ADOPTION AND ABANDONMENT OF GUM ARABIC AGROFORESTRY IN SUDAN

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ABSTRACT

Deforestation of the gum belt in Sudan is a serious problem that threatens agricultural production. Although several programs have been developed to rehabilitate the belt area, adoption of the gum agroforestry system has not been widespread. Many original adopters have abandoned gum production and the bush-fallow crop rotation that traditionally involves the gum tree. This paper focuses not only on the adoption of gum agroforestry but also on the abandonment of the same technology by farmers who adopted in the past. We use farm-level data from western Sudan and analyze gum adoption and abandonment using a bivariate probit model to identify the most important factors influencing the decisions on gum arabic production and the traditional bush-fallow system. Empirical results show that gum (dis) adoption is determined not only by structural factors like farm size and farm fragmentation but also by factors that affects the opportunity cost of labor. The study suggests that abandoning gum production should be understood in light of changes induced by drought in both the international market for gum and the economic environment in the region.

Keywords: *Acacia*; bush-fallow; bivariate probit; deforestation; drought; socioeconomic

INTRODUCTION

Deforestation, growing scarcity of tree products, and environmental degradation have created serious problems for rural land use in many developing countries. To address this threat a large number of projects have been developed to promote the adoption of agroforestry. Farmers in developing countries, however, show low rates of adoption and/or abandonment soon after adoption (Pattanayak et al. 2002). Faced with this situation many researchers have called for socioeconomic appraisal of agroforestry system (Current et al. 1995; Mercer and Miller 1998). This study aims to identify socioeconomic and institutional factors that are likely to explain the adoption and abandonment of the gum agroforestry system in Sudan.

The paper highlights the environmental role of gum agroforestry in agricultural production in Sudan and focuses on the decline of gum arabic production. The study contributes to a new understanding of the evolution of agroforestry systems, since it focuses not only on the adoption of gum trees but also on the abandonment of the same technology by farmers who adopted in the past. Analysis of this aspect provides additional insight for policy makers and helps in identifying factors that stimulate gum production. We use primary data obtained from a farm-level survey in Western Sudan and applied a bivariate probit model to analyze the process of gum arabic adoption and subsequent abandonment. Empirical results from survey data are summarized, and the socioeconomic and institutional factors influencing adoption or abandonment of gum arabic and the bush-fallow system are discussed.

The structure of the paper is as follows. Section 2 describes the gum agrofrestry system and section 3 discusses the recent decline in Sudanese gum trade. Section 4 explains the empirical model used to analyze gum adoption and abandonment. In section 5 the data and statistical results are summarized. Section 6 contains the empirical results and the discussion. The final section provides policy conclusions.

THE GUM ARABIC AGROFORESTRY SYSTEM

Gum arabic is produced from two acacia varieties, which are found to a varying intensity in the gum belt of Sub-Saharan Africa. These varieties are *Acacia senegal* and *Acacia seyal*. *Acacia senegal* is widely distributed and shows a remarkable adaptability to both drought and frost. It grows in areas with an annual rainfall of 200-800 mm (NAS 1983). *Acacia senegal* is found in Africa across a belt extending from Senegal to Ethiopia, passing through Mali, Nigeria, Chad, Somalia, and Sudan. It is known by many different local names, but in Sudan both the tree and its gum are called Hashab. Sudan is known to have a higher density of *Acacia senegal* with a uniform distribution of the tree in pure stands, making the country the most important producer of hashab gum arabic (Macrae and Merlin 2002). In order for hashab to produce gum the tree has to be tapped or injured about 3-6 weeks before collection. The other gum-producing tree—*Acacia seyal*—grows almost in the same geographical zone but in areas with slightly higher rainfall than areas populated with *Acacia senegal*. The gum produced from *Acacia seyal* is known locally as Talha and is regarded as being inferior to Hashab in terms of quality.[1]

The land use system for gum production is a bush fallow system.[2] Under this system each plot of land is used to cultivate crops for about 4-5 successive years followed by a period of 15-20 years of fallow under regenerating hashab. When the production of gum arabic declines, the trees are cut to put the plot under cultivation and during this period the tree coppices naturally. The tree is known to offer a number of environmental benefits, the most important are that its extensive lateral root system reduces soil erosion and run off and as a leguminous tree it fixes nitrogen which improves soil fertility (Pearce 1988; Barbier 2000). Deans et al. (1999) predict nutrient and organic matter accumulation in *Acacia senegal* fallow over 18 years in northern Senegal and recorded a substantial increase of N and K in surface soil with plantation age. Their study concluded that N accumulated in 15 years of fallow provides good sorghum yields for at least four cropping cycles. Based on these benefits *Acacia senegal* is a preferred species in the semi-arid areas of the Sahel and is used on a large scale as a buffer zone against desertification. Nonetheless, the gum arabic belt is suffering from increased deforestation due to drought, population movement, and the declining market for gum arabic.

