Title: Physiological functioning of five-year old planted West African provenances of *Vitellaria paradoxa* C.F. Gaertn (karité) in Gonsé, Burkina Faso

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Summary

The constraints of the long interval before fruiting and variability of annual yields of the most dominant parkland species (*Vitellaria paradoxa* C.F. Gaertn) in West Africa are addressed through a participatory selection and multiplication programme. Trials on five provenances from Burkina Faso (3), Mali (1) and Senegal (1) were established in Burkina Faso. The objectives were to (1) characterize the wetting profile under which the trees are growing by monitoring soil water; (2) quantify variation in seasonal transpiration by the provenances under investigation; (3) model the response of these provenances to inter-annual rainfall fluctuations using the WaNuLCAS model. The design was a complete randomised blocks with single tree as the experimental unit repeated once within each of the 35 blocks (70 replicates). Five years after planting, the results showed that the survival rate did not differ significantly even though Botou provenance was superior and Senegal provenance showed the lowest survival rate. Passoré, Mali and Botou-Fada showed the highest height and collar diameter whereas the provenances of Senegal and Gonsé performed poorly. As a consequence, Passoré and Mali provenances showed the highest transpiration rates per tree and depleted more soil water. However, these provenances transpired less water per unit area of leaves suggesting a better water use efficiency making them more suitable for semi-arid regions of West Africa. Further data is required to model the long-term effects of these provenances on soil water balance and their fruit production before reliable recommendations can be made to farmers.

1. Introduction

Agroforestry parkland systems are the most widespread land-use systems in the Sahelian region of West Africa and critical for the region's production of food crops. In the parklands, farmers grow annual crops and scattered trees form an open permanent upperstorey (Nair, 1993). *Vitellaria paradoxa* C.F. Gaertn, locally known as karité, is the dominant tree species (Hopkins and White, 1984). Following studies on population dynamics (IRHO, 1952, Marchal, 1980; Oudba, 1983; Gijsbers *et al.*, 1994), it has been established that karité is threatened due to poor regeneration.

The status of karité, and the associated parkland farming systems, may be enhanced through farmer practices that favour regeneration of mature trees. Another option is the production and distribution of seedlings to establish 'planted parkland' systems. However, the long interval before fruiting and wide variability in the volume and quality of annual yields (fruits and oil) are major constraints to domestication of this species (Hall *et al.*, 1996). Institut de l'Environnement et de Recherches Agricoles (INERA) and the ICRAF Sahel Regional Programme are addressing these challenges through a participatory selection and multiplication programme. The selection of "plus trees" is based on farmers' knowledge of individual tree productivity and other favoured characteristics (e.g. tree morphology, precocity in fruit production, and fruit taste and oil content), as well as site characteristics such as slope, soil and management.

Trials on five provenances from Burkina Faso (3), Mali (1) and Senegal (1) were initiated in Burkina Faso during 1997. Seeds were collected from at least 25 samples per provenance and seedlings were transplanted to an experimental site at Gonsé in 1999. Until recently, data collection has focused on morphological characteristics such as the height, diameter and branching of seedlings. However, because the Sahel is characterized by low, very unpredictable, uni-modal rainfall patterns, the ability of provenances to adapt to inter-annual rainfall fluctuations is also an important parameter for provenance selection and recommendation.

There is a need to determine the water use of the provenances. It is hypothesized that adaptation to the uncertain rainfall would favour provenances which have deeper root systems or have a higher root: shoot ratio. By monitoring the recharge of water into the soil profile and the water uptake by different provenances, it should be possible to provide reliable parameters to model the response of the provenances to climate changes and land degradation. It is recommended that modelling be done using WaNuLCAS which has been tested in semi-arid Kenya by ICRAF (Muthuri *et al.*, 2004).

2. Objectives

The objectives of the study are to:

1. characterize the wetting profile under which the trees are growing by monitoring soil water;
2. quantify variation in seasonal transpiration by different provenances;
3. model the response of different provenances to inter-annual rainfall fluctuations using the WaNuLCAS model.

3. Materials and methods

3.1. Study site

The site of the study is at Gonsé, a village located 25 km north-east of the city of Ouagadougou, Burkina Faso, West Africa (12°25' N and 1°20' W) at an altitude of 300 m.a.s.l. The rainfall is uni-modal with a mean annual rainfall over the last 30 years of 730 mm, mean ETP of 168 mm and mean temperature of 28°C (Figure 1). The soils are sandy clay to clay-sandy Ferriginous leached with very low nutrient content.

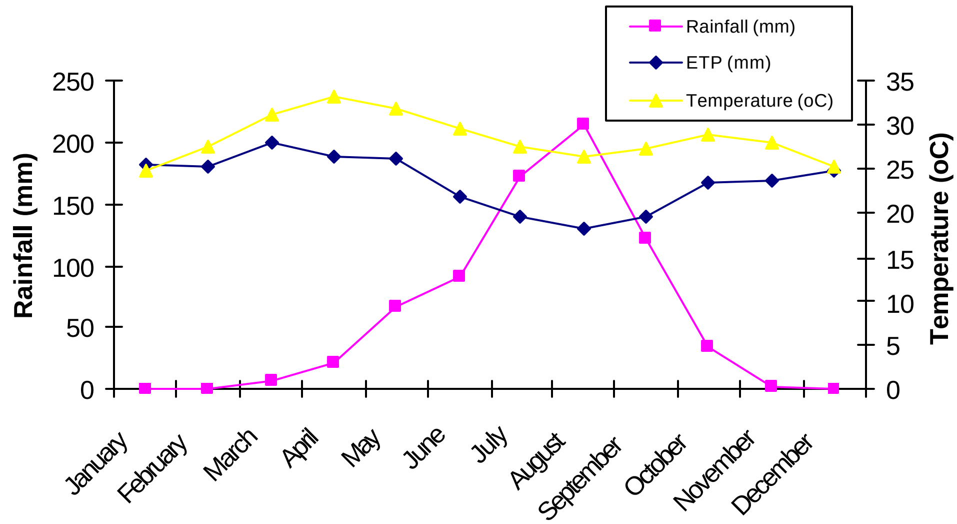

Figure 1: Mean rainfall (mm), mean ETP (mm) and mean temperature (°C) of the last 30 years at Ouagadougou, the nearest meteorological station to Gonsé, Burkina Faso.

3.2. Tree seed collection and seedlings production

The seeds of six provenances of Burkina Faso (3), Mali (2) and Senegal (1) were collected between 4 June and 13 August 1997 (Table 1). Except in Senegal, seed collection was done on at least 25 sample trees per provenance with respect to the required distance between two sample trees and taking into account the site characteristics (slope, soil, management) and those of the sample tree itself (morphology of tree) and fruit (taste of pulp, oil content, precocity in fruit production). Thirty to fifty seeds per provenance were sown in a nursery as soon as they arrived. Seedlings were transplanted to the experimental field at Gonsé in Burkina Faso two years later, in 1999.

3.3. Experimental design

Due to insufficient number of plants, the two provenances from Mali were grouped and included in the experiment as one provenance and that resulted in an experiment of five provenances. The design was complete randomised blocks with a single tree as the experimental unit repeated once within each block. As the total number of the blocks was 35, each experimental unit was replicated 70 times. The plant spacing was 5 m between the plants within the row and 8 m between the rows. The total area of the experiment was 17,520 m^2.

Table 1: Characteristics of the sites where the seeds were collected in Burkina Faso, Mali and Senegal, West Africa

Provenances	Latitude	Longitude	Slope /Soil	Rainfall (mm an^{-1})	Number of sampled trees	Stand type
Karaba (Mali)	12°55'03 N	4°53'48 W	Loamy sandy soils well drained	852.4	27	Farmed field
Djanon (Mali)	12°20'12 N	7°30'23 W	Moderate slope / Loamy sandy soils well drained	1 000	33	Farmed field
Samecouta (Senegal)	12°36'20 N	47'39 W	Steep slope, Clay sandy soils	900	12	Farmed field
Botou-Fada (Burkina Faso)	12°38'59 N	1°5'58W	Flat low land / Sandy soils	600	25	Farmed field
Gonsé (Burkina Faso)	12°19'55	1°17'46W	Flat land / Clay-sandy soils	700	25	Farmed field
Passoré (Burkina Faso)	12°55' 29N	2°17'52W	Flat land / low lands well drained	600	25	Farmed field

3.4. Data collection and analysis

3.4.1. Morphological parameters

The morphological parameters measured on all surviving individuals were as follows.

- Survival rate: assessed every year
- Total height: recorded yearly from the ground level to the tip of the youngest leaf
- Collar diameter: recorded at 1 cm from the ground using callipers and the monitoring of this parameter started in 2002 to avoid damage to the tiny plants before this date;
- Total number of leaves assessed once in 1999, three times in 2000 and four times in 2001. Monitoring of this parameter on all trees was stopped in 2004 when it became very tedious. Instead the total number of leaves were counted on only ten randomly selected trees for each provenance. On the same sample (ten per provenance), 30 randomly selected leaves were removed and their surface measured.

3.4.2. Tree transpiration

Tree transpiration rate, which is an expression of water use by the tree, was estimated from sap velocity measured using Stem Dynagauge type D\SGB25 (Delta-T Devices Ltd, UK). The method involved the use of heat transfer by measuring xylem sap flow velocity by injecting small pulses of heat into the conducting wood. The product of sap velocity and the cross-sectional area of the stem provided an estimate of the volume flow per unit of time.

Data was collected on 20 tree samples out the 25 selected randomly to compose five replicates of each species. Because the logger could handle only 4 sets of sensors, we concurrently recorded the transpiration of four provenances per replicate leaving out one provenance systematically. That gave four replