However, fallow land is monitored by the farmer who advocates for resource exploitation, which promotes the growth of woody plants. Leaving zaï plots fallow encouraged an increase in the number of trees [23].

5.3 Valorization of Forest Zaï Products

In the zaï plots, the farmer's attention was focused on the trees that directly benefit him. These trees served as a source of medicine, provided food (fruits, leaves), fodder, and wood (Table 4). Across the entire study area, traditional medicine remained the primary source of healthcare. Access to health services was limited not only by a lack of infrastructure but also by a lack of resources. The species most frequently used for healthcare purposes were *Cassia sieberiana* (33%) and

Guiera senegalensis (31%). These species had the advantage of treating several diseases simultaneously. *Cassia sieberiana* was an important medicinal plant for the people of Yaadga [10]. *Guiera senegalensis* grows in the Sahel-Sudanian zone and has cough-reducing, fever-reducing, and antidiarrheal properties [24]. A density of 151 ha^{-1} for *Cassia sieberiana* and 220 ha^{-1} for *Guiera senegalensis* was recorded on a plot developed as a zaï in Gourga [25]. Non-timber forest products contribute significantly to human nutrition. The main trees preserved in the field for food use are *Lannea microcarpa* (82%), *Vitellaria paradoxa* (62%), and *Sclerocarya birrea* (45%).

These species were of great socio-economic importance to producers. They contribute to the fight against food insecurity in the Yaadga Province [10]. The lack of fodder is one of the main constraints to livestock farming in the North. To overcome this problem, local populations were increasingly turning to woody plants to feed their livestock, especially during

Table 3 Comparative densities of woody species sampled in the plots.

	Density of individuals in the fields (ha)			Density of individuals in fallow land (ha)		
Villages	Adults	Seedlings	Strains	Adults	Seedlings	Strains
Gourga	324.37	272.5	76.25	637.5	430	205
Oula	245	255.71	297.14	1363.33	508.33	18.33
Sonh	210.55	500.55	176.66	895	590	10
Ziga	251.25	486.87	45.62	935	182.5	0
Average	257.79	378.9	148.91	957.7	427.7	58.33

Table 4 Mains species used by producers.

Species		Parts used	Uses	Frequency (%)				
Main species used in pharmacopoeia Therapeutic virtues								
Botanical name	Local name in Moore	Parts used		Gourga	Oula	Sonh	Ziga	Total
Cassia sieberiana DC.	*Kombressaka*	Le, Ba, Ro	Stomach aches, wounds, malaria, jaundice, eyes, nail infections, constipation	38.23	0.43	25	25	33.07
Guiera senegalensis J. F. Gmel	*Wiliwiga*	Le, Ba, Ro, Fl, Fr, Tap	Body aches, dysentery, malaria, colds, coughs, stomach aches, kidney problems, eye problems, diarrhea, convalescence, bewitchment, decoction	47.05	31.3	25	18.8	30.76
Piliostigma reticulatum (DC.) Hochst.	*Bangandé*	Le, Ba, Tap	Malaria, stomach aches, proctitis, wounds, jaundice, cough, constipation, decoction	17.64	18.8	15.62	6.25	14.61
Main species used in human food—Seasons of the year								
Lannea microcarpa Engl. & K. Krause	*Sibga*	Fr	Rainy season	76.5	81.25	78.12	90.62	81.53
Vitellaria paradoxa Gaertn.f	*Taaga*	Fr	Rainy season	64.7	71.87	71.87	75	62.3
Sclerocarya birrea (A. Rich.) Hochst.	*Nobga*	Fr	Dry season	50	37.5	40.62	50	44.61
Most commonly used forage species—Animals fed								
Acacia sieberiana DC.	*Kombressaka*	Le, Fr	Beef, goat, sheep	17.64	50	34.37	21.87	30.76
Piliostigma reticulatum (DC.) Hochst.	*Bangandé*	Le, Fr	Beef, goat, sheep	26.47	21.87	9.37	40.62	25.38
Pterocarpus lucens Guill. & Perr.	*Pinpinrega*	Le, Fr, Tap	Beef, goat, sheep	29.41	12.5	18.75	18.75	20

Table 4 to be continued

Species used in crafts—Tools made								
Annogeisus leiocarpus (DC.) Guill. & Perr.	*Siiga*	Wood	Daba handle, pickaxe handle	5.88	0	18.75	25	12.3
Combretum aculeatum Vent.	*Kourkoutouga*	Wood	Pickaxe handle	0	3.12	6.25	31.25	10
Combretum micranthum G. Don	*koïga*	Wood	Pickaxe handle, pestle	0	0	18.75	9.37	6.92
Diospyros mespiliformis Hochst. Ex A. Rich.	*Ganka*	Wood	Pickaxe handle	5.88	0	18.75	3.12	6.92