THE DECLINE IN SUDANESE GUM TRADE

Gum arabic has few local uses, but is demanded on the international market mainly by the pharmaceutical and food industries. Sudan is historically known to be a major exporter, however, during the past 30 years production in Sudan shows alarming signs of overall decrease and also a substantial year–to-year variation. The average production in Sudan has

[1] Hashab gum is known as hard gum in the world market and talha gum is known as friable or flaky gum.
[2] In this study we focus on hashab agroforestry system and we use the terms gum agroforestry and hashab agroforestry system interchangeably.

declined from 46,000 metric tons (MT) in the sixties to 28,000 MT in the nineties. Figure (1) shows the total exports on the world market since 1925 and the share of Sudan. Years of the Sahel drought (1970s-1980s) marked a turning point in the export of gum arabic with the level of export declining to around 25,000 MT; this led many importers to seek alternative sources of supply and to turn to manufactured substitutes. During the 1990's world exports have started to pick momentum again, however, exports from Sudan almost remained the same, due to stagnating production in Sudan as well as the growing competition of other exporters, mainly Chad and Nigeria. Figure (2) indicates hashab grades on the export market have fallen greatly after 1995. The price of talha gum on the other hand has remained the same as the demand has increased at roughly the same rate as supply.

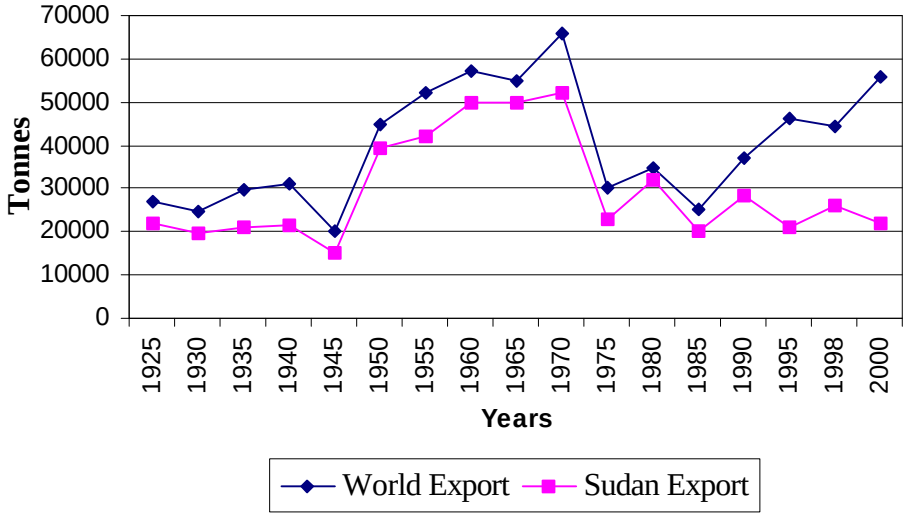

Figure 1: World market and Sudan exports of gum arabic (1925-2000).[3] *Source:* Macrae and Merlin (2002).

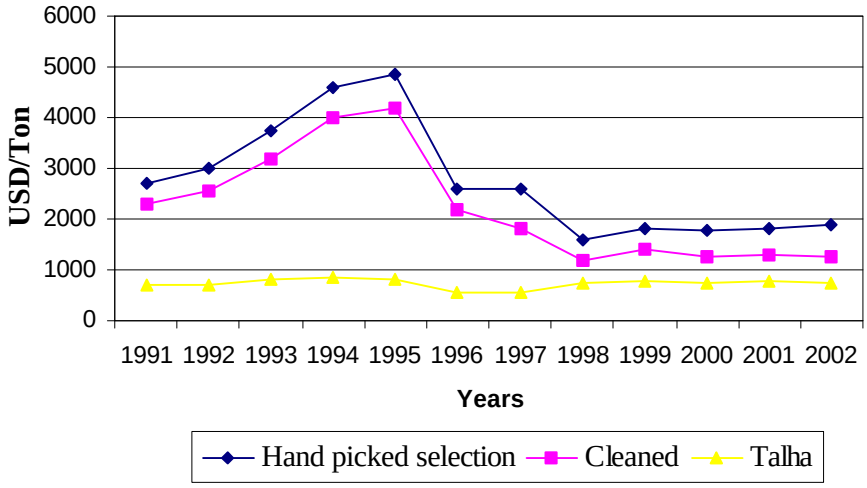

Figure 2: Export prices by grades of gum arabic- Port Sudan FOB ($USD/Tons).[4] *Source*: Gum arabic company annual reports.

[3] Exports in this figure include both Hashab and Talha gum.

[4] Hand picked selection (HPS) and Cleaned are the top grades of hashab gum. HPS- is a form of clean and uniform size granules that have been carefully selected and fetch a premium price. Cleaned grade consists of whole or broken lumps.

Since the early eighties a number of development projects have been sponsored by international donors to rehabilitate the gum belt in Kordofan and Darfur region. Most important was the restocking programs and the promotion of gum trees planting, where seedlings produced in central nurseries were delivered to farmers free of charge supported by extension service.[5] Policy makers had attributed the decline in gum production mainly to drought and desertification and the resulting tree destruction. Restocking of the gum belt was therefore perceived as a mean of reversing the trend of environmental degradation and sustaining the economic and environmental benefits of gum land use system. Despite these efforts, gum production remained low. In our view, climatic factors can explain seasonal variation in gum production but are not the only reason for the declining trend in production. Particularly after all these rehabilitation efforts, other factors related to the incentive structure and the behavior of farmers must have contributed to the continuous decline in gum production.

