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Examining disadoption of gum arabic production in Sudan

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Abstract Gum arabic production in Sudan has developed over the years in a well-established traditional bush-fallow system in which the gum tree (*Acacia senegal*) is rotated with annual crops. Following the Sahel drought, the gum area has suffered from deforestation and gum production has declined. Several programs have been developed to stimulate gum production; however, many original adopters have disadopted gum production and the bush-fallow system. In this paper we apply a logit model to study the decision-making behavior of farmers in west Sudan and to identify the socio-economic factors influencing disadoption of gum production and gum agroforestry system. Variables that measure farmer's wealth were found significant in explaining the disadoption behavior. Off-farm work was also found to positively influence the disadoption decision. Results show that a higher level of income from annual crops decreases the probability of disadoption, which suggests that annual crops and gum production do not compete but rather complement each other within the farm household economy. Therefore, policy measures aiming to boost the production of annual crops in the region might reduce seasonal labor migration and accordingly stimulate gum production.

Keywords *Acacia senegal* · Bush-fallow · Deforestation · Drought · Socio-economic

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Introduction

The importance of farmers' adoption of improved agricultural technology has long been of interest to agricultural extensionists and economists. Quantitative and qualitative studies that explored farmers' adoption behaviors suggested several factors to explain the observed differential adoption behavior (Feder et al. 1985; Rogers 2003). These factors include, among others, demographic variables, technology characteristics, information sources, knowledge and awareness, attitude and group influence.

Earlier evidence led to the categorization of adoption behavior into innovators, early adopters, early majority, late majority and laggards. This is based on validated studies that adoption behavior of any agricultural

technology would follow a normal distribution curve in a given social system (Rogers 2003). However, an important component of the innovation decision-making process that has received little recent research is the discontinued adoption behavior which is the decision to reject an innovation after having previously adopted it. Rogers (2003) reported two types of discontinuance. The first type are replacement discontinuance where farmers reject the technology in order to adopt a better one that supersedes it. The second one is disenchantment discontinuance where a decision to reject the technology results from dissatisfaction with its performance.

Empirical analyses of the factors that predisposes farmers to discontinue adoption behavior of agricultural technology are not given due attention in the literature. 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 in Sudan, where it is estimated that more than 40% of the producers have disadopted gum production during the 1993–1998 period (Awouda 1999). This paper aims to identify the socio-economic and institutional factors that are likely to explain the reasons behind discontinuing gum production and gum agroforestry in Sudan. The paper contributes to agroforestry adoption literature, since it focuses on the disadoption of a sustainable technology by farmers who adopted the technology in the past. Analysis of this aspect provides additional insight for policy makers and might help in identifying the key factors that stimulate gum production.

We use primary data obtained from a farm-level survey in Kordofan region and apply a logit model to analyze the disadoption of gum arabic production. Empirical results from survey data are summarized, and the socioeconomic and institutional factors influencing disadoption of gum arabic and the gum agrorforestry are discussed. The structure of the paper is as follows. Section "Background information" highlights the various role of gum production to farmers in the dry lands of Sudan, sketches the background of declining gum production in Sudan and describes the study area. In section "Survey design" we describe the survey design and this is followed by section "Disadoption layers" that gives a discussion on the reasons behind gum disadoption and the different disadoption layers in our sample. Section "Hypothesis and summary statistics" describes the variables that are hypothesized to influence gum disadoption and provide the summary statistics for the variables. In section "Model framework" we explain the methodology and empirical model used to analyze gum production disadoption. Section "Determinants of disadoption" contains the empirical results and the discussion. The final section "Conclusion" provides policy conclusions.

Background information

Gum production: the promise and the problem

The dry lands in general are characterized by very low and highly variable rainfall, which increases the risk of agricultural production. Risk diversification, therefore, becomes an essential objective of the dry land farmers. One important way to diversify in the Sahel dry lands has been through production of gum arabic. In West and Central Sudan, the production of gum arabic has at times been a totally dominant component of the farming system, and remains so for some parts. Gum arabic is a resin collected from several species of Acacia but in this study we focus on the gum collected from *Acacia senegal*. Gum arabic is widely sought after in importing countries for use as an emulsifiers in confectionary and beverages, photography, pharmaceutical and other manufacturing industries (Barbier 2000).

