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A traditional agroforestry system under threat: an analysis of the gum arabic market and cultivation in the Sudan

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Abstract

The main aim of this study is to review the environmental and socioeconomic sustainability of the gum arabic farming system in central Sudan. A further aim is to analyse some of the main factors influencing production in recent decades in order to understand the future trade potential and consequently the smallholder livelihood. The study shows that end-user imports of gum arabic have increased during recent decades. Gum arabic is mainly for uses such as soft drinks, confectionary, and pharmaceuticals. However, even with this increased demand the production in Sudan, the main country of production, is declining. The producers, mainly smallholders, suffer from fluctuating prices. If the gum arabic farming system should be able to provide the environmental benefits of improved soil fertility and the socioeconomic benefits of risk spreading and dry season income opportunities, the prices paid to smallholders must be stabilized at a fair level, otherwise a shift to other crops or practices might take place.

Introduction

Drylands are characterized by high variations in rainfall, which place agriculture at great risk. Risk spreading by diversification becomes essential and one important way to diversify in the African Sahel has been through production of gum arabic. In central Sudan, the production of gum arabic has at times been a totally dominant component of the farming system, and remains so in some parts.

Gum arabic is a resin collected from several species of Acacia.[1] The term *arabic* was added because the gum reached Europe from Arabian ports. Its first known uses were in ancient Egypt as

[1]According to the Joint FAO/WHO Expert Committee on Food Additives (JECFA) 'gum arabic is as a dried execute obtained from the stems and branches of *Acacia senegal* (L.) Willdenow or *Acacia seyal* (fam. *Leguminosae*)' (JECFA. 1999. Compendium of Food Additive Specifications, Appendum 7, Joint FAO/WHO Expert Committee on Food Additives 53rd session, Rome 1–10 June 1999. Rome, Italy). The definition of the World Customs Organization (WCO) is wider and refers to gum arabic as the product from various Acacias (The Economist Intelligence Unit. 2000. EIU Country profile for Sudan (1999–2000). London, United Kingdom, 50 pp). In Sudan the gum from *Acacia senegal* (hashab) is most often separated from the gum of *Acacia seyal* (talh). These different definitions of gum arabic imply a rather vague notion of the actual meaning.

early as 2000 BC, in foods, adhesives, and paint (Seif el Din and Zarroug 1996). Today the gum has local uses as a laundry starch, as a famine food (Freudenberger 1993) and in plastering, but local trade and subsistence use has been, and still is, insignificant in relation to the amount exported (Seif el Din and Zarroug 1996). One of its major uses today is as an emulsifier for citrus oils in fruit-based soft drinks (Anderson 1993) and cola-type drinks (Chikamai 1996). Other uses are in confectionery, pharmaceutics, and photography (Barbier 2000).

The Sudan continues to be the world's leading producer of gum arabic. At the end of the 1990s, it contributed 70–90% of world production. Most of the gum is produced by smallholders on individual farms where the trees grow naturally. The trees are mainly valued for their capacity to increase soil fertility and to provide income during the dry season, when there is little other agricultural income. In this sense, the system can be seen as an environmentally and socioeconomically sustainable system. It is therefore crucial to understand whether the system is moving toward a collapse, as claimed at the beginning of the 1990s (Larson and Bromley 1991; Freudenberger 1993).

The aim of this study, is to review the environmental and socioeconomic sustainability of the gum arabic farming system in central Sudan and to analyse some of the main factors influencing production in recent last decades in order to understand the future potential of the trade and thus the potential income of smallholders. The study involved: (1) assessing the international demand for gum arabic, (2) illustrating the production and reviewing the causes of declines or variations in production, and (3) assessing the market price. There are of course many factors that impact on production, but this study focuses on the economic factors using regional and national data.