EMPIRICAL MODEL

A large number of studies have considered factors determining the rate, timing and extent of adoption of agricultural innovations (Feder et al. 1985; Rogers 1995). However, few studies have considered factors influencing disadoption (Neil and Lee 2001) is a notable exception. Failure to take disadoption into consideration implies an implicit assumption that adoption choice is irreversible. Such assumption does not hold in the case of gum agroforestry system in Sudan, where it is estimated that more than 40% of the producers have abandoned gum production during the period 1993-1998 (Awouda 1999).

In the case of the gum agroforestry system, farmers in the gum belt typically face two decisions: whether to adopt the system and, later, whether to abandon or maintain it. The issue of abandonment is examined among the adopters of gum arabic production only. The distinction of the gum adoption process into adoption versus nonadoption and continuous adoption versus abandonment provides an opportunity to empirically reveal factors that affect the decision on the land use system (Neil and Lee 2001).

The empirical model used in this study is a bivariate probit model (Pindyck and Rubinfeld 1998). The decision framework includes two dichotomous decisions, the initial adoption decision and the subsequent continuous adoption decision, the second contingent on the outcome of the first. The contingent nature of the second decision requires that coefficients not only reflect the probability of continuous adoption, but also the factors that affect the conditional probability that the farmer will continue to adopt, given that the farmer has already adopted:

$$p(y_2 = 1) \mid (y_1 = 1) \qquad (1)$$

Where

p indicates the probability of continued adoption $(y_2 = 1)$ if a decision on adoption has been made in the first part $(y_1 = 1)$.

[5] Gum belt restocking projects took place during the period 1980-1995 and were implemented in three phases. Estimates of the number of hashab seedlings distributed during this period exceed 15 millions seedlings (Awouda, 1999).

Since the second decision is the reversal of the first, the disturbance terms of the two equations are likely to be correlated as some unobservable characteristics, captured in the error terms of the adoption equation, can influence the error terms in the continuous adoption equation.

The bivariate probit model is used because it provides a correlation term, r , that represents how the unobserved characteristics affecting the first decision are related to the second. Moreover, the model may be modified to account for the sample selection problem implicit in the decision framework, as it is not possible to abandon the gum agroforestry system unless one has first adopted it; hence y_2 is not observed when y_1 is equal to zero. In the model specification we assign $y_1 = 1$ to the adoption decision, hence $y_1 = 0$ indicates nonadoption. Similarly $y_2 = 1$ is assigned to continued production of gum and $y_2 = 0$ to abandonment. Therefore, positive coefficients in both decisions will be associated with increased probability of gum arabic production and negative coefficients with a decreased probability.

The specification for the two equations bivariate probit model with sample selection is given by Neil and Lee (2001):

$$
\begin{aligned}
&z_{i1} = b_1' x_{i1} + e_{i1}, y_{i1} = 1 \text{ if } z_{i1} > 0, y_{i1} = 0 \text{ if } z_{i1} < 0, \\
&z_{i2} = b_2' x_{i2} + e_{i2}, y_{i2} = 1 \text{ if } z_{i2} > 0, y_{i2} = 0 \text{ if } z_{i2} < 0, \\
&e_{i1}, e_{i2} \sim BVN(0,0,1,1,r),\ Var[e_1] = Var[e_2] = 1, Cov[e_1, e_2] = r, \qquad (2)
\end{aligned}
$$

(y_{i2}, x_{i2}) is observed only when $y_{i1} = 1$,

Where

z_{ij} Latent variable representing the utility the i^{th} farmer receives from adopting gum production (j = 1) and continuing to adopt gum production (j = 2)

x_{ij} A set of explanatory variables affecting the i^{th} farmer decision

b_j' Coefficients of the explanatory variables

e_{ij} Disturbance term of the adoption equation (j=1) and the abandonment equation (j=2).

BVN Bivariate normal distribution

The model considers the effect of the explanatory variables x_{ij} on three probabilities: First, the probability that a farmer adopts and continues to produce gum:

$$p(y_{i1} = 1, y_{i2} = 1) = p(z_{i1} > 0, z_{i2} > 0) = f_2(b_1' x_{i1}, b_2' x_{i2}, r) \qquad (3)$$

Second, the probability that a farmer adopts and later abandons gum production:

$$p(y_{i1} = 1, y_{i2} = 0) = p(z_{i1} > 0, z_{i2} < 0) = f_2(b_1' x_{i1}, -b_2' x_{i2}, -r) \qquad (4)$$

Third the probability that a farmer never adopts:

$$p\ (y_{i1} = 0, y_{i2} \text{ unobserved}) = p(z_{i1} < 0) = f_1(-b_1' x_{i1}) \qquad (5)$$