Production of gum arabic takes place under a traditional land use system known as the gum arabic cultivation cycle (or *Acacia senegal* bush fallow). Under this system the land is used to cultivate crops for about 4–6 successive years, after which the land is abandoned to an *Acacia senegal* bush fallow for 15–20 years. Gum harvest usually starts when the tree has regenerated for 5–6 years and when the production of gum arabic ceases, the trees are cut and used for fuel wood and the land is put under cultivation. Gum harvest provides the small farmers with an important source of income during the dry season when there is no income from other agricultural crops. As the labor input and financial output occurs during a different time compared to other crops, gum represents away to diversify the livelihood and to alleviate the risk.

In addition 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 is a limiting nutrient in the dry lands and thereby improves soil fertility (Breman and Kessler 1997; Barbier 2000). The tree also had many important local uses, such as fuel-wood, building materials for huts, wells, and fences, and animal fodder. Nonetheless, the gum arabic belt is suffering from increased deforestation due to drought, population movement and the recent changes in the international market structure of gum arabic (IEED and IES 1990; Keddeman 1994; Barbier 2000).

The Sahel drought had resulted in large number of *Acacia senegal* tree mortality and accordingly gum production had declined as well as the income for the local farmers (Keddeman 1994). In order to sustain the level of gum production in Sudan and the environmental benefits associated with *Acacia senegal*, a number of development projects have been sponsored in 1980s by international donors to rehabilitate the gum belt in Kordofan and Darfur region. Most important are the restocking programs and the promotion of gum trees planting, which took place during the period 1980–1995, where seedlings produced in central nurseries were delivered to farmers free of charge supported by extension service. Estimates of the number of *Acacia senegal* seedlings distributed during this period exceed 15 millions seedlings (Awouda 1999).

Despite these efforts, gum production remained low and many original adopters have disadopted gum production and the gum agroforestry system. In our view, climatic factors can explain seasonal variation in gum production, but they 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 and the observed disadoption behavior.

The study area

The gum belt in Sudan is divided into two main distinct areas. Mainly sandy area, in the west, consists of North Kordofan, West Kordofan, South Kordofan, North Darfur and South Darfur states. The second is clay land in the east, which is formed by provinces of Kassala, Blue Nile and White Nile. For the purpose of this study we selected Kordofan region since it is the main producing area of gum arabic in Sudan with a share of more than 50% of the total gum production. In addition the area has been a major focus of the gum belt restocking activities which were implemented by the Sudan government with the collaboration of international donor organizations during the 1980's and early 1990's.[1] Furthermore, it spouses the largest gum arabic market in Sudan in El Obeid city. Figure 1 shows the location of the study area in Sudan and the different land use system in the study area.

In the past traditional agriculture in Kordofan was often described as subsistence rain-fed agriculture combined with limited amount of cash cropping. At present the practice of cash cropping is considerable in amount and increasing in importance. The bush fallow cultivation, which primarily involves the use of Acacia tree during the fallow period, has changed in recent decades to more or less continuous cropping (Olsson and Ardö 2002). The principal production alternatives in this system include millet and sorghum as stable food crops; and gum arabic, groundnut, sesame and Roselle (*Hibiscus* sp.) as the most important cash crops. Two or more crops are often grown in one field so as to spread risks and to adjust labor demand during peak periods. Livestock provides needed products to the household and acts as a form of insurance against poor crops harvest, and is therefore also a principal production activity.

The majority of labor demand is met with family labor supplemented with hired and communal labor in case of labor shortage. Seasonal labor migration is also an important income earning activity in the region. Migrating agricultural laborers head to destinations including the Gezira and other irrigation schemes in central Sudan, for cotton picking and sugar cane cutting, and to the mechanized farming schemes in Eastern Sudan mainly for sorghum and sesame harvest operations (El-Dukheri 1997). In addition to these major activities there are limited local employment opportunities including wage labor in market centers within the area.

[1] At least 10 internationally financed projects had been undertaken during the 1980s and 1990s in Kordofan region focusing on desertification control by reforestation of Acacia Senegal; the largest one (Restocking the Gumbelt for Desertification Control)-under the direction of UNSO and the Dutch government-ceased in 1994 (Keddeman 1994).