The assessment of the international demand was based on data from the US International Trade Commission and Eurostat. The national production data were obtained from the Gum Arabic Company in Khartoum while the rainfall data originated from the Climatic Research Unit in East Anglia. The market price assessment was based on data from El Obeid crop market in Sudan. Information was also gathered in repeated fieldwork carried out in Sudan from 2000–2004. The fieldwork was based on interviews with smallholders and key informants in the gum-producing areas of the Sudan.

Basic features of gum arabic production

Although *Acacia senegal* is found in parts of Asia, it is grown predominantly in sub-Saharan Africa, especially in the Sahelian–Sudanian zone. In the absence of better distribution maps, Figure 1 shows the location of the Sudan within Africa and provides an estimate of the distribution of *Acacia senegal* based on the limiting isohyets, which are approximately 150 mm in the north and 600 mm in the south (Jamal and Huntsinger 1993). Within this zone, the density of *Acacia senegal* varies. In Sudan, the main zone of production of gum arabic is in Western and Northern Kordofan, in the centre of the country. These two states produced 48% of the total Sudanese production between 1990 and 1999 according to the Gum Arabic Company.

The best gum arabic is said to come from *Acacia senegal* (L.) Willdenow (hashab in Sudanese Arabic). Another major source is *Acacia seyal* Delile (*talh*), but it is generally agreed that the gum from *Acacia seyal* is inferior. The two main species have somewhat different distributions. Most *Acacia seyal* grows on clay soils and on water-accumulating sites such as depressions, or in fairly high-rainfall areas. *Acacia senegal* generally grows in lower rainfall areas and on sandy soils (Badi et al. 1989). Here we concentrate on the role of *Acacia senegal* gum (referred to as gum arabic) in farming systems in the central Sudanese gum belt, which is the main gum producing area in Sudan.[2]

In the traditional bush fallow system, *Acacia senegal* grows on the land when it is in fallow. The tree can reach 4–5 m in height. To obtain the gum, pieces of bark are partially removed once a year, whereupon resin is exuded in droplets from the wound. These droplets grow to nodules 2–5 cm in diameter and are picked. A couple of additional pickings commonly follow after 1 or 2 weeks (Seif el Din and Zarroug 1996). The procedure does not damage the growth of the tree if correctly done.

[2]The section on international demand refers to the resin of various Acacia species (WCO definition) and Figures 2–4 refer to gum from *Acacia senegal* and *Acacia seyal* (JECFA definition). Data on a more detailed level were not available.

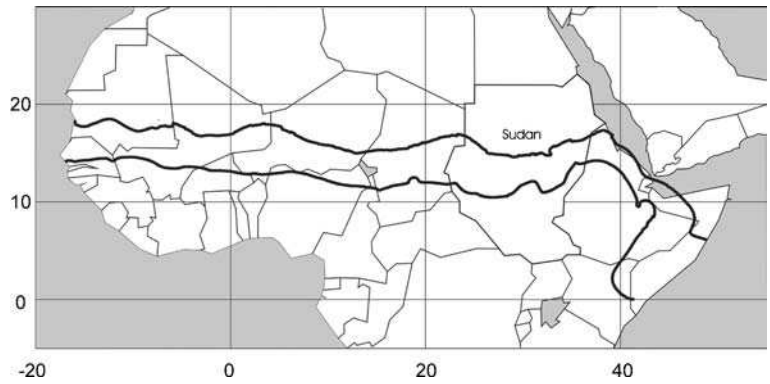

Figure 1. The northern (150 mm isohyet) and southern (600 mm isohyet) probable limits of the distribution of *Acacia senegal*. Source of rainfall data: Climatic Research Unit, University of East Anglia, UK and Vose R. S., Schmoyer R.L., Steurer P.M., Peterson T.C., Heim R., Karl T.R. and Eischeid J.K. 1992. The Global Historical Climatology Network: Long-Term Monthly Temperature, Precipitation, Sea Level Pressure, and Station Pressure Data, Oak Ridge National Laboratory.

Gum production begins to decline when the tree is about 15 years old (Badi et al. 1989).

When the land is taken back into cultivation, the tree is coppiced. The land is then cultivated until its fertility falls below an acceptable level. During this time most of the trees regenerate naturally by coppice growth. Three to five years after cutting, they may be tapped again. At best, the number of trees that regenerates is the same as the number before the cutting (Badi et al. 1989).

The system depends on being able to keep land in fallow, and one threat to the system has been the decrease in the area under fallow. In the 1950s and 1960s, the period of fallow was 12–20 years (Gerakis and Tsangarakis 1970) and in some places as long as 20–40 years (Deans et al. 1999).

It is not only the gum arabic that is important, but also the leaves, which are nutritious browsing and fodder. Furthermore, the wood from the trees makes good firewood and timber and finally the fruits may be used for medicinal purposes (Jamal and Huntsinger 1993).

Gum is not only important for the smallholders, but also for the country of Sudan. Although gum arabic is not as economically important to the Sudan as it once was, it is still one of the main agricultural exports from the rainfed agricultural area. Until the introduction of cotton in 1920, gum arabic was the main source of export revenue in Sudan (Ahmed 1999). During the 1960s and until 1973, gum arabic was as valuable an export as groundnut and sesame. Between 1974 and 2000, the value of this commodity varied considerably, with maximum revenue in 1987 of US$ 78.8 million and a minimum in 1999 of only US$ 19.2 million. Its relative importance has now decreased further. In 1997, the revenue from gum arabic was US$ 26.1 million, 4.4% of the total national export of US$ 594.2 million,[3] now representing only 4% of total revenues. In recent years, the value has been around US$ 20 million according to the Gum Arabic Company.

Sustainability of the system

The environmental sustainability of the gum production system involves mainly its impact on soil fertility. *Acacia senegal* is often reported to fix nitrogen (Pearce 1988; Barbier 2000) and, if so, it would be an important contributor to farming systems in which the use of fertilizers is rare or non-existent. The nitrogen-fixing potential of *Acacia senegal* is nonetheless in some doubt (Deans et al. 1999). There is little information on the effect of the trees on properties of sandy soil (El Tahir et al. 2004). El Tahir and colleagues compared the effects of *Acacia senegal*, *Acacia seyal*, and *Acacia tortillis* after 3 years from planting and found higher nitrogen levels under *Acacia senegal*, eventhough it could not be proven that the tree fixes nitrogen. Another study in the

[3]As referred to in The Economist Intelligence Unit. 2000. EIU Country profile for Sudan (1999–2000). London, United Kingdom, 50 pp.

sandy soils of the Sudan found higher nitrogen and soil organic carbon levels under the *Acacia senegal* canopy than outside (Gerakis and Tsangarakis 1970). However, neither study could conclude whether the higher contents were a result of nitrogen fixation or, for example, accumulation from litter and wind-blown plant debris. Studies in Senegal have found that no nitrogen-fixing nodules exist on adult trees (Bernhard-Reversat 1982). Eventhough there is no proof that the tree fixes nitrogen, it is clear that it improves soil fertility.

The wood is important for firewood and construction. *Acacia senegal* together with *Acacia mellifera* are preferred for charcoal-making in the central parts of the Sudan. The importance of *Acacia senegal* as a building material and firewood is of course a threat to environmental sustainability, as the trees reduce soil erosion and improve soil fertility. The economic importance of these factors cannot always be taken into account as the profits need a longer time perspective.

Poverty alleviation is one of the main aspects of gum production in socioeconomic sustainability. Gum arabic provides smallholders with important sources of income during its harvest period in the dry season, at times when income from other agricultural crops is low. As the labour input and financial output occur during a different time period compared to other crops, gum is a way for smallholders to diversify their livelihoods and to alleviate the risk for subsistence crises. However, it has to be borne in mind that gum arabic can only alleviate this risk if the money received can be used to buy food. For example, during and after the severe drought and famine in the mid-1980s, it became obvious that the supply of food through the local markets had failed. Even in the midst of the severe drought of 1984–1985, there was no net shortage of food at the national level and the country continued to export food (Olsson 1993). To smallholders, this implies that food markets cannot be trusted in times of crisis and producing food has therefore, become a priority. Even if gum production has the potential to generate income, the income does not help if food becomes unavailable in the market. Little has been documented about the economic contribution of resins to rural households. In Ethiopia, the economic return on gum from *Acacia senegal* and four other trees species is estimated to make up one third of the total income (Lemenih et al. 2003).

Another potential for gum production is the role it could play in the implementation of international agreements on climate change (UN Framework Convention on Climate Change, UNFCCC), desertification (UN Convention to Combat Desertification, UNCCD) and biodiversity (UN Convention on Biodiversity, UNCBD). Promoting gum production over the vast land areas of the Sahel would result in benefits for all three conventions – carbon would be sequestered in the ecosystem, land degradation would be counteracted and favourable conditions for biodiversity would be enhanced. There is extensive literature on such win–win situations (Olsson and Ardö 2002).

Important factors for future production

International demand

One of the biggest threats to the international gum trade is that end-users may turn to substitutes, particularly if the gum-producing countries cannot provide a reliable supply (Anderson 1993). If end-users change to a substitute, they are unlikely to change back because of high investment costs. Indeed, this has already happened in the confectionery industry, where the high prices of gum arabic in the 1980s and 1990s forced many manufacturers to replace gum arabic with modified starches (Anderson 1993). On the other hand, gum arabic has the great advantage that it is a natural product containing few calories, which consumers are increasingly requesting (Pearce 1988). However in other industries, such as in ink production, the natural aspect of gum arabic may confer fewer advantages.

To illustrate the demand, the patterns of import to the USA and France, two of the biggest end-users, were studied. Imports (re-exports subtracted[4]) to the USA increased between 1976 and 2003, from 6674 tonnes in 1976 to 14,088 tonnes in 2003. There were large variations during this period. The linear trendline showed an increase of 60% for the entire time period and an increase of more than 100% since the beginning of the 1990s. A similar pattern was seen in France, where the

[4]No figures for re-exports were used for 1976–1988, which means that the imports appear to be higher than the actual values.

trendline of the imports (re-exports subtracted) showed an increase of 40% and also more than 100% since the end of the 1990s. It is difficult to distinguish the relative contributions of *Acacia senegal* or *Acacia seyal* to these figures since data are not separated to this detailed level. Some sources state that Seyal gum is more important, since it is gaining in importance in the international trade and now represents 50% of a trade previously dominated by gum from *Acacia senegal* (Ibrahim and Osman 2001). Others report that 70% of gum arabic in international trade originates from *Acacia senegal* and only 15–25% from *Acacia seyal* (the remainder comes from other closely-related species) (Chikamai 1996).

One of the peculiarities of the gum trade with the USA is a shift in sources. Of the leading exporters to the USA, France, and Chad have played an increasingly important role, whereas the gum arabic exported directly from the Sudan has decreased. Due to illegal border exchanges, it is highly possible that a proportion of the amount imported from Chad actually originated from the Sudan. The decrease in imports from the Sudan reflects to some extent the diplomatic relationships between the Sudan and the USA. On November 3, 1997, the Clinton administration issued Executive Order No. 13067 (US Federal Register 1997) imposing a trade embargo against the Sudan. In early 1999, gum arabic was excluded from the embargo.[3] Consequently, the diplomatic relationship between the Sudan and the USA does not seem to pose a significant threat to gum arabic production as the USA has increased imports from France and from countries neighbouring the Sudan such as Chad, in addition to excluding gum arabic from the embargo.

