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Gum arabic production in *Acacia senegal* plantations in the Sudanian zone of Cameroon: Effects of climate, soil, tapping date and tree provenance

Gum exudate after tapping *Acacia senegal* in Northern Cameroon.
Photograph R. Peltier.

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RÉSUMÉ

PRODUCTION DE GOMME ARABIQUE EN PLANTATIONS D'*ACACIA SENEGAL* EN ZONE SOUDANIENNE DU CAMEROUN : EFFET DU CLIMAT, DU SOL, DE LA DATE D'INCISION ET DE LA PROVENANCE DES ARBRES

La présente étude a été menée sur des plantations *d'Acacia senegal* (L.) Willd. installées en zone soudanienne du Cameroun entre les isohyètes 650 mm et 1 250 mm. L'étude concerne la croissance de l'espèce, le choix de la date d'incision et l'influence des facteurs climatiques et édaphiques sur la production de gomme arabique. Les plantations ont été réalisées de 1985 à 1989 et les essais de saignée de 1993 à 1998. L'espèce a présenté généralement une bonne adaptation et une bonne croissance dans les différentes conditions de site de la zone d'étude. Les observations montrent une meilleure production de gomme quand la saignée a été réalisée en début de saison sèche, lorsque l'humidité relative diminuait. Selon l'isohyète, la date optimale de saignée s'est étalée du 10 octobre (650 mm) au 25 novembre (1 250 mm). Entre 650 mm et 800 mm de pluviosité annuelle, la production moyenne annuelle de gomme dans chaque site a été de 100 g à 500 g par arbre saigné, correspondant à un rendement à la parcelle de 50 à 250 kg/ha/an pour une densité de 500 arbres/ha. Au-dessus de l'isohyète 1 000 mm, la production s'est montrée plus aléatoire. Bien qu'à l'échelle pluriannuelle la production de gomme ait été similaire dans les différents types de sols, le niveau de production annuelle a été plus variable sur sol sableux que sur sol argileux. La provenance soudanienne locale a été en général plus productive que toutes les provenances introduites d'origine sahélienne (Sénégal, Soudan) ou d'Inde. En plus de leur clarté remarquable, les quelques échantillons de gomme analysés de la provenance locale ont montré des propriétés classiques typiques des exsudats d'*A. senegal* de la ceinture sahélienne.

Mots-clés : date d'incision, facteur édaphique, facteur climatique, provenances d'*Acacia senegal*, agroforesterie.

ABSTRACT

GUM ARABIC PRODUCTION IN *ACACIA SENEGAL* PLANTATIONS IN THE SUDANIAN ZONE OF CAMEROON: EFFECTS OF CLIMATE, SOIL, TAPPING DATE AND TREE PROVENANCE

This study was conducted in the Sudanian zone of Cameroon, where annual rainfall ranges from 650 to 1,250 mm, to assess the growth of *Acacia senegal* (L.) Willd. and evaluate the influence of tapping dates, as well as climatic and edaphic effects on gum arabic production. The tree plantations were established between 1985 and 1989, and the tapping tests were carried out between 1993 and 1998. Generally good adaptation and growth of the species were observed in the different site conditions of the study area. To optimize gum production, the best time to tap the trees was at the beginning of the dry season, when the relative humidity dropped. Depending on the location along the climatic gradient, the optimum tapping date varied from October 10th (650 mm isohyet) to November 25th (1,250 mm isohyet). At 650 to 800 mm annual rainfall, the average gum production per site varied from 100 to 500 g per tapped tree, corresponding to 50-250 kg/ha with a density of 500 trees/ha. However, in sites with annual rainfall higher than 1,000 mm, the gum production was generally lower and uncertain. Although the mean production on the different types of soil did not differ significantly when years were combined, the annual production was more variable and more dependent on climatic variations on sandy soils than on clay soils. The local Cameroon Laf provenance was more productive than foreign Sahelian (Senegal, Sudan) or Indian provenances. First observations and analyses of gum samples from the local provenance showed an outstanding brightness and classical properties typical of *A. senegal* exudates in the Sahel region.

Keywords: tapping date, edaphic factor, climatic factor, provenances of *Acacia Senegal*, agroforestry.

RESUMEN

PRODUCCIÓN DE GOMA ARÁBIGA EN PLANTACIONES DE *ACACIA SENEGAL* EN LA ZONA SUDANESA DE CAMERÚN: EFECTOS DEL CLIMA, SUELO, FECHA DE INCISIÓN Y PROCEDENCIA DE LOS ÁRBOLES

El presente estudio se llevó a cabo en plantaciones de *Acacia senegal* (L.) Willd. establecidas en la zona sudanesa de Camerún, entre las isoyetas de 650 mm y 1 250 mm. Este estudio se refiere al crecimiento de la especie, la elección de la fecha de incisión y la influencia de los factores climáticos y edáficos en la producción de goma arábiga. Las plantaciones se efectuaron de 1985 a 1989 y los ensayos de incisión de 1993 a 1998. La especie presentó generalmente una buena adaptación y un buen crecimiento en las distintas condiciones de sitio del área de estudio. Las observaciones muestran una mejor producción de goma si las incisiones se realizan al inicio de la temporada seca, cuando disminuye la humedad relativa. La fecha óptima para incisiones se determinó en función de la isoyeta entre el 10 de octubre (650 mm) y el 25 de noviembre (1 250 mm). Entre 650 mm y 800 mm de pluviosidad anual, la producción promedio anual de goma por sitio varió de 100 g a 500 g por árbol entallado , lo que corresponde a un rendimiento por parcela de 50 a 250 kg/ha/año con una densidad de 500 árboles por hectárea. En la zona que recibe más de 1 000 mm, la producción mostró una mayor irregularidad. Aunque a escala plurianual la producción de goma fue similar en los distintos tipos de suelo, el nivel de producción anual fue más variable en suelo arenoso que en suelo arcilloso. La procedencia sudanesa local se reveló, en general, más productiva que las procedencias introducidas de origen saheliense (Senegal, Sudán) o de la India. Además de su notable claridad, las muestras de goma analizadas de la procedencia local mostraron propiedades clásicas que caracterizan a los exudados de *A. senegal* en la región del Sahel.