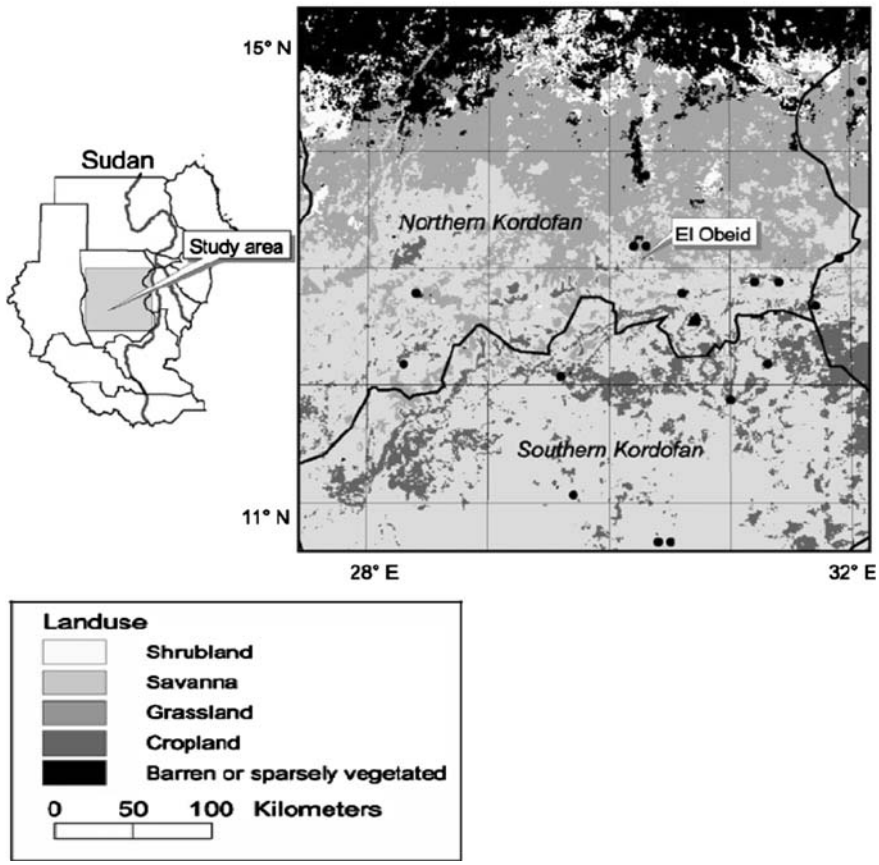

Fig. 1 Study area. Source: Ardö and Olsson (2003)

Survey design

The main objective of this chapter is to investigate factors that contributed to disadoption of gum production and gum agroforestry in Kordofan region. We collected data from a field survey conducted between January and July 2003 in Kordofan region (West Sudan). Kordofan was selected due to its long history of gum production. In addition this area has been a major focus of the gum belt restocking activities which were implemented after the Sahel drought by the Sudanese government in collaboration with international donor organizations. Kordofan region is administratively divided into three states: north, south and west Kordofan. First, 20 villages were purposefully chosen based on past restocking activities. In the absence of an official census and in order to generate a sample of households, a household roster was compiled by asking each village headman to name all the household heads under their authority. The household census provided the sampling frame within which we stratified households in each village into three categories: 'adopters' (who are currently producing gum), 'disadopters' (who had previously produced gum but who had discontinued the practice for at least 3 years before the survey time), and 'non-adopters' (who had not produced gum before). Hereafter, a 1-in-5 random sample was drawn from each stratum in each village making a total sample size of 377 households, during data processing, however, 9 were dropped out because of missing data and inconsistencies, leaving 368 households for which data was available.[2]

The questionnaire covered various socio-economic characteristics of the farm household and its surrounding institutional environment. Socio-economic factors include land holdings, family size, age and education of the household head, and income composition. Institutional factors are the distance to the nearest town market, formal exposure to extension and credit as well as problems encountered with gum

[2] The number of farm households interviewed from each state classified by adoption category is shown in Appendix A.

production. Before the questionnaire was administered it was pre-tested in one of the study villages in north Kordofan to evaluate validity of the questions and the structure of the questionnaire and to verify pre-coded responses included in the questionnaire. The purpose was to check clarity, relevance and sequence of the questions and identify missing items. After the pre-testing, the questions were revised and the questionnaire was finalized.

Disadoption layers

The final dataset consist of 228 adopters, 81 non-adopters and 59 disadopters. Because adoption took place on average 20 years ago and as we only have information at the time of sampling, it will be difficult to analyze why non-adopters did not adopt (e.g. farm size as well as other variables that affected the adoption process in the past might have changed). We therefore dropped the non-adopters category from the sample and analyzed only continuous adoption versus disadoption decision using a total sample of 287 respondents.[3] Furthermore, as mentioned earlier, disadopters are defined as those who stopped gum production for at least 3 years as from the survey period; however, discontinuing gum production does not necessarily mean abandoning the gum agroforestry system as it depends on whether or not the farmer still maintains the gum trees. Therefore the sample of disadopters could further be divided into partial disadopters. These are those who have stopped gum production but retained the tree and therefore may eventually re-adopt gum production. Full disadopters are those who stopped gum production but did not maintain the tree. Furthermore not having the tree is not necessarily an active choice for those who had fully disadopted as 15 disadopters lost their trees due to external factors i.e. mainly through drought and/or displacement. Figure 2 shows the different disadoption layers and their percentage in our sample.

[3] In an earlier stage of the analysis we have used a bivariate probit model to study both the initial adoption and the subsequent disadoption, however, because of the possible selection bias in measuring past behavior using current data we decided to remove the adoption stage and focus only on the continuous adoption stage.

Unfortunately, the small sample of disadopters and the disproportionate split of the sample in the subsequent disadoption layers as shown in Fig. 2 did not allow us to investigate the partial and the full disadoption decision in more detail, instead we removed from the sample those farmers who lost their trees by drought and displacement (15 cases and 25% of the sample) because their full disadoption decision is not necessarily an active choice. This leaves us with a sample of 44 disadopters out of which 36 cases are partial disadopters and 8 cases of full disadopters for whom abandoning gum agroforestry is an active choice. The limited number of full disadopters in our sample suggests that partial disadoption—whereby farmers abandon harvesting the gum but maintain the trees—is the rule rather than the exception. As mentioned earlier, gum production represents an important way to diversify income sources and the gum tree acts as a form of insurance and provides hedging against risk inherent in monocropping for poor farmers. This explains why farmers do not tend to fully abandon the gum agroforestry. Also farmers might maintain the tree in anticipation of an increase in the gum prices.

Table 1 shows farmers' stated reasons for disadoption. A high percentage of the respondents (50%) mentioned low gum returns as main reason for abandoning. Gum tapping and gum production are highly elastic to prices and little gum is produced when prices are low and when prices are high the trees are over-tapped 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 dis-incentive 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 86% 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 64% sold their gum at prices lower than the floor price. Other important reasons for disadoption stated by the farmers are engagement in off farm work (23%), insufficient land (14%) and production of other crops (11%).

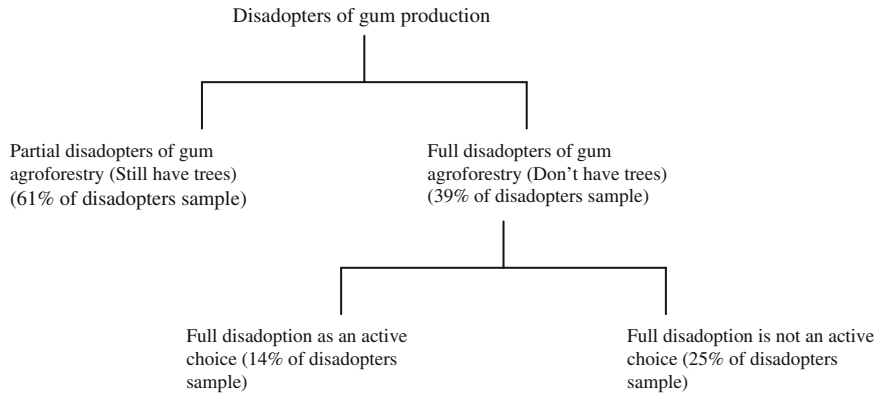

Fig. 2 The different disadoption layers

Hypothesis and summary statistics

Several factors such as farm size, farm fragmentation, distance of plot from the homestead, engagement in off-farm work, income from annual crops, experience in gum production, etc. were hypothesized to influence disadoption of gum production. Farm size is expected to be positively associated with continued adoption as farmers with small holdings are more likely to convert the Acacia land either for the production of food crops or for the production of other cash crops that give relatively higher returns. On the other hand farmers, with large holdings are in a better position to follow the traditional gum rotation. Similarly, farm fragmentation is expected to have a positive effect on continued adoption as farmers who have large number of plots can leave some plots under *Acacia senegal* stand and cultivate annual crops on the other plots in order to reduce the time of commuting to and from plots. We expect that average distance of plots to the homestead will have a negative effect on continued adoption as smaller distance would imply less commuting time.