Variable and declining production and its reasons

Reliable production levels and prices are crucial for the end-user, but have not been achieved in recent decades. From the earliest available figures on gum arabic production in 1901, production levels rose steadily to the mid-1960s. From that point production slumped and has been characterized by great variations (Figure 2). In 1994 the production reached almost 50,000 tonnes, which was about 80% of the maximum production experienced during the 20th Century, suggesting

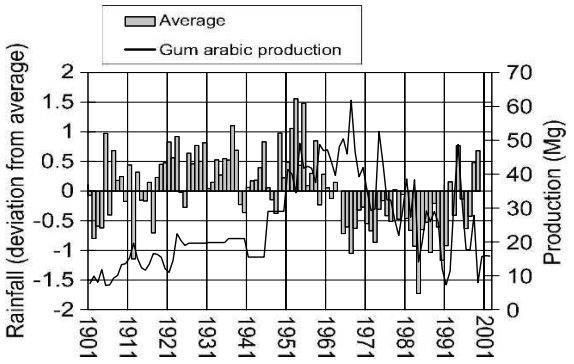

Figure 2. Gum arabic production (1901–2002) and precipitation (z-score) (1901–1999) in the gum belt of the Sudan. The precipitation data is normalized with the z-score expressed as the values' departure from mean as a proportion of one standard deviation. Source of data: Production: 1901–1925 (Forestry Dept.), 1926–1950 Radaf A.A.E.-A. 1983. Sudan Gum – A History of its Production and Trade up to 1982. Dept. of History, University of Bergen, Bergen, Norway, 210 pp., 1951–1960 (Ministry of Agriculture), 1961–1963 (Ministry of Finance), 1964–1968 (Forestry Dept.) and 1969–2002 (Gum Arabic Company). Precipitation: Climatic Research Unit, University of East Anglia, UK, and Vose R.S., Schmoyer R.L., Steurer P.M., Peterson T.C., Heim R., Karl T.R. and Eischeid J.K. 1992. The Global Historical Climatology Network: Long-Term Monthly Temperature, Precipitation, Sea Level Pressure, and Station Pressure Data, Oak Ridge National Laboratory.

that the country still has a great potential for gum production. The time series gives a somewhat misleading picture for the period after 1986, when smuggling to countries like Chad, Nigeria, Ethiopia, Uganda, and Kenya became important (Barbier 2000). The main stimulus for smuggling was that in 1986, the world market price rose (El Khalifa et al. 1989). It has been estimated that in 1987, 15–20% of Sudan's potential export was smuggled (El Khalifa et al. 1989). Smuggling involves local traders as well as farmers (Barbier 2000). The increase in smuggling, however, can most probably not obscure the fact that the production of gum arabic has declined since the end of the 1960s.

The reasons for the decline in production have been debated. Some authorities identify low precipitation as the central cause (Mohie el Deen 1991).[5] Drought affects gum production both directly and indirectly. The direct effect is by damage

[5]As referred to in Iqbal M. 1993. International Trade in Non-wood Forest Products: An Overview. Rome, Italy, Food and Agricultural Organization, FO: Misc/93/11 – Working paper.

to trees, eventhough the tree is indigenous and well-adapted to the dry environment and the erratic nature of rainfall. The indirect impact on gum production from drought is probably more severe. When crop yields decline during dry periods, farmers may be forced to compensate by cropping larger areas and/or cutting down trees for firewood and timber for personal consumption or extra income.

Figure 2 also shows the trends in gum production and rainfall. The rainfall curve is a composite of the data from eight rainfall stations in the gum belt and shows that since the 1960s, the area has been drier than in the first six decades of the century. The decrease in gum production does not occur until a decade after the beginning of the decline in precipitation, which can be explained by the indirect effect of drought. The production was high for a couple of years after the drought in 1984 but by the end of the 1980s, it had reached its lowest level since the beginning of the 20th Century. Another explanation for the decline in gum production has been severe attack by pests after the drought (Jamal and Huntsinger 1993).