Palabras clave: fecha de incisión, factor edáfico, factor climático, procedencias de *Acacia Senegal*, agroforestería.

Introduction

In the arid and semi-arid regions of Africa, land degradation and soil fertility depletion are considered to be the major threats to natural resource conservation and food security (Garrity *et al.*, 2010). One of the potential solutions to land degradation is to promote the utilization, regeneration and planting of a native under-utilized legume tree: *Acacia senegal* (L.) Willd., the main species in the world producing the internationally traded arabic gum. *A. senegal* is a widespread woody species in the pastoral zones of Sahelian Africa. The larger natural stands are on deep sandy soils (fixed old dunes) in areas receiving from 300 to 500 mm annual rainfall (Dione, 1996). However, scattered *A. senegal* stands also occur on clay soils with an annual rainfall of 600 mm in Central and Eastern Sudan (Obeid, Seif El Din, 1970). In Northern Cameroon, *A. senegal* is common and mixed with other species in woodland savannas receiving up to 900 mm annual rainfall.

A. senegal shows promise as a multipurpose species for its range of products and uses: gum arabic, fodder and wood production, and soil fertility improvement (Raddad *et al.*, 2005). As an N_2-fixing species, *A. senegal* improves degraded lands and nutrient deficient soils (Isaac *et al.*, 2011). This species is particularly used in tree improved fallows to replenish soil fertility (Deans *et al.*, 1999; Raddad *et al.*, 2005), and intercrops well with sorghum and other grasses (Gaafar *et al.*, 2006). Its ability to produce arabic gum (the true food-grade gum as it contains no toxins) is of particular economic interest which justifies a rural forestry based on plantations, following the example of the Sudanese agroforestry farming system (Palou Madi *et al.*, 2010). Nevertheless, the success of *A. senegal* plantations in the Sudanian zone, which is wetter than its main zone of origin, will depend, for economic reasons, on the gum yields of the plantations (Harmand *et al.*, 1997). In Burkina Faso, for example, natural and artificial stands show high yielding potentials with up to 710 mm annual rainfall (Soloviev *et al.*, 2010).

Ballal *et al.* (2005a) in the Sahelian zones of Sudan, and Dione (1996) in Senegal showed that gum production occurs only during the dry season, when the trees are shedding leaves. A threshold of water stress, consecutive to rain stoppage and dry air, seems required to trigger gum exudation (Dione, Vassal, 1998). Ballal *et al.* (2005a and b), and Raddad and Luukkanen (2006) showed a positive relationship between gum yield and rainfall in the season preceding tapping and/or between gum yield and soil water content at the end of the rainy season.

Ballal *et al.* (2005a) found that gum yield was positively correlated with tapping intensity, rainfall, and minimum and maximum temperatures at tapping time, and negatively correlated with tapping time, and minimum and maximum temperatures at gum collection. Late tapping reduced the production of gum.

In Northern Cameroon, experimental plantations of *A. senegal* have been created since 1985, in various pedoclimatic sites between 650 and 1,250 mm annual rainfall. The objective of the present study was to assess the growth of *A. senegal* and to evaluate the influence of the tapping date, as well as climatic and edaphic effects on gum production. Local provenance was compared with other Sahelian origins in terms of gum production and quality. This article synthesizes the results obtained on arabic gum production from 1993 to 1998 in order to answer the following questions:

- Can *A. Senegal* produce gum in the Sudanian Cameroonian zone, with 650 to 1,250 mm annual rainfall? The hypothesis being that a given level of water stress is required for gum exudation.
- Is it necessary to adapt the tapping calendar to the combination of provenances and sites? The hypothesis being that leaf shedding and then the tapping date depend on both parameters.
- Is there an influence of the soil type on the survival rate, tree growth and gum production? The hypothesis being that the soil water regime resulting from the soil type will influence tree growth and gum production.
- Can Sahelian provenances produce gum in Northern Cameroon? The hypothesis being that provenances are adapted to their zone of origin and may produce little gum in this wetter area.

Ultimately, answering these questions will determine the possibility of and provide information on developing sustainable and profitable gum production systems in the different areas of Northern Cameroon. However, fair prices can be offered for Cameroon gum only if it reaches quality standards. As no information was available on Cameroon gum, standard quality tests were performed and results are briefly presented in this article.

One of the potential solutions to land degradation is to promote the utilization, regeneration and planting of a native under-utilized legume tree: *Acacia Senegal*.
Photograph R. Peltier.

Materials and methods

Location and plant material

The production of arabic gum was studied in seven sites in which *A. senegal* was planted between 1984 and 1989. Table I shows the characteristics of the sites and the plantations, all located in areas receiving an annual rainfall ranging from 650 to 1,250 mm (figure 1). There were three types of soils: sandy ferruginous soils (referred to as sandy soils), clay planosol "Hardé" (referred to as planosol) and clay vertisol. In the locations of Balda and Makalingay (figure 1), the local provenance (Cameroon Laf), located 10 km south of Mouda, was compared to two provenances from Sahelian Sudan (Sudan North Kordofan and Sudan Blue Nile), two provenances from Northern Senegal (Senegal Diarno and Senegal Loumbé) and one provenance from India (table I). Sudan is the main arabic gum producing country, whereas Senegal provides the high quality Ferlo gum. India is an isolated area for *A. senegal*, with potential alternative genetic resources. The trees were planted with spacing of 4 m x 4 m (density of 625 trees/ha). The provenance comparison trials and two other trials on tree species screening (Aïssa Hardé and Salak) were set up in randomized complete block designs with four repetitions. The dimensions of the plots were 28 m x 28 m (49 trees altogether, including 25 useful trees). The other trials (Mouda, Ngong and Touboro) consisted in mono-provenance plots, without experimental design. The survival rate of each plantation was evaluated and the height of the trees was measured in each plot from 1985 to 1997.

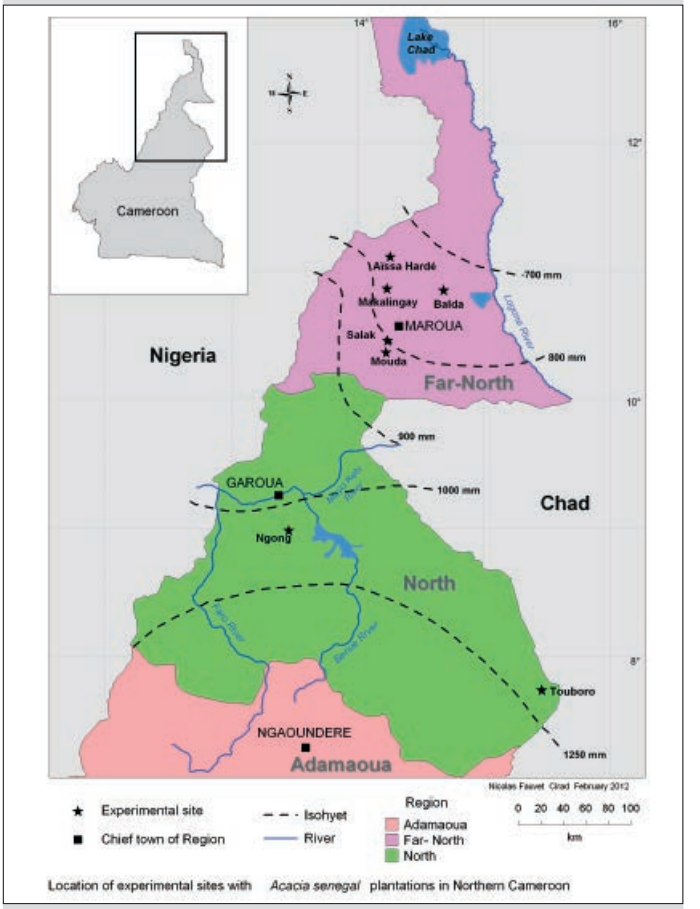


Figure 1.
Experimental sites with *Acacia senegal* plantations in Northern Cameroon.

Table I.
Description of the different experimental sites and *Acacia senegal* plantations in Northern Cameroon.

Location	Latitude and longitude	Altitude (m)	Soil	Annual rainfall (mm)	Origin of provenance	Annual rainfall in original site of provenance	Planting year	Survival rate (%) 1994	Survival rate (%) 1997
Aïssa Hardé	11°07'00"N 14°19'45"E	325	Ferruginous (Sand dune)	650	Cameroon Laf (Clay soil)	800 mm	1984	80	45
Balda	10°53'20"N 14°38'00"E	330	Ferruginous (Sand dune)	700	Sudan Blue Nile India Barmer Raj. Senegal Diarno Senegal Loumbé Cameroon Laf	less than 600 mm 243 mm 540 mm 550 mm 800 mm	1985	84 34 60 67 87	83 28 60 60 85
Makalingay	10°51'35"N 14°15'00"E	416	Ferruginous (Sand dune)	700	Sudan Blue Nile Sudan North Kordofan Cameroon Laf	less than 600 mm 365 mm 800 mm	1989	73 96 93	68 94 90
Salak	10°27'48"N 14°14'21"E	430	Planosol 'Hardé' (Clay soil)	800	Cameroon Laf	800 mm	1985	83	80
Mouda	10°22'48"N 14°13'43"E	450	Vertisol (Clay soil)	800	Cameroon Laf	800 mm	1984	85	69
Ngong	9° 02' 09"N 13°30'38"E	330	Ferruginous (Sandy soil)	1100	Cameroon Laf	800 mm	1989	100	100
Touboro	7°46'29"N 15°21'5"E	525	Ferruginous (Sandy soil)	1250	Cameroon Laf	800 mm	1986	100	100

Tapping treatments

The tapping trials were carried out from 1993 to 1998. Tapping, an essential treatment to induce gum exudation, was practiced with tools and the standard method used in Senegal. It consisted in removing 4-cm-wide and 30-cm-to-1-m-long strips of bark to expose the sapwood. Selected branches had a diameter greater than 5 cm and a smooth bark. Tapping was performed on two to three branches of each tree during the first four years (1994 to 1997), on all the branches during the production season 1997-98. After tapping, gum started to exude and formed nodules which were harvested and weighed every two weeks. The yield of each tree was cumulated over the harvesting period, starting at the beginning of the dry season in October or November and ending in April. In 1997-98, two tapping dates were compared in all the locations but Touboro: early tapping in October (from 10th to 21st depending on the location, see table 3) and late tapping on November 10th, except in Ngong, where tapping was performed on December 18th. The Touboro plot was tapped once on November 25th. In each situation (site, provenance) and for each year and date of tapping considered, 20 trees were randomly selected and tapped; in the complete block designs, five trees were selected in each of the four blocks.

In the production season 1996-97, three tapping dates were tested in Salak, and air humidity and temperature were obtained from a nearby meteorological synoptic station.

Analyses of variance were carried out to study the factors provenance and date of tapping. In the case of a significant F-test, treatment means were compared using a Newman-Keuls HSD test. Gum production data were subjected to t-tests to analyze the differences between years and between sites within the local provenance (Cameroon Laf).

Gum samples of *A. senegal* were collected in 1998 from a few trees of Sudanese and local provenances, the latter in two locations (Makalingay and Aïssa-Hardé) and included gum obtained from holes bored by insects. They were analyzed at the cellular Laboratory of Physiology of the University of Rouen in France. The analyses related to the traditional properties, i. e. viscosity, molecular mass, Lovibond colorimetric index and specific optical rotation.

Results and discussion

Survival rate and growth of *A. senegal*

More than 80% of the planted trees from the local provenance (Cameroon Laf) survived after about 10 years in all the locations (table I). In Makalingay and Balda, survival rates of the Sudanese, Senegalese and Indian provenances were 68-94%, 60-67% and 28%, respectively (table I). The height growth of the local provenance ranged from 400 to 630 cm, 8 to 13 years after planting in the different sites (figure 2). Hence, and compared to observations in Senegal (Deans *et al.*, 1999) and Sudan (Raddad, Luukkanen, 2006), this growth was acceptable under a wide range of pedoclimatic conditions, with an annual rainfall from 650 to 1,250 mm, comprising sandy soils, and clay soils (vertisols and planosols "Hardé") (figure 2). However, in the latter situation, suitable rainwater harvesting measures such as small dykes and depressions were necessary to reduce surface runoff and thus to ensure a good start of the seedlings (Peltier, Eyog Matig, 1988; Harmand, 1993). After ten years, the higher survival rate and height growth observed in Touboro (annual rainfall of 1,250 mm) showed a good adaptation of the species to sub-humid areas.

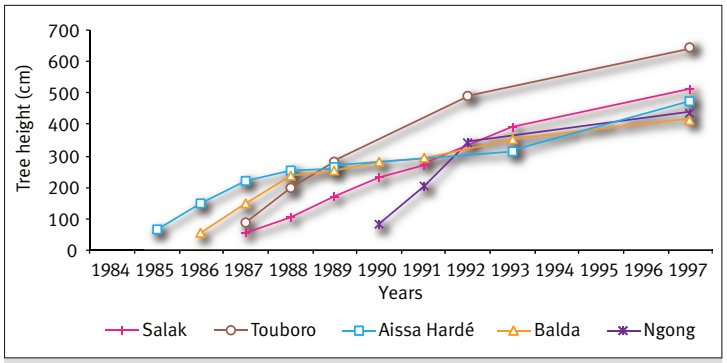


Figure 2.
Height growth of the local provenance (Cameroon Laf) of *Acacia senegal* in different locations of Northern Cameroon.

In the locations of Balda and Makalingay, the local provenance (Cameroon Laf: smooth bark on the left), was compared to two provenances from Sahelian Sudan (Sudan North Kordofan and Sudan Blue Nile: rough bark on the right). Photographs R. Peltier.

Seasonal dynamics of gum production

Gum exudation occurred approximately three weeks after tapping and continued up to April-May, at the arrival of the first rains. The peak of production occurred at variable dates. In Salak, considering the five years of production, maximum production was obtained at the end of December for early tapping (October), and in January for late tapping (November) (figure 3). This peak of production (g/tree/15 days) showed a positive linear correlation with the total annual production (g/tree). The simple regression model was significant (n= 6, P = 0.05; r^2 = 0.64):

Annual production = 4.69 x + 21.9

With annual production (g/tree), x peak of production (g peak/tree); data points were mean yield of the peak of production in relation to annual yield (average of 20 trees). Ballal *et al.* (2005a) proposed to use this type of model based on the yield of the first or second picking (Raddad, Luukkanen, 2006), and the date of tapping to predict the yield of the current year.

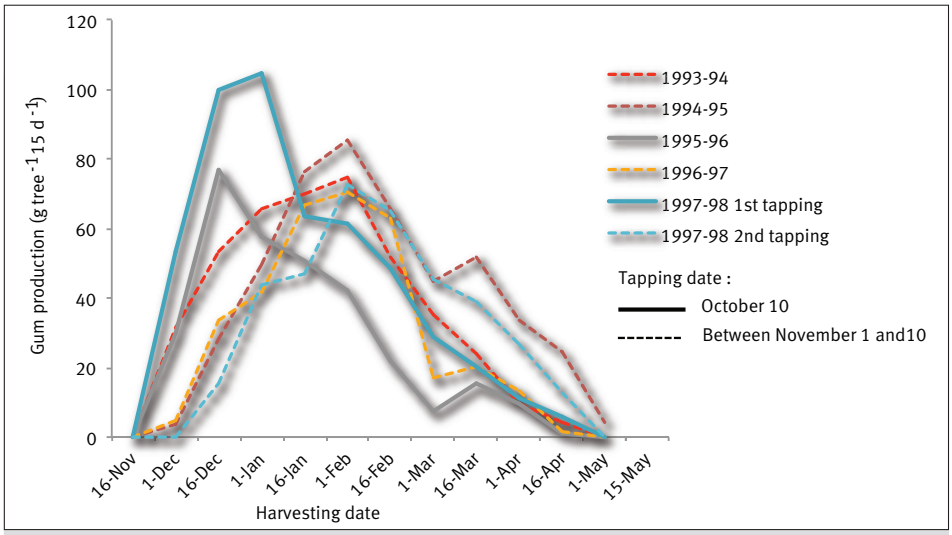


Figure 3.
Gum production (g/tree) in the local provenance (Cameroon Laf) of *Acacia senegal* every 15 days according to the tapping date and the year. Data from the site of Salak (Far North Province of Cameroon).

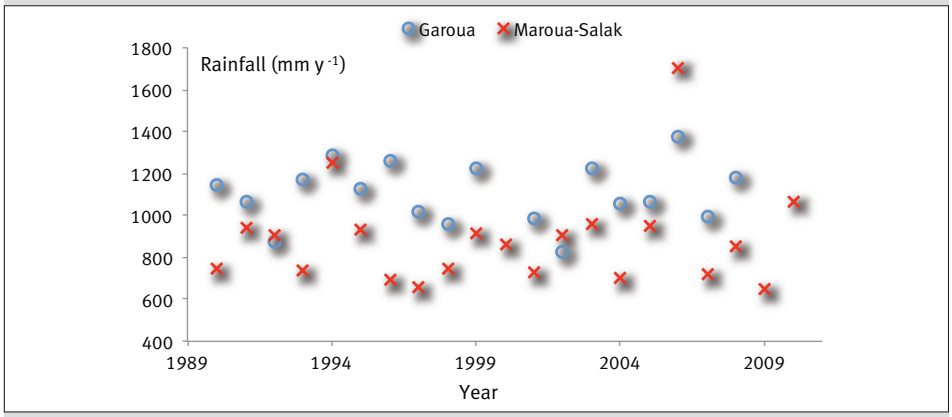


Figure 4.
Annual rainfall (mm/yr)) during the period 1990-2010 in Maroua-Salak (Far North Cameroon) and Garoua (North Cameroon).
Data from the synoptic stations of Maroua and Garoua airports.

Gum production and climatic factors in the Sudanian zone of Cameroon

No significant variation was observed in the annual rainfall during the period 1990-2010 (figure 4): for example, for the periods 1993-98 and 2000-10 the average annual rainfall was 800 mm and 860 mm in Maroua-Salak (Far North Region), and 1,085 mm and 1,035 mm in Garoua (North Region), respectively. Therefore, we consider that the results obtained locally in 1993-98 are still valid for the 2000-2010 decade (figure 4).

Gum yield varied from 0 to 1,530 g/tree, and the maximum was observed at Makalingay during the period 1997-98. Inter-tree variability of gum yield was high even within plots, regardless of the site or provenance (data not shown), similarly to previous results in other countries (Ballal *et al.*, 2005; Raddad, Luukkanen, 2006; Jacques *et al.*, 2010).

In the Far North Region of Cameroon (Balda, Makalingay, Salak and Mouda) with 650 to 800 mm annual rainfall (semi-arid area), the average gum production over 3 to 5 years of tapping was about 215 g per tapped tree (including the non productive trees), i. e. 110 kg/ha/y for a density of 500 trees/ha (table II). During the period 1997-98, the average gum yield of the local provenance varied from 170 to 500 g per tapped tree, i. e. from 85 to 250 kg/ha at the plot level, when tapping was carried out at the right time and with high intensity (see below) (table III). In the Senegalese Sahel (Ferlo area, with 250 to 400 mm annual rainfall), Dione (1996) reported average productions varying from 45 to 350 g/tree according to sites, i. e. 11 to 90 kg/ha, as plantation densities were about 250 trees/ha. In Western Sudan (Northern Kordofan State, with 358 mm mean annual rainfall), Ballal *et al.* (2005a) reported during height years, average productions varying from 215 to 280 g/tree/y according to tapping dates, i. e. 86 to 112 kg/ha for a density of 400 trees/ha. Comparatively, *A. senegal* seems a bit more productive in the Far North Region of Cameroon where rainfall varies from 650 to 800 mm than in the Sahelian zones of Senegal and Sudan where natural populations of *A. senegal* are more widespread. Therefore, gum production seemed linked to the occurrence of a pronounced dry season and not to a low annual rainfall. The higher water supply occurring during the wet season in the Far North Region of Cameroon compared to Senegal and Sudan may be beneficial to gum production. A multi-local study in Burkina Faso (Soloviev *et al.*, 2010) showed no clear relationship between gum production and annual rainfall, although the highest yield (225 g/tree)

Table II.
Mean gum production (g/tree/y) in the local (Cameroon Laf) provenance of *Acacia senegal* in seven locations in Northern Cameroon. Means within a line (campaign) followed by the same letter are not significantly different at P≤0.05 (n = 20).

	Experimental site						
	Salak	Mouda	Makalingay	Balda	Aïssa Hardé	Ngong	Touboro
Soil	Planosol	Vertisol	Ferruginous sandy soil				
Age of plantation (y)	8-12	10-13	5-8	9-12	10-13	5-8	11
1993-94	218	-	-	-	-	-	-
1994-95	251 a	-	127 b	123 b	186 ab	102 b	-
1995-96	157 a	124 a	20 b	-	-	51 b	-
1996-97	173 a	-	185 a	227 a	-	-	-
1997-98	252 b	175 b	503 a	330 ab	391 a	21 c	210 b
Mean	210 a		209 a	226 a		58 b	
Standard deviation	44		207	103		41	

Table III.
Mean gum production (g/tree/y) in the local provenance (Cameroon Laf) of *Acacia senegal* according to the tapping date in seven locations in Northern Cameroon in the campaign 1997-98.
Means within a line (location) followed by the same letter are not significantly different at P≤0.05 (n = 20).