Where

f_1 The univariate normal cumulative distribution function

f_2 The bivariate normal cumulative distribution function

The probability of abandonment of the i^{th} individual is the product of each of these individual probability density functions, expressed in log form. Summing over all individuals in the sample gives the log likelihood function:

$$\ln L = \sum_{y_1=1, y_2=1} \ln f_2\left[b_1' x_{i1}, b_2' x_{i2,} r\right] + \sum_{y_1=1, y_2=0} \ln j_2\left[b_1' x_{i1}, -b_2' x_{i2}, -r\right] + \sum_{y_1=0} \ln f_1\left[-b_1' x_{i1}\right]. \quad (6)$$

Maximum likelihood estimates are obtained by taking the derivatives of the log likelihood function with respect to the coefficients and the correlation term and setting them simultaneously equal to zero (Greene 1990).

$$\frac{\partial \ln L}{\partial b_1} = \frac{\partial \ln L}{\partial b_2} = \frac{\partial \ln L}{\partial r} = 0 \quad (7)$$

The statistical software package Limpdep 7.0 was used to generate the maximum likelihood coefficients, standard errors and r values. If the null hypothesis that r = 0 is not rejected, implying no correlation between the error terms of the two equations, the two equations may be estimated with separate probit models.

We have used this model to suggest a possible explanation for the low adoption rate as well as abandonment of the system. We estimated two different specifications; (i) adoption and (ii) continued adoption to analyze which factors are most important in explaining the adoption and/or abandonment of gum agroforestry system. As adoption took place on average more than 20 years ago, only variables that are relatively stable over time (e.g., farm size, distance to the nearest market) are included in the adoption equation. Whereas variables that reflect current activities such as off-farm income, livestock units and current market value of assets are included in the abandonment equation. The equations below represent the general form of the decisions modeled:

$$y_1 = b_0 + b_1 AGE + b_2 EDUC + b_3 MKTDIST + b_4 FARMSZ + e_1 \quad (8)$$

$$y_2 = b_0 + b_1 AGE + b_2 EDUC + b_3 MKTDIST + b_4 FARMSZ + b_5 OFFICOM. + e_2 \quad (9)$$

Where

AGE	Age of the household head
EDUC	Education level of the household head
HHSZ	Household family size
FARMSZ	No of hectares owned by the household head
OFFICOM	Total income generated from off farm activities in thousands Sudanese dinars.[6]

[6] 1 Euro = 280 Sudanese dinars (SD), July 2003.

SURVEY DESIGN AND SUMMARY STATISTICS

Survey design

The data used in this study were collected through an interview of farmers in Kordofan region of Western Sudan during the period March-July 2003. Kordofan was selected based on its long history of gum production, more than half of gum arabic produced in Sudan comes from this region. A random sample of 27 villages was selected from three states in Kordofan. In each village we carried out an informal discussions and semi-structured questionnaire to collect data from key informants on land tenure, land use systems, livelihood strategies as well as the existing institutional structure. Thereafter a census was performed of all farming households in each village to construct the sampling frame for the study. We stratified farm households at each village into three categories: "adopters" who were currently producing gum, "disadopters" who had previously produced gum but discontinued the practice for at least 3 years as from the survey time, and "nonadopters" are those who had not produced gum before. Households were randomly drawn from each stratum at each village, out of the 377 collected observations, 368 are used in this analysis.[7]

Table 1. Description of explanatory variables and expected signs.

Explanatory variable	Description	Expected sign for adoption	Expected sign for continued adoption
FARMSZ	Farm size (hectares);	+	+
AGE	Age of household head (years);	+	+
EDUC	Education level of household head (years);	+	+
FMSZ	Family size;	+/-	+/-
FRAG	Farm fragmentation (number of farm plots);	+	+
EXTNDUM	1 if the farmer has received extension services during the last 3 years, 0 otherwise;	+	+/-
MKTDIST	Distance to the nearest town market in Km;	+/-	+/-
PLOTDIST	Average distance of plots from the house in Km;	–	–
CREDDUM	1 if the farmer received credit during the last 3 years, 0 otherwise;	+	+/-
INHERIT	Size of inherited land (hectares);	+	+
ADULT	Number of adult members over 14 years;	+	+
EXP	Experience in gum production measured by years of adoption;	n/a	+
LUNIT	Livestock units (index where livestock numbers are aggregated using following weighing factors; camel = 1, horse=0.9, cow=0.8, donkey=0.8, sheep=0.4, goat=0.4);	n/a	+/-
OFFICOM	Income from off farm work in 000 SD	n/a	-
ASTCV[8]	Current value of assets owned by the household (000 SD);	n/a	-
r	Correlation term between decisions	?	?

n/a = Not applicable

The questionnaire covered various socioeconomic characteristics of the farm household and its surrounding institutional environment. Socioeconomic factors include land holdings, family size, age and education of the household head, and income composition. Institutional

[7] During the analysis 9 observations were excluded because of missing data or because they are outliers.