Other sources claim that unfavourable socioeconomic policies have had a greater impact than precipitation. Larson and Bromley (1991) believe that the pricing policies contributed to a loss of production. Jamal and Huntsinger (1993) also refer to prices and their lack of association with demand: prices have often remained low even after supply levels have fallen. Others too have blamed the low economic incentives for the farmers (Pearce 1988; Barbier 2000). The export price is set by GAC (Gum Arabic Company) which therefore, has a large impact on the pricing policy. GAC was established in 1969 by the Sudanese government to control all exports of gum (Larson and Bromley 1991). The organization is two-thirds privately owned and one-third publicly owned.[5] The presence of GAC has a positive impact compared to other gum-producing countries. Mauritania, Senegal, Mali, Nigeria, Chad, Ethiopia, and Somalia also produce gum arabic, but do not support an institution like the GAC, and in none is the trade so well structured.[5]

A characteristic of the sources above, and of the present study, is that few have actually studied the impact of environmental and socioeconomic factors on the smallholders. It is essential to understand what dictates the production at the local level as a complement to studies using regional and national data.

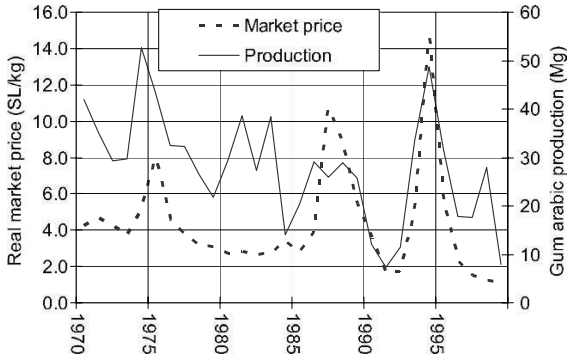

Figure 3. The real market price (SL = Sudanese Pounds) of gum arabic at El Obeid crop market and the Sudanese production for 1970–2000. US$ = 580.9 Sudanese Pounds (SL) in 1995. Source of data: Prices (El Obeid crop market) and production Gum Arabic Company in Khartoum.

Fluctuating prices

A stable market price is essential for the producers. In Figure 3, data on production are compared to the real market price.[6] There may be several middlemen, so that the price actually received by the farmer may be lower than the values in Figure 3. During the last three decades, the price has experienced three peaks, with increasing amplitude. It is evident that falling production has been met by price increases on three occasions (1975, 1987, and 1994), yet the real price of gum arabic has generally followed a downward trend. The present real price is only 25% of the value in 1970.

Fluctuating prices endanger production, because smallholders only can consider the prices to be temporary. For example the real market price of gum arabic increased by 870% between 1992 and 1994, yet 3 years later it had decreased to below the 1992 price. One obvious consequence of a period of low prices is the cutting or neglect of trees. Periods of high prices, on the other hand, may encourage over-tapping. The short peaks in

[6]The nominal prices were adjusted to real prices with the Consumer Price Index (World Bank. 2001. The 2001 World Development Indicators CD-ROM, Win*STARS, version 4.2, 32 bit, International Bank for Reconstruction and Development, The World Bank.) The year 1995 is the base year (=100) when US$ = 580.9 Sudanese Pounds (SL).

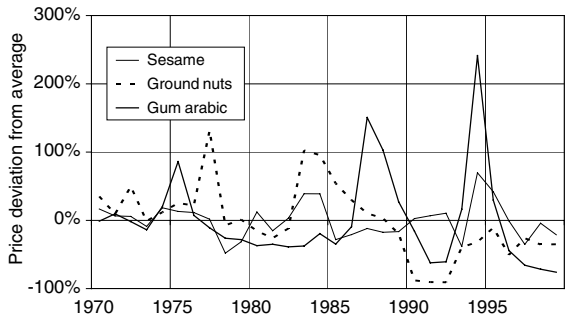

Figure 4. Real prices at the El Obeid crop market of the major agricultural commodities from traditional rainfed agriculture in the gum belt of the Sudan expressed as price deviation from average 1970–1999 price. Source of data: El Obeid Crop Market 2002.

high prices lasted for only one or two seasons, and did not necessarily favour farmers in a longer term. Over-tapping took place in the 1970s when GAC increased the domestic market price considerably in an attempt to introduce incentives for production after a period in which production had fallen after a drought (Larson and Bromley 1991). Fluctuations of price within a season also affect productions, as our interviews revealed, because farmers do not have the economic possibility to store the gum in anticipation of the highest price. Evaporation in storage leads to a lower weight, which is another reason for the farmer to sell as soon as possible (El Khalifa et al. 1989).

Gum arabic differs from other crops in the fact that the prices for other crops are more governed by demand, as they do not have institutions like GAC.[7] The real market price of gum arabic is compared to that of other crops in Figure 4. Fluctuations were large for all crops, but they were the most significant for gum arabic.

Since the Sudan is by far the leading producer of gum, it is able to influence the world market price. However, in 1994 the laws on exporting gum arabic were changed in Sudan. Now it is not only GAC that may export processed gum arabic, although GAC is still the only company that may export crude gum arabic (A. Gaafar, pers. comm. 2002). The fact that the Sudanese market has been deregulated to some extent might have some positive effect on future gum production and the gum market.

[7]As referred to in Elamin E.M., Mahmoud D.H. and El Nam N.A. 2000. Pricing Policies and Agricultural Export Performance in Sudan: the Lessons from the 1970s through 1990s. Seventh Annual Conference of the Economic Research Forum for the Arab Countries, Iran and Turkey, Amman, Jordan, Economic Research Forum.

Conclusions

The farming system of gum arabic seems ideal in the context of environmental and socioeconomic sustainability. This is because it is a system well-integrated in Sudanese society, it creates income during the dry season and it improves soil fertility. However, production has declined and also varied increasingly from year to year over the last three decades, which puts the entire system in jeopardy. The overriding question about gum arabic production hinges on the future international demand for this commodity. It was found that there has been an increase in the imports of gum arabic to the USA and France (1976–2003), which suggests an increasing demand. One source of uncertainty is that the data represent gum from different types of Acacia and not specifically *Acacia senegal*. The diplomatic relationship between the Sudan and the USA does not seem to pose a significant threat to the USA imports as the USA has increased indirect imports from France and from neighbouring countries to the Sudan such as Chad, in addition to excluding gum arabic from the embargo imposed on the Sudan.

It is now crucial for the Sudan and private companies including GAC to prove that they can stabilize the supply of gum arabic on the world market. It would also be advantageous if other countries in the Sahel could increase their production in order to stabilize the market and balance the impact of future natural variations due to rainfall.

The reasons for declining and variable production are reported as a combination of factors, both climatic and socioeconomic. Few sources, including this study, have actually studied the impact of environmental and socioeconomic factors on the livelihood of smallholders. It is essential to understand what determines the production at local level as a complement to studies using regional and national data.

Finally, the data reviewed here show no signs of the international trade in gum arabic moving toward a collapse. Gum production may continue

to be an important source of income for smallholders in central Sudan and to improve environmental and socioeconomic sustainability. However, it is essential that policies assist in price stabilization, so as to avoid over-tapping and neglect of trees by the smallholders.

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References

Ahmed M.E.N.T. 1999. The Socio-economic Role of *Acacia senegal* in Sustainable Development of Rural Areas in the Gum Belt of the Sudan. Der Fakultat fur Forst-, Geo- und Hydrowissenschaften. Technical University of Dresden, Germany, 277 pp.

Anderson D.M.W. 1993. Some factors influencing the demand for gum arabic (*Acacia senegal* L Willd) and other water-soluble tree exudates. Forest Ecol. Manage. 58: 1–18.

Badi K.H., Ahmed A.E.H. and Bayoumi A.A.M.S. 1989. The Forests of the Sudan. Agricultural Research Council, Khartoum, Sudan, 184 pp.

Barbier E.B. 2000. The economic linkages between rural poverty and land degradation: some evidence from Africa. Agric. Ecosyst. Environ. 82: 355–370.

Bernhard-Reversat F. 1982. Biogeochemical cycle of nitrogen in a semi-arid savanna. Oikos 38: 321–332.

Chikamai B.N. 1996. A Review of Production, Markets and Quality Control of Gum Arabic, Technical co-operation programme (project no. TCP/RAF/4557). Food and Agricultural Organization, Rome, Italy, 169 pp.

Deans J.D., Diagne O., Lindley D.K., Dione M. and Parkinson J.A. 1999. Nutrient and organic-matter accumulation in *Acacia senegal* fallows over 18 years. Forest Ecol. Manage. 124: 153–167.

El Khalifa M.D., Sammani M.O.E., Abdel Nour H.O., Pearce D.W., Barbier E.B., Markandya A. and Burgees J.C. 1989. Gum Arabic Rehabilitation in the Republic of the Sudan, Vol. 3: Literature Review. The Republic of the Sudan; International Institute for Environment and Development & Institute of Environmental Studies, Khartoum, 38 pp.

El Tahir B.A., Madibo G.M., El Wakeel A.S. and El Hag F.M.A. 2004. Influence of *Acacia senegal*, *A.seyal* and *A. tortillis* on some properties of sandy soil in North Kordofan State, Sudan, Vol. 12. University of Khartoum Agricultural Science, 127–141.

Freudenberger M.S. 1993. Regenerating the gum Arabic economy: local-level resource management in northern Senegal. In: Friedman J. and Rangan H. (eds), In Defense of Livelihood: Comparative Studies on Environmental Action. Kumarian Press, West Hartford, USA, pp. 231, 52–78.

Gerakis P.A. and Tsangarakis C.Z. 1970. The influence of *Acacia senegal* on the fertility of a sand sheet ("Goz") soil in the central Sudan. Plant and Soil 33: 81–86.

Ibrahim A.M. and Osman M.E. 2001. Report of the meeting of the network for natural gums and resins in Africa (NGARA). In: Chikamai B.N., Mbiru S.S. and Casadei E. (eds), Gums and Resins production in Sudan. Kenya College of Communications Technology, Nairobi, pp. 43–49.

Jamal A. and Huntsinger L. 1993. Deterioration of a sustainable agro-silvo-pastoral system in the Sudan – the gum gardens of Kordofan. Agroforest. Syst. 23: 23–38.

Larson B.A. and Bromley D.W. 1991. Natural resource prices, export policies, and deforestation: the case of Sudan. World Develop. 19: 1289–1297.

Lemenih M., Abebe T. and Olsson M. 2003. Gum and resin resources from some Acacia, Boswellia and Commophora species and their economic contribution in Liban, Southeast Ethiopia. J. Arid Environ. 5: 465–482.

Mohie el Deen F.A. 1991. The use of GIS, GPS and satellite remote sensing to map woody vegetation in Kazgail area, Sudan. ITC J. 1: 3–10.

Olsson L. 1993. On the causes of famine-drought, desertification and market failure in the Sudan. Ambio 22: 395–403.

Olsson L. and Ardö J. 2002. Soil carbon sequestration in degraded semiarid agro-ecosystems – perils and potentials. Ambio 31: 471–477.

Pearce D. 1988. Natural resource management and anti-desertification policy in the Sahel-Sudan zone: a case study of gum arabic. GeoJournal 17: 349–355.

Seif el Din A.G. and Zarroug M. 1996. Production and commercialization of gum arabic in Sudan. In: FAO (eds), Report of the International Expert Consultation on Non-Wood Forest Products: Yogyakarta, Indonesia, 17–27 January 1995. Food and Agricultural Organization, Rome, Italy, pp. 465, 1–7.

US Federal Register 1997. Executive Order 13067 – Blocking Sudanese Government Property and Prohibiting Transactions With Sudan. 3195-01-P. 62: 59987–59990.