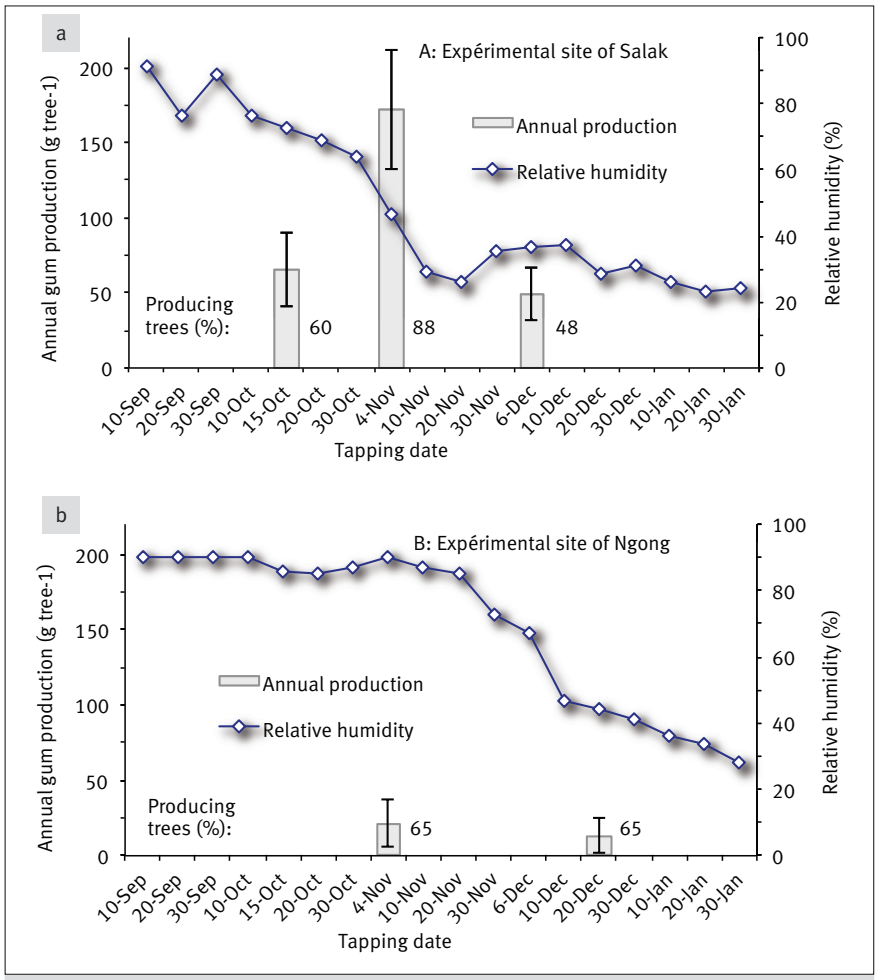
Tapping date	10-Oct	17-Oct	21-Oct	10-Nov	25-Nov	18-Dec	P value
Aïssa Hardé		390.7 a		198.2 b			0.0002
Balda			206.4 a	330.1 a			0.06
Makalingay	503.2 a			393.8 a			0.7
Salak		252.2 a		186.5 a			0.06
Mouda		174.9 a		107.3 a			0.15
Ngong			21.7 a			13.5 a	0.4
Touboro					210		

was recorded in the location with the highest rainfall (710 mm per year) and the lowest (45 g/tree) in the driest location (565 mm). Moreover, Ballal *et al.* (2005b) showed in Sudan (North Kordofan) a positive correlation between annual gum yield over a six year period and annual rainfall received during the season preceding tapping. In the Senegalese Sahel, Dione (1996) also mentioned a positive correlation between annual rainfall and gum production over a seven year period. Also, in the Nigerian Sahel, Oleghe and Akinnifesi (1992) showed that an adequate water supply will help the production of gum in the dry season. In Senegal, Giffart (1973), Sene (1988) and Dione (1996) reported the need for significant rainfall during the rainy season, followed by a hot dry season to support gum production.

However, the results showed average gum yields in Ngong (1,100 mm annual rainfall) generally much lower than those in drier sites, suggesting that above 1,000 mm annual rainfall (sub-humid area) gum production declines. Nevertheless, the first gum yield recorded in Touboro (1,250 mm) was comparable with that in sites of the Far North (table III). This is encouraging for the prospects of gum production in the Southern Sudanian zone.

Table II shows that gum yield in year 1997-98 was higher than in the previous years in almost all cases. The average temperature in November 1997 was higher (29°C) than those in November in the four previous years (26°C to 27°C). Such high temperatures at tapping time are known to be beneficial to gum exudation (Ballal *et al.*, 2005a). However, the higher

More than 80% of the planted trees from the local provenance (Cameroon Laf) survived after 10 years in all the locations (Ngong on the left and Balda on the right). Photographs R. Peltier.



Figures 5.
Annual production of gum arabic in the local provenance (Cameroon-Laf) of *Acacia senegal* according to the tapping date in Salak (A) (Far North Province of Cameroon) and Ngong (B) (North Province of Cameroon).

yield in 1997-98 could also be due to the fact that all tree branches with diameters larger than 5 cm were tapped, whereas in the previous years, this was only the case for two to three branches per tree. However, BALLAL *et al.* (2005b) reported that increasing the number of tapped branches per tree from 3 to 8 resulted in a low addition of gum yield.

Tapping date and gum production

During the production season 1996-97, three tapping dates were compared for the local provenance in Salak (figure 5A). The production was examined in relation to the relative humidity of the tapping period. Gum yield was significantly higher when tapping was carried out during the sharp decrease of the relative humidity (November 4) than when it was carried out before or after the change in air humidity. The higher efficiency of tapping carried out during the seasonal climate transition was confirmed by the higher percentage of producing trees.

For the production season 1997-98, table III shows the production obtained in each location at different tapping dates. The production was higher for trees tapped early (October), but the only significant difference between this production and that of the second tapping date (November 10) was in Aïssa Hardé. BALLAL *et al.* (2005b) recorded that late tapping reduced gum yield by 40-50% in two different locations in North Kordofan.

Effect of uncontrolled coleopteran (Bostrychidae) attacks at the end of the rainy season in Ngong (1100 mm annual rainfall). These insects dug galleries in stems and branches causing early defoliation and profuse exudation from 250 g to 1 kg of gum per attacked tree per year. Photographs R. Peltier (left) and J.-M. Harmand (right).

Additional observations made in 1997-98 in Salak showed that trees had lost about 50% of their foliage when they were tapped for the first time (October 17), whereas the second tapping (November 10) resulting in less production corresponded to 80% defoliation. Consequently, the phenological stage could constitute a good indicator for the choice of the tapping date. Considering the low accuracy of the visual estimation of the degree of defoliation, the level of 50% defoliation is in accordance with Sene (1988) and Dione (1996) who mentioned that in Senegal higher gum exudations were obtained after tapping trees at two thirds of their defoliation. Low gum yield in Ngong (figure 5B) may similarly be related to too early (October 24) or too late (December 18) tapping. In this location, leaf flushes following late rains made the choice of the tapping date based on the phenological stage of trees difficult. In Touboro (1,250 mm annual rainfall) gum yield following late tapping (at the end of November) was comparable with that in sites of the Far North Region (table III), which shows that managing the tapping date may be a key to ensure higher gum yield in sub-humid areas.

On the whole, as late tapping, after the drop in air humidity produced lower yields, our data are not consistent with the mere reference to a required threshold in water stress. There seems to be a limited favourable tapping time for gum production. Data collected could not indicate whether leaf fall was a mere indicator of favourable climatic conditions or a necessary physiological status to induce gum biosynthesis. However, other qualitative observations tended to indicate that defoliation seems to be necessary for gum exudation. In Salak (800 mm), two of the 80 trees tapped over four years did not produce gum. These trees remained green later during the dry season. Similarly, tapping leafy branches in January did not induce exudation, whereas defoliated branches of the same trees, tapped at the beginning of the dry season, produced gum. Moreover, other observations showed that *A. senegal* trees planted in alluvial zones with shallow water table, neither defoliated at the beginning of the dry season, nor produced any gum arabic. Trials were not set up on these sites.

Another major observation on gum exudation was the effect of uncontrolled coleopteran (Bostrychidae) attacks at the end of the rainy season in Ngong (1,100 mm) in 1994 and Aïssa Hardé (650 mm) in 1997. Each time, these insects dug galleries in stems and branches causing early defoliation and profuse exudation from 250 g to 1 kg of gum per attacked tree per year. A 216 kg/ha production was obtained in Ngong in 1994-95 at the plot scale in response to insect attacks (Harmand, Bois, 1997). In Sudan, Jamal (1994) reported two species of Bostrychidae which bored galleries in the trunks of acacias: *Apate monachus* Boh. and *Sinoxylon senegalense* Karsch.

From a practical standpoint, indicative periods to carry out tappings can be proposed according to the geographical location, climatic conditions and phenological stage of the trees (Maroua and North of Maroua: October 15th – November 10th; Ngong, south of Garoua: November 10th – December 5th).

Tappings carried out for five consecutive years did not seem to exhaust the trees, which indicated that exploitation might last over ten years, even twenty years as suggested by Muthana (1988) for Sudan.

Effect of soil type on gum production

Over the study period (all years confounded), mean annual gum production from the local provenance in the different locations did not show any significant differences between sandy and clay soils. On the other hand, annual gum productions showed higher variations (higher standard deviation) on sandy soils than on clay soils (table II). Gaafar (2005) showed that gum production was positively correlated to soil water at 75-150 cm soil depth. Clay soils would thus guarantee a relatively stable production in spite of the interannual variability of climatic conditions, whereas, on ferruginous sandy soils, the level of production seems to depend on the seasonal rainfall pattern. This confirms results by Séguiéri (1990) who observed in the same region that the development of the vegetation was more influenced by climatic variations on sandy soils than on clay soils as soil water content was more related to rainfall variations on sandy soils.

Influence of tree provenance on gum yield

Imported provenances have been compared to the local one (Cameroon Laf) on the sites of Balda and Makalingay, both located in the Far North Region of Cameroon on sand dunes with 700 mm annual rainfall. The imported provenances originated from drier areas of Senegal, Sudan and India.

At Balda (table IV-A), over the three-year monitoring period, the gum yield per tree was significantly higher in the local provenance than in imported provenances, except in 1997-98 when the Senegal Diarno provenance also performed well. Per area unit, the advantage of the local provenance was even greater, as it had the higher survival rate.

At Makalingay (table IV-B), the production of the local provenance was significantly higher than that of the Sudan Blue Nile provenance. However, gum yield of the second Sudan provenance, North Kordofan, was significantly lower only in 1996-97. Rainfall was low in 1995, which caused reductions in gum production in 1995-96 in the Cameroon and Sudan Blue Nile provenances, but not in the Sudan North Kordofan provenance. The latter seemed to adapt to lower rainfall and appeared less sensitive to the interannual variations of the climatic conditions. In 1997-98, the most productive tree was from Sudan North Kordofan (1,530 g), with a value higher than that of the most productive local tree (840 g). This provenance could thus include remarkable individuals that could be used in a breeding program ("plus trees", Soloviev *et al.*, 2010). Moreover, its survival rate was high in Makalingay.

On the whole, our results confirmed the hypothesis that in wetter areas, Sahelian provenances may not experience the level of stress needed to produce high levels of gum. The local provenance performed better, both in terms of survival rate and gum production. Furthermore, according to Raddad and Luukkanen (2006) who showed that provenances from clay parts of the Sudanese gum belt were better adapted for fast growth, high biomass and gum productivity than provenances from the sand region, the clayey characteristics of the soil of Laf could also be in favor of the local Laf provenance.

Tables IV.
Mean gum production (g/tree/y) in different provenances of *Acacia senegal* in two experimental sites in the Far North Province of Cameroon. Means within a line (campaign) followed by the same letter are not significantly different at P≤0.05, according to Newman-Keuls HSD test (n = 4).

A – Experimental site of Balda Campaign (tapping date)	Provenance					
	Cameroon Laf	Senegal Loumbé	Senegal Diarno	India	Sudan Blue Nile	P value
1994-95 (2-Nov)	123 a	86 b	100 b	86 b	65 b	0.05
1996-97* (17-Oct and 10-Nov)	187 a	74 b	48 b	58 b	51 b	0.0001
1997-98* (21-Oct and 13-Nov)	268 a	60 b	309 a	141 b	97 b	0.0001

B – Experimental site of Makalingay Campaign (tapping date)	Provenance			
	Cameroon Laf	Sudan North Kordofan	Sudan Blue Nile	P value
1994-95 (1-Nov)	127 a	56 ab	21 b	0.04
1995-96 (15-Oct)	21 b	60 a	6 b	0.02
1996/97 (8-Nov)	185 a	67 b	12 b	0.01
1997-98** (10-Oct and 11-Nov)	448 a	349 a	34 b	0.0001

* In 1996-97 and 1997-98 gum yields were the average of two tapping dates.
** In 1997-98 gum yields were the average of two tapping dates.

Table V.
Intrinsic viscosity, molecular mass, colorimetric index and specific rotation angle of gum samples from *Acacia senegal*, collected in Northern Cameroon.

Site	Makalingay			Aïssa Hardé	
Origin	Gum samples from tapping				Gum samples from insect attacks
Provenance	Cameroon Laf	Sudan North Kordofan	Sudan Blue Nile	Cameroon Laf	Cameroon Laf
Viscosity (mL/g)	17.1	18.6	17.7	24.3	16.4
Molecular Mass (g/mol)	375,000	370,000	322,000	1,780,000	718,000
Lovibond colorimetric Index	1.6	1	1.1	1.4	1.2
Specific optical rotation at 25°C (aqueous solution 1 %)	-26°	-	-	-27°	-

Characteristics of gum produced by Sudan and local provenances
(table V)

Intrinsic viscosity ranged between 16 and 19 mL/g. Only one sample of the local (Cameroon Laf) provenance from Aïssa-Hardé was abnormal, although not exceptional. Similar results were observed on fresh and authenticated samples of Senegalese Ferlo gum, with no further anomaly (Fenyo, Personal Communication). Similarly, the average molecular masses were typical for gum arabic; the correlation between high viscosity and high molecular mass was evident for sample 4. The values of the colorimetric index were remarkably low. These samples would be classified in the trade as "selected sort" or "hand-picked selected", i.e. the cleanest, clearest and of greater value. The specific optical rotations were also typical for the gum of *A. senegal* (Fenyo *et al.*, 1998). The gum collected following exudation due to insect attacks had similar properties to those obtained by tapping. The Cameroonian gum samples analyzed had classical properties, typical of *A. senegal* exudates from the Sahelian zone.

Tappings carried out for five consecutive years did not seem to exhaust the trees: example of good healing of the bark in Ngong.
Photograph R. Peltier.

Conclusion

Although Northern Cameroon is not as dry as the traditional producing regions of Sudan and Senegal, it proved suitable for gum arabic production. The local provenance of *A. senegal* survived and grew well in the different conditions of the study area with 650 to 1250 mm annual rainfall. Between 650 and 800 mm annual rainfall, average gum production was 215 g per tapped tree and could go up to 500 g/tree, i.e. 250 kg/ha/y for a density of 500 trees/ha. A high rainfall during the wet season preceding a well-established dry season seemed beneficial for gum production. However, in sites with an annual rainfall higher than 1,000 mm, the gum production was generally lower and uncertain, maybe because of the insufficient water stress encountered in these sites.

One main aim of the study was to determine the optimum tapping date in the different sites of Northern Cameroon. As in Sahelian areas, gum exudation occurred after tapping applied when the rain stopped, the air humidity dropped and the trees lost their leaves. Tree tapping applied early in the dry season was more effective than after the seasonal climate transition characterized by a drop in the relative humidity.

On sandy ferruginous soils, annual gum production was more variable than on clay soils as the soil water content was more related to climatic variations on sandy soils. Nevertheless, on a multiannual scale, the levels of production were comparable for both types of soils. Therefore, numerous locations can be suitable for productive *A. senegal* plantations in Northern Cameroon, provided that soils dry out and trees can defoliate early in the dry season.

The local provenance of *A. senegal* was the most productive and should be preferred for plantation. This confirmed the hypothesis that Sahelian provenances may require a dryer environment for high gum production. Conversely, it showed that gum exudation is not limited to provenances adapted to extreme aridity.

These results on gum production in various pedoclimatic situations pave the way for an in-depth research on the ecophysiological drivers of gum arabic exudation by *A. senegal*. The longevity and gum production capacity in the long term of *A. senegal* stands still have to be assessed in different contrasting climate/soil conditions. In perspective, one way to alleviate insufficient water stress in sub-humid areas could be the use of compounds susceptible to have an effect on gummosis and gum exudation, such as Ethephon (2-chloroethylphosphoric acid), which releases ethylene and mimics the physiological stress believed to trigger gummosis.

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