Other studies have shown that off-farm income 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). We expect a negative association between engagement in off-farm work and continued gum adoption, as off-farm work competes with gum production for labor during the dry season and it also might imply a decline in farmers' dependence on gum as a dry season income.[4] Farmer's gross revenue from other annual crops is expected to have a negative effect on continuous adoption as it might imply horizontal expansion of agriculture into Acacia areas.[5] We also expect a negative relation between groundnuts harvest and continued adoption because of overlap in harvest timing and competition on labor use.

The influence of livestock units on disadoption is less clear. 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 excludes agricultural land holding and Acacia trees, and only includes items used for off-farm work (such as animals' carts and small shops) we expect, a priori, that

Table 1 Farmers' stated reasons for disadoption

Reason for disadoption	Proportion of disadopters[a] (%)
Low gum returns	50
Have off-farm work	23
Insufficient land	14
Production of other crops	11
Lack of finance	9
Other reasons	5

[a] Due to multiple responses in some cases, percentages do not sum to 100

[4] Because a major part of the household's off farm income comes from remittances of migrating family members and is not necessarily earned by the household head from working off farm, we therefore did not include off farm income in our analysis but rather included a dummy indicating whether the household head works off farm or not.

[5] The dimension of the farm gross revenue is one calendar year (and represents the returns from crops for the agricultural season preceding the survey period i.e. 2001/2002). We have excluded gross revenue from gum because disadopters do not have returns from gum and we have excluded groundnut revenue because we have included the quantity harvested from groundnut as a variable in our analysis.

the variable 'current asset values' will have a negative influence on continued adoption. The effect of farmer's age on the decision on continuing to produce gum arabic 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). Previous research revealed a positive relationship between age and the likelihood of agroforestry adoption (Pattanayak et al. 2003). We also hypothesized that age is positively related to continued adoption as older farmers are less likely to opt for other off-season income sources, specially those involving seasonal migration. In a similar way we expect that farmer's experience in gum production to have a positive effect on the probability of continued adoption.

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 continued adoption. The effect of family size on disadoption 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.

Literature on adoption of agricultural technology suggests that extension and credit services bear a positive sign in explaining the likelihood of adoption.[6] However, it is not clear if they will have the same effect on the disadoption decision. The effect of market distance on adoption and disadoption of gum agroforestry is ambiguous; in case the farm gate prices are fairly uniform, the distance variable could capture the price effect and may, therefore, be negatively related to continuous adoption as 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 access to off-farm work and thus a positive expected relationship is possible. Table 2 summarizes the variables that are hypothesized to influence gum disadoption.

[6] Credit here refers to formal credit extended by the GAC to farmers via the Gum Producers Association.

Table 3 represents summary statistics from surveyed farm households, divided into two groups: adopters of the gum production and disadopters. Adopters appeared to have larger farm size land compared to disadopters. This is not surprising, as shown by the stated reasons for disadoption, where 14% of the disadopters mention insufficient land as a reason for discontinuing gum production. Adopters have high non-gum income which may suggest adopters are more dependent on farming activities in general. Also a higher percentage of adopters have received credit and extension services as compared to disadopters.

Model framework

For the purpose of this paper we use a logit model and following Neil and Lee (2001) we assume that the dependent variable is dichotomous such that: $y = 1$ if the farmer continues to produce gum and $y = 0$ if the farmer disadopts gum production. We are interested in the probability that the farmer continues to produce gum: $P(y = 1|x)$, where x is a vector of explanatory variables.

The logit model assumes an underlying latent variable y_i^* representing the utility the ith farmer receives from continuing to adopt gum production, for which we observe the binary variable y_i where:

$$y_i = 1 \quad \text{if} \quad y_i^* > 0 \quad \text{and} \quad y_i = 0 \quad \text{if} \quad y_i^* < 0 \qquad (1)$$

The underlying response variable y_i^* is defined by the following regression equation:

$$y_i^* = \beta_0 + \sum_{j=1}^{k} \beta_j' x_{ij} + u_i \qquad (2)$$

where x_{ij} is a set of explanatory variables affecting the ith farmer decision and k number of explanatory variables included in the equation. β_0 is a constant, β_j' coefficients of the explanatory variables j and u_i is the disturbance term. From the relationships (1) and (2) we get

$$P_i = \text{Prob}(y_i = 1) = \text{Prob}\left[u_i > -\left(\beta_0 + \sum_{j=1}^{k} \beta_j' x_{ij}\right)\right] = 1 - F\left[-\left(\beta_0 + \sum_{j=1}^{k} \beta_j' x_{ij}\right)\right] \qquad (3)$$

where F is the cumulative distribution function of u. In this case the observed values of y are realizations

Table 2 Description of explanatory variables and expected signs

Explanatory variable	Description	Expected sign for continued adoption
Age	Age of household head (years)	+
Agesq	Age square	−
Educ	Education level of household head (years)	+
Exp	Farmer's experience in gum production (years of adoption)	+
Expsq	Experience square	?
Plotdist	Average distance of plots from the house in km	−
Frag	Farm fragmentation (number of farm plots)	+
Farmgrv[a]	Farm gross revenue obtained from other crops (excluding gum and groundnut) in 000SD per year	−
Gnut	Quantity harvested of groundnut in kg	−
Creddum	1 if the farmer received formal credit during the last 3 years, 0 otherwise	+/−
Extndum	1 if the farmer has received extension services during the last 3 years, 0 otherwise	+/−
Astcv[b]	Current value of assets owned by the household (000 SD)	−
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)	+/−
Mktdist	Distance to the nearest town market in km	+/−
State1	Dummy variable equals 1 if the farmer lives in south Kordofan, 0 otherwise	+/−
State2	Dummy variable equals 1 if the farmer lives in west Kordofan, 0 otherwise	+/−
Fmsz	Family size	+/−
Farmsz	Farm size (hectares)	+
Offdum	1 if the farmer works off-farm, 0 otherwise	−

[a] SD refers to Sudanese Dinar 1 USD was equivalent to 250 SD during the survey period

[b] 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 land and jewelry the current value is the purchase price, as these assets do not loose value by use

of a binomial process with probabilities given by (3) and varying from trial (depending on x_i). Hence the likelihood function is given by (Maddala 1999)

$$L = \prod_{y_i=0} F\left[-\left(\beta_0 + \sum_{j=1}^{k} \beta_j' x_{ij}\right)\right] \prod_{y_i=1} 1 - F\left[-\left(\beta_0 + \sum_{j=1}^{k} \beta_j' x_{ij}\right)\right] \quad (4)$$

The functional form of F (the cumulative distribution function of u) depends on the assumption made about u_i in (2). If the cumulative distribution of u_i is the logistic distribution, we have the logit model and in this case,

$$\text{Prob}(y_i = 0) = F(-\beta' x_i) = \frac{\exp(-\beta' x_i)}{1 + \exp(-\beta' x_i)} = \frac{1}{1 + \exp(\beta' x_i)} \quad (5)$$

Hence, the probability that the farmer will continue to produce gum is:

$$\text{Prob}(y_i = 1) = 1 - F(-\beta' x_i) = \frac{\exp(\beta' x_i)}{1 + \exp(\beta' x_i)} \quad (6)$$

Determinants of disadoption

We estimated the logit model using the statistical software package Limpdep 7.0 to generate the maximum likelihood coefficients, standard errors, marginal effects and measures of goodness-of-fit (chi-square statistics (χ^2) and the number of cases that are correctly predicted). The equation below represents the general form of the decision modeled:

Table 3 Mean comparisons of adopters and disadopters

	Adopters, $N = 228$ (84%)	Disadopters, $N = 44$ (16%)
Age of household head (years)	44.49	44.93
Age square of the household head (years)	2203.19	2189.29
Experience in gum production	35.97	11.95
Experience square	44171.87	274.14
Education level of household head (years)	2.73	2.89
Family size	7.36	8.32
Farm size (ha)	53.63	40.66
Average distance of plots from the house in km	9.21	16.53
Farm fragmentation	2.74	2.02
Farm gross revenue (000 SD per year)[a]	256.18	99.93
Quantity harvested of groundnut in kg	405.05	470.19
Credit (%)	16.23	4.55
Extension (%)	21.49	11.36
Current value of assets owned by the household (000 SD)	140.54	160.13
Livestock units	9.89	6.32
Distance to the nearest town market in km	66.57	55.89
Off farm dummy (%)	32.46	61.36
Number of farmers in the sample living in South Kordofan (%)	26.75	22.73
Number of farmers in the sample living in West Kordofan (%)	21.93	56.82

[a] Gross revenue for cash crops calculated based on quantity harvested times the selling price per unit farmers get. As food crops are not normally sold but rather consumed by the household we have used the average price reported by key informants at the village level to calculate the gross revenue for food crops

$$y^* = \beta_0 + \beta_1 \mathrm{AGE} + \beta_2 \mathrm{AGE}^2 + \beta_3 \mathrm{EXPER} + \beta_4 \mathrm{EXPER}^2 + \beta_5 \mathrm{EDU} + \beta_6 \mathrm{FMSZ} + \beta_7 \mathrm{FRMSZ} + \beta_8 \mathrm{PLOTDIST} + \beta_9 \mathrm{FRAG} + \beta_{10} \mathrm{FARMGRV} + \beta_{11} \mathrm{GNUT} + \beta_{12} \mathrm{CREDDUM} + \beta_{13} \mathrm{EXTNDUM} + \beta_{14} \mathrm{ASTCV} + \beta_{15} \mathrm{LUNIT} + \beta_{16} \mathrm{MKTDIST} + \beta_{17} \mathrm{OFFDUM} + \beta_{18} \mathrm{STATE1} + \beta_{19} \mathrm{STATE2} + U$$

Table 4 presents the results of the logit model, variables that appear significant with negative sign are: experience square, asset current value, livestock units, off farm dummy, groundnut harvest, family size and the dummy for state2. Variables that are significant with positive sign are: experience, farm fragmentation and farm gross revenue.

The logit estimates show that the variable experience is positive and the squared term of the variable is negative and both are significant at 1%, indicating that the probability of continued adoption increases with experience though it increases at a decreasing rate. The data suggest that variables that measures farmer's wealth (livestock units and asset current value) are important determinants of disadoption. Livestock and assets provides farmers with alternative income sources, for instance, livestock provide the needed insurance and supplement income in case of harvest failure, and assets can either be liquidated to smooth income or used for running small-scale entrepreneurial business at the village level (such as animal drawn carts). This implies that relatively wealthier farmers might depend less on gum as an income source. Results also indicate farm fragmentation has a positive effect on continuous adoption since operating more fragmented farms enables farmers to follow the traditional gum cultivation cycle. A marginal increase in farm fragmentation increases the likelihood of continuous adoption by 2%. A similar finding was reported in the Philippines, where farm households with more fragmented holdings are found to achieve higher levels of conservation (Pattanayak and Mercer 1998).

The dummy for off-farm work is significant at 1% level and the probability of continuing gum

Table 4 Binomial logit model results for continuous adoption

Variable	Coefficient estimate	SE	Marginal effect
Constant	4.4412*	2.4062	
Age	−0.0979	0.1021	
Age square	−0.0001	0.0011	
Experience	0.1427***	0.0306	0.0033
Experience square	−0.0000***	0.0000	−0.0000
Education	−0.0328	0.0684	
Family size	−0.14833*	0.0814	−0.0034
Farm size	0.0015	0.0043	
Plot distance	−0.0159	0.0226	
Farm fragmentation	0.8552***	0.2884	0.0196
Farm gross revenue	0.0089***	0.0030	0.0002
Groundnut harvest	−0.0005*	0.0003	−0.0000
Credit	1.4074	1.0840	
Extension	0.5557	0.7238	
Asset current value	−0.0022**	0.0011	−0.0000
Livestock units	−0.0506***	0.0185	−0.0012
Market distance	−0.0033	0.0079	
Off farm work (dummy)	−1.4553***	0.5146	−0.0334
State 1	−0.5541	0.7735	
State 2	−1.4121**	0.6268	−0.0324
Log likelihood	−64.7781		
Log likelihood ratio index	0.4619		
Model chi-square	111.21***		
Correct predictions (%)			
Continue to adopt ($n = 228$)	96.49		
Abandon ($n = 44$)	50.09		
Overall ($N = 272$)	90.44		

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

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

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

production decrease by 3.5% for household heads who work off-farm. This was expected because 23% of the adopters mentioned having off-farm income as a key reason for disadoption. During the 1970's 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 (Awouda 1999). Labor is frequently cited in the adoption literature as a constraint to agroforestry systems, because in many cases labor demand for tree management operation coincides with labor demand for other agricultural operations (Current et al. 1995). However, in the case of gum agroforestry most labor input for the production of gum occurs during the dry season when there is little work in other agricultural crops. The dry season is also the period when most off-farm labor takes place and most of the seasonal migration occurs. 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 dummy negatively influences the continuity in gum production supports the above explanation for the decline in gum production.

The negative and significant effect of family size on the probability of continuous adoption have two intuitive interpretations, first large family size are likely to have more labor which in turn increase the possibility that part of the family members can work off farm and earn income through seasonal labor migration and therefore decrease the dependence of household on gum as off season income source. The other interpretation is that large family size implies more people to feed and therefore, a priority for the

production of food crops i.e. more land will be devoted to food crops.

Interestingly and contrary to expectations we found that farm gross revenue from annual crops increases the probability of continuous adoption. The intuitive interpretation for this result is that a high income from annual crops will lead to a strong inducement for labor to remain in the villages and reduce migration. This in turns increases the availability of labor in the dry season for gum harvest and therefore, low income from annual crops could be the cause of migration in search for off-farm income. As expected, the quantity harvested of groundnut, which is a proxy of opportunity cost of labor during the gum collection season, decreases the probability of continuous adoption.

Another significant variable in our result is the dummy for West Kordofan; this reflects the structure of our sample as a large number of disadopters are drawn from West Kordofan (50%). The variables 'extension' and 'credit' that are found to be significant factors for adoption of technology in several other studies (Feder et al. 1985) did not appear to be significant determinants of continuous adoption of gum production. Generally, economic instability and government budget constraint limit the influence of formal institutions in remote areas of Sudan; this explains why extension and credit were not found to be significant determinants for the continuity in gum adoption. Finally, our model has a highly significant chi-square and high percentage of correct predictions. The number of households that are correctly classified into their actual adoption category is 90%.

Conclusion

Gum arabic production in Sudan has developed over the years in a well-established traditional bush-fallow system in which the gum tree (Acacia senegal) is rotated with annual crops. Following the Sahel drought the gum area in Sudan has suffered from deforestation and gum production has declined. Several programs have been developed to boost gum production; however, many original adopters have dis-adopted gum production and the gum agroforestry system. In this paper we distinguish between partial disadopters (those who discontinue gum production but maintain the tree) and full disadopters (those who discontinue gum production and do not maintain the tree). Our survey sample shows that partial disadoption is the rule rather than the exception (81% of our final sample are partial disadopters). Gum trees act as a form of insurance and provide hedging against the risk inherent in monocropping for poor farmers, and therefore, farmers might be reluctant to uproot the tree and fully disadopt the agroforestry system.

We applied a logit model to study the decision making behavior of farmers in west Sudan and to identify the socio-economic factors influencing disadoption of gum production and gum agroforestry. Results show that variables that measure farmer's wealth (livestock units and asset current value) were significant determinants of disadoption. Both livestock and assets can be liquidated to smooth income in case of poor annual crops harvest; therefore, wealthier farmers are more likely to abandon gum production. The factors that affect the opportunity cost of labor during the gum collection season such as the quantity of groundnut harvested and off-farm work were found important in explaining the disadoption decision. Therefore, policies that consider the returns of investments in gum production relative to alternative labor investment opportunities is likely to have a higher impact on continuous adoption of gum agroforestry.

Results also reveal that farm gross revenue from annual crops has a positive effect on continuous adoption. This can be explained as follows, on the one hand, the positive effect of the income from annual crops might indicate that adopters devote a large proportion of their labor time for the production of annual crops and gum whereas disadopters tend to work more off-farm. On the other hand, low income from annual crops could be a reason to abandon gum production and to migrate or search for off-farm work. This specific result suggests that gum arabic and other agricultural crops (except groundnut because of overlap in harvest time) do not compete but rather complement one another in the household farming economy, and good return from annual crops is a pre-requisite for gum production. Policy measures that aim to improve agricultural production in the region will induce farmers to settle in their villages and reduce the seasonal labor migration trend which will in turn increase the availability of labor for gum production.

Appendix

Appendix A Number of farm households interviewed from each state

State	Administrative unit	No. of villages selected	No. of households interviewed	Sample size based on adoption category		
				Adopter	Non-adopter	Dis-adopter
North Kordofan	Um Rawaba	3	63	38	17	8
	Sheikan	3	55	36	15	4
	Bara	3	60	39	15	6
	Subtotal	9	178	113	47	18
West Kordofan	Nuhud	3	60	28	19	13
	Gabaish	3	52	25	10	17
	Subtotal	6	112	53	29	30
South Kordofan	Jadid-Abu Nawara	3	37	29	2	6
	Al Sarajia	2	41	33	3	5
	Subtotal	5	78	62	5	11
	Total (sample)	20	368	228	81	59

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