[8] The current value of the asset was calculated by deducting an annual depreciation expense of 2.5% for buildings and 10% for other fixed (durable) assets e.g. radios and agricultural machines. For lands and jewelry the current value is the purchase price, as these assets do not loose value by use.

factors are the distance to the nearest town market, formal exposure to extension and credit as well as problems encountered with gum production. Table 1 summarizes the expected sign on the coefficients of the variables measuring the determinants of adoption and abandonment. Both farm size and the size of the inherited land are expected to be positively associated with adoption and continued adoption as farmers with small holdings will give more priority to the production of food crops. On the other hand farmers, with large holding are in a better position to follow the traditional gum rotation. In a similar view, farm fragmentation is expected to have a positive effect on both adoption and continued adoption as farmers who have large number of plots can leave some plots under hashab stand and cultivate annual crops on the other plots. We expect that average distance of plots to the homestead will have a negative effect on both decisions, as smaller distance would imply less commuting time.

Previous research revealed a positive relationship between age and the likelihood of agroforestry adoption (Pattanayak et al. 2002). We also hypothesized that age is positively related to both adoption and continued adoption as older farmers are less likely to opt for other off-season income sources, especially those involving seasonal migration. It also hypothesized that farmers who have produced gum for a longer period of time (as measured by years of adoption) will have greater appreciation of the benefits of the system, as compared to recent adopters; therefore, we expected a positive coefficient sign in the abandonment equation. Educated farmers have been found to have greater likelihood of adopting conservation technologies (Adesina et al. 2000). We hypothesize education of the household head to be positively associated with both equations. The effect of family size on both adoption and abandonment is difficult to predict. On one hand family size, is a proxy of household labor supply which implies a positive relationship. On the other hand, large families have more persons to feed and will strive to secure food requirements first; therefore a negative relationship is also possible. We hypothesize that the number of adult members in the family to be positively associated with both decisions as it implies less labor constraint.

Literature on adoption of agricultural technology suggests that extension and credit services bear a positive sign in explaining the likelihood of adoption. However, it is not clear if they will have the same effect on the abandonment decision. The effect of market distance on adoption and abandonment of gum agroforestry is ambiguous; the distance variable captures the price effect and may, therefore, be negatively related with both equations (long distance to the market imply a longer marketing chain and a lower price incentive). However, the further away the farmer from the market the lower the probability of having off-farm income and thus a positive expected relationship in both adoption and abandonment equations.

We include the variables *off-farm income*,[9] *livestock units* and *current value of assets* owned by the household, in the abandonment equation as they represent competing activities and wealth. Studies have shown that off-farm work positively influences adoption of agricultural technologies (Adesina et al. 2000), as off-farm incomes may allow farmers to meet the inherent costs of new technologies (such as seeds and hiring of labor). However, we expect a negative association between off-farm income and continued gum adoption, as off-farm income implies a decline in a farmer's dependence on gum as a dry season income. The effect of livestock units on abandonment is less clear, while gum agroforestry provides fodder for animals; livestock otherwise, might also imply less reliance on gum as source of income and therefore, both positive and negative influence are possible. As the category of assets

[9] Off-farm income sources include farm labor on a seasonal migrant basis (to irrigated and mechanized sectors), local entrepreneurial business, employment and entrepreneurial business away from the village on a temporary migrant basis, and remittances.

excludes agricultural land holding and hashab trees and only includes items used for off-farm income (such as animals' carts and small shops) we expect, *a priori*, that the variable current asset values will have a negative influence on continued adoption.

Data

Table 2. Farmers' stated reasons for abandonment.

Reason for abandonment	**Proportion of abandoner***
Low gum returns	43 %
Have off-farm work	26 %
Moved or displaced	19 %
Lost hashab	16 %
Insufficient land	11 %
Lack of finance	4 %
Other	2 %

Due to multiple responses in some cases, percentages do not sum to 100.

Table 2 shows farmers' stated reasons for abandonment. A high percentage of the respondents (43%) mentioned low gum returns as main reason for abandoning. Gum tapping and gum production are highly elastic to prices (Bateson and Tohami 1986). Little gum is produced when prices are low and when prices are high the trees are overtapped and sometimes killed in the process (Larson and Bromley 1991). The gum marketing and pricing policy are controlled by the Gum Arabic Company (GAC) which was established by the government to control gum trade and ensure fair returns to the gum producers by operating a minimum price mechanism. The policy on the minimum floor price is, however, not properly functioning and creates a disincentive for gum production and the planting of trees. Most farmers sell their gum to intermediate merchants, although the direct cash they receive is less than the announced floor price. About 85% of the surveyed producers do not sell their product in the GAC auction markets due to lack of cash, transport and small quantity produced and 65% sold their gum at prices lower than the floor price. Other important reasons for abandonment stated by the farmers are off farm work (26%), displacement (19%) and loss of hashab assets due to drought (16%).

Table 3 represents summary statistics from surveyed farm households, divided into three groups: adopters of the gum agroforestry system, abandoners and nonadopters. Adopters appeared to have significantly larger farm size and larger size of inherited land compared to the other two groups. This is not surprising, as shown by the stated reasons for abandonment where 11% of the abandoners mention insufficient land as a reason for discontinuing gum production. Abandoners earn significantly more off-farm income and adopters have the lowest average off-farm income. This may suggest adopters are more dependent on farming activities in general and specifically gum production as an important source of income.

The average age of the sampled farmers is 43 years; nonadopters are younger than the other two groups. Education level of the sampled farmers is low, the average years of formal education is 3, however, nonadopters appeared to have the highest average of formal education compared to the other two groups. The data do not reveal significant distinction between the three groups in relation to extension services, but a higher percentage of adopters receive credit services.

Table 3. Mean comparisons of adopters, nonadopters, and disadopters.

	Adopter N = 228	**Nonadopter N= 81**	**Disadopter N= 59**
Farm size (hectares)	53.63[b]	24.74[b]	38.17
Age of household head (years)	44.5	36.71[f]	45.49
Education level of household head (years)	2.73	4.79[f]	2.68
Family size	7.36	6.6[d]	8.31[d]
Farm fragmentation	2.74[a]	2	2.08
Extension (%)	21.5	23.5	10.2
Distance to the nearest town market in Km	66.57[a]	41.96	51.92
Average distance of plots from the house in Km	9.24	7.29	14.67
Credit (%)	16.2[a]	2.5	5.1
Member of agricultural society (%)	14.5	7.4	10.7
Size of inherited land (hectares)	48.26[b]	19.03[b]	27.96
Number of adult members over 14 years	3.65	3.13	3.44
Experience in gum production (years of adoption)	21.47[c]	N/A	13.75[c]
Livestock units	9.89	6.18	6.27
Income from off farm work (000 SD)	338.91[a]	604.65	642.37
Current value of assets owned by the household (000 SD)	140.54	264.71	163.23

[a] Mean for adopter is different from the other two means Games-Howell test at $\alpha = .05$. [10]
[b] Mean for adopter different from non adopter Games-Howell test at $\alpha = .05$.
[c] Mean for adopter different from disadopter Games-Howell test at $\alpha = .05$.
[d] Mean for nonadopter different from disadopter Games-Howell test at $\alpha = .05$.
[f] Mean for nonadopter is different from other two means Games-Howell test at $\alpha = .05$.

DETERMINANTS OF (DIS) ADOPTION

In this section we discuss the empirical results of our model in relation to the findings of other adoption studies and the implications for the promotion of a sustainable gum agroforestry system.

Table 4 presents the results of the two specifications of the bivariate probit model; care was taken not to include collinear variables in the same specification. In model (1) we include farm size, which is replaced by size of inherited land in model (2) for both adoption and abandonment equations. We also replace years of experience in model (2) with age in model (1) for the continuos adoption equation (as pair-wise correlation reveals significant level of correlation between farm size and size of inherited land, age and years of adoption).[11] We estimated a general model including the variables in table 1; some of the variables however, were not significant in the estimation and were dropped out in a step-wise process. The variables extension and access to credit that are found to be significant factors for adoption of technology in several other studies (Feder et al. 1985) were not found to be significant determinants of (dis) adoption of gum agroforestry. Generally, economic instability and government budget constraint limited the influence of formal institutions in remote areas of Sudan; this explains why extension and credit were not found to be significant determinant for gum adoption.

Model results confirm the critical importance of farm size and size of inherited land for the initial adoption of gum production. Considering the time span between the planting of hashab tree and the harvesting of the gum (6-7 years) as well as the long term rotation of the

[10] Games-Howell post hoc test was used as it does not assume equal variances and give accurate results when the sample sizes are unequal.
[11] Correlation matrix is shown in appendix A.1.

plantation (20-30 years) only farmers with large holdings and stable ownership will be able to adopt gum agroforestry system. Previous research on the adoption of sustainable agricultural practices shows similar findings. In northern Honduras small farmers appear hesitant to commit their only plot to cover crops if no other land is available for the wet season (Triomphe 1996).

Table 4. Bivariate probit coefficient estimates for adoption and continuous adoption.

		Model 1		**Model 2**	
Decision	**Variable**	**Coefficient estimate**	**SE**	**Coefficient estimate**	**SE**
Adopt	CONSTANT	-1.1005***	.3807	-1.3078***	.3731
	AGE	.0207***	.0059	.0259***	.0059
	EDUCATION	-.0492**	.0210	-.0421**	.0212
	FARM SIZE	n/a	n/a	.0045**	.0019
	SIZE OF INHERITED LAND	.0049***	.0018	n/a	n/a
	FARM FRAGMENTATION	.2288***	.0775	.1964**	.0798
	MAKET DISTANCE	.0101***	.0032	.0097***	.0031
Continuous adoption					
	CONSTANT	-1.1482***	.4311	-1.0469***	.3246
	AGE	.0034	.0076		
	EDUCATION	-.0264	.0272	.0159	.0355
	FARM SIZE	n/a	n/a	.0011	.0019
	SIZE OF INHERITED LAND	.0037**	.0016	n/a	n/a
	FARM FRAGMENTATION	.3448***	.0819	.2412***	.0869
	MAKET DISTANCE	.0099***	.0026	.0086***	.0027
	EXPERIENCE	n/a	n/a	.0245***	.0068
	LIVESTOCK UNITS	n/a	n/a	.0009	.0051
	OFF-FARM INCOME	-.0002**	.0001	-.0002**	.0001
r	Correlation term	.9504***	.1781	.8705***	.1999
	Loglikelihood	-284.8375		-277.2608	
	Loglikelihood ratio test	109.8423***		124.9956***	
	Loglikelihood ratio index	0.1616		0.1839	

*** Significant at the $\alpha = 0.01$ level ($p<0.01$)

** Significant at the $\alpha = 0.05$ level ($p<0.05$)

* Significant at the $\alpha = 0.1$ level ($p<0.1$)

A significant and negative coefficient for education on the first decision stage (adopt) is contrary to expectations. Other studies have shown positive effects for education (Shultz 1964; Boahene 1995). Feder et al. (1985) argue that higher education levels may be associated with better information on the conservation measurement and more management expertise. But in our case, higher education is likely to be related to more accessibility to off-farm work and less reliance on gum as off-season income source.

The effect of farmer's age on adoption decision can be taken as a composite effect of farming experience and planning horizon. While the longer farming experience amongst older farmers is expected to have a positive effect on adoption, younger farmers may have a longer planning horizon and, hence, may be more likely to adopt sustainable technology practices (Lapar and Pandey 1999). Our results show that gum production is adopted by older

generations of farmers as we found age increase the probability of adoption. Young and productive farmers are expected to have access to other sources of income, such as wage labor in casual jobs at village or urban centers, petty trade and agricultural wage labor in mechanized and irrigated schemes. Ghadim and Pannell (1999) presented a conceptual framework which show learning over time to be a significant factor in agroforestry adoption. Our results show that experience as measured by years of adoption has a positive effect on continued adoption in line with expectations.

Results reported in table (3) show that nonadopters are usually wealthier in terms of asset ownership, relatively younger, more educated and living closer to the market compared to the other two groups. These distinguishing characteristics provide them better positions for entering the labor market and for earning alternative income sources such as running entrepreneurial business and earning wage labor in seasonal migration. Another study on migratory labor from the gum belt has shown that migratory laborers are young and productive and predicted that seasonal migration trend is likely to continue in the future which might lead to a gradual disappearance of gum profession (Abu El Gasim and Hammer 1989).

Market distance is found to be a significant determinant of both adoption and continued adoption, farmers living further away from the market are more likely to adopt and continue adopting gum agroforestry. The intuitive interpretation for this result is that farmers remotely-located have less access to off-farm work and are more likely to adopt gum agroforestry to diversify their income sources and have some hedging against the risk associated with monocropping systems. The negative and significant relation of off-farm income with continues adoption supports this interpretation. Neil and Lee (2001) document a similar result in northern Honduras and they attributed disadoption of velvet bean system partly to the improved transportation infrastructure, which increased employment opportunities and the opportunity costs of labor. Results also indicate farm fragmentation has a positive effect on both adoption and continued adoption since operating more fragmented farms enables farmers to follow the traditional gum cultivation cycle. A similar finding was reported in the Philippine, where farm households with more fragmented holdings are found to achieve higher levels of conservation (Pattanayak 1998).

Results for the second conditional decision to abandon or continue producing gum show that size of inherited land is positively associated with continued gum adoption. Displacement due to drought and desertification have caused some of the original adopters to loose their hashab and land (table 2) and forced them to rely more on rental arrangements. Land tenure in terms of acquisition, exchange of rights and transfer in the study area is governed by customary rules and regulations (El-Dukheri 1997). There is no selling and buying of land and acquisition generally takes place through inheritance, though some rental arrangements do exist based on cash payments, crop sharing or free temporary use from the community land. It has been argued that distortions to individual incentives under customary land tenure may cause serious underinvestment in land but customary land tenure institutions may evolve toward greater individualization with more secure individual rights (Ault and Rutman 1979). Individual and transferable land titles are usually regarded important for inducing immobile land-related investment (such as tree planting and conservation), thus explaining the positive effect of size of inherited land for continued adoption of gum agroforestry.

Another significant variable in the abandonment equation is off-farm income, which is found to be negatively associated with continued gum production; this was expected as 26% of the

adopters mentioned off-farm income as a key reason for abandonment. During the 1970s gum production was the second important income source after annual crops but recently income from labor wage migration has gained increasing importance in most parts of the gum belt (IEED and IES 1990). Labor is frequently cited in the adoption literature as a constraint to agroforestry systems, because in many cases labor need for tree management operation coincides with labor demand for other agricultural operations (Current et al. 1995). However, in the case of gum agroforestry system most labor input for the production of gum occurs during the dry season when there is little work in other agricultural crops. Gum trees are tapped in October and November and the picking can continue until March, production of annual crops starts in May by clearing the fields and after this month highly labor-intensive months follow. The dry season is also the period when most off-farm labor takes place and most of the seasonal migration occurs.

Awouda (1999), Macrae and Merlin (2002) stated that migration of labor during the gum collection season to the irrigated and mechanized schemes and other urban centers where better wages are provided is one of the factors behind the decline in gum production. The result that off-farm income negatively influences the continuity in gum production supports the above explanation for the decline in gum production. This result indicates that farmers are looking for better economic options and abandonment of gum agroforestry system should not be strictly related to drought, instead it has to be understood in light of the changing economic environment.

Table 5 shows the marginal effects of changes in X_i on the conditional probability that farmers will continue adopting gum agroforestry given that they initially adopt. Results indicate that a marginal increase in farm fragmentation increases the likelihood of continuing gum adoption by over 7.5% to 13% and for every extra hectare inherited by the farmer the probability of continued adoption increase by 0.14%. Farmers living more distant from the market are more likely to adopt and for every extra Km away from the town market the probability of continuing gum adoption increase by 0.27% to 0.38%. Results on the marginal effect of experience show that for every year a farmer has practiced the gum agroforestry, the likelihood of continuing adoption increase by 0.76%, while for an extra 1000 SD gained by the farmer from off-farm work the probability of continuing gum adoption consistently decrease by 0.01%.

Table 5. Estimated marginal effects of x_J on $p(y_2 = 1 | y_1 = 1)$.

Variable	Model 1 Average Change in $p(y_2 = 1 \mid y_1 = 1)$	Model 2 Average Change in $p(y_2 = 1 \mid y_1 = 1)$
SIZE OF INHERITED LAND	.0014	
LAND FRAGMENTATION	.1331	.0750
MAKET DISTANCE	.0038	.0027
EXPERIENCE		.0076
OFF-FARM INCOME	-.0001	-.0001

The loglikelihood ratio index for the two models is found to be 0.16 and 0.18 respectively and the loglikelihood ratio test is found to be significant at 1% for both models. Moreover, the high significance of r at 1% level in both models, indicates the disturbance terms of the two equations are correlated which implies the bivariate probit model is the appropriate

approach for analyzing the factors that affect the decisions. The positive sign of the correlation term r suggests that the unobservable factors that led the farmers to adopt are the same factors contributing to the continued adoption of gum production.

DISCUSSION AND CONCLUSIONS

In this paper we use both an econometric and a qualitative approach to analyze socioeconomic and institutional factors influencing the farmers' decision to adopt or abandon gum arabic production. The econometric results suggest that gum adoption is determined not only by structural factors (e.g., farm size and farm fragmentation) but also by factors that affect the opportunity cost of labor. Market distance plays an important role in the decisions for gum adoption and abandonment, since opportunity costs of labor rise where market distance is nearer and alternatives to gum production become economically viable. This explains why farmers living in remote areas are more likely to adopt and less likely to abandon the production of gum arabic. Similarly, off-farm income has a negative and significant effect on continued adoption indicating that gum abandonment is related to the returns on alternative economic options.

Our results, generally, show that the gum system is adopted by older and less educated farmers as we find that age has a positive effect on the probability of adoption, and that education has a negative effect. Both findings suggest that gum arabic will not be adopted if alternative income opportunities are high. Young and more educated farmers can compete better in the labor market and earn alternative incomes from entrepreneurial business or seasonal migration. These specific results might have severe repercussions on the sustainability of gum agrofrestry, as one might expect that gum production will not be appealing for future generations.

In our econometric approach we could not fully capture the price effect and the dynamic nature of the problem since the analysis is based on cross-section data. However, many farmers mentioned low gum returns as the main reason for abandoning the system. The erratic supplies of gum from Sudan during the Sahel drought, the development of starch-based substitutes and the emergence of other exporting countries have changed the structure of the international market for gum from Sudan being a monopoly setting prices to a price taker. This makes it very difficult to design policies for protection of gum arabic particularly because it would require increasing the profitability of gum arabic production, whereas world market prices are given.

In summary, this study gives insights in the historical evolution of the gum agroforestry system in Sudan. During the predrought period Sudan was a dominant producer and the world market prices were high, consequently the producers' prices were favorable and remunerative to induce gum adoption. After the Sahelian drought the structure of gum demand in the international market has changed and prices have fallen. This has jeopardized the incentive structure needed for inducing adoption and continuation of the gum system. The drought has also lead to destabilization in the region and massive displacement of farmers from the gum belt area to central parts of Sudan. As a result farmers became well informed about off-farm employment options and better connected to markets. All these factors have contributed to the failure of the postdrought restocking efforts.

APPENDIX A.1 CORRELATION MATRIX

	FARMSZ	FRAG	INHERIT	EXP	AGE	EDUC	OFFICOM	MKTDIST
FARM SIZE	1.00	.25	.86					
LAND FRAGMENTATION	.25	1.00						
SIZE OF INHERITED LAND	.86		1.00					
EXPERIENCE				1.00	.70			
AGE				.70	1.00	-.36		
EDUCATION					-.36	1.00		
OFF-FARM INCOME							1.00	-.03
MAKET DISTANCE							-.03	1.00

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