Legend: Le: leaf; Ba: bark; Tap: tapinanthus, Fl: flower; Fr: fruit; Ro: root.

the dry season. The main species harvested were: *Faidherbia albida* (45%), *Acacia sieberiana* (31%), and *Piliostigma reticulatum* (25%). However, within the region, the pressure on the trees varies from one village to another. These differences in frequency of mention were due to the floristic composition and abundance of these various species in the villages. The flowers and pods of *Piliostigma reticulatum* promote the fattening of sheep [22]. In the study area, certain species were preferred for utilitarian crafts. The main ones were *Annogeisus leiocarpus* (12.3%), *Combretum aculeatum Vent.* (10%), *Combretum micranthum* (6.92%) and *Diospyros mespiliformis* (6.92%). They were particularly valued for the strength of their wood. The craft objects, which were primarily intended for consumption on the farm, included pickaxe and hoe handles. The wood was used for heating, building houses, and in the manufacture of certain agricultural tools for rural households [26].

5.4 Factors Influencing the Adoption of Forest Zaï

The results of the logit model showed that most of the variables examined had the predicted signs. Variables such as farmers' perception of fallow land (PJACH), the number of small ruminants (NBPETIRUM), and the number of hoes (NBHOUE) on the farm positively and significantly affected farmers' decisions to adopt the forest zaï technology at the 1% significance level. Indeed, farmers' perception of a technology can influence its adoption [27]. A study conducted by these authors in Ethiopia on the adoption of stone bunds indicated a positive correlation between this variable and the adoption of the technique.

The influence of small ruminant numbers on the adoption of soil and water conservation techniques varies by region. This variable was not significant in the adoption of the zaï agricultural system and stone bunds by farmers in Yaadga [13]. In contrast the same variable is positively correlated with the adoption of stone bunds for farmers in Central Ethiopia [27]. In our case, farmers with large numbers of small ruminants expressed a need for grazing land. In the region, farmers were developing strategies to protect shrubs from goats and sheep. At harvest time, they cut the stems at chest height to prevent small ruminants from breaking the retained shrubs. Since the hoe is the primary tilling tool, farmers cannot expand their cultivated area and leave other fields fallow, hence the use of the forest zaï technique.

The variables "sources of care" (SS) and "equipment loan" (PRETMAT) are positively correlated with the adoption of the technology, but only at the 10% significance level. In rural areas, access to medical care is very difficult. Farmers who rely on traditional medicine as their primary source of care retain medicinal trees in their fields. By adopting the forest zaï technique, these farmers increased their reserves of medicinal plants. The forest zaï system requires significant investments in labor, time, and land protection, which cannot be undertaken without a minimum of social support. In the context of the Mossi societies of Yaadga, lending agricultural equipment is not a voluntary act of individual cooperation, but a structuring social obligation. Refusal to lend equipment exposes the producer to symbolic sanctions (loss of reputation, conflicts, marginalization) that can affect their future access to

Table 5 Logit model estimation results.

Explicatives variables	Coefficients	Z statistic
PJACH	2.882218*	4.938121
NBVELO	-0.851871*	-3.064727
NBHOUE	0.200927*	2.729334
NBPETIRUM	0.060910*	2.419054
PRETMAT	0.856446**	1.727131
QMO	-0.026675**	-1.712403
SS	0.923070**	1.696190
DUREEXPLOIT	0.030977	1.572282
SUPERDISPO	-0.031840	-1.358579
NIVINSTRUCT	-0.474269	-0.996233
CONSTANTE	-2.504855	-3.031956
LR statistic (10df)		54.86128
Probability (LR stat)		0.000000033
Adoption correctly predicted (%)		80
Non adoption correctly predicted (%)		71.67
Total correctly predicted (%)		76.15
N		130

Significance: * = 1 %; ** = 10%.

labor, information, and local resources. Producers who adopt the forest zaï system strengthen their social position and visibility within the community, thereby increasing their participation in reciprocal networks.

6. Conclusion and Recommendations

This study was conducted in the Sudanian-Sahelian zone (Yaadga Province), an area characterized by significant degradation of natural resources. It analyzed the factors influencing the adoption of the forest zaï technique and the potential for adding value to its products in rural communities. A significant number of woody species are retained in fields and preserved in fallow land by over 75% of farmers. These species, primarily shrubs, are more densely distributed in fallow land than in fields. They play an important socio-economic and agronomic role. The adoption of forest zaï depends not only on technical or economic factors, but also on the integration of producers into local social networks. Policies promoting this technology would benefit from building upon existing groups, lineages, and community structures, in order to ensure that only the most integrated producers reap the rewards.

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Conflict of Interest Declaration

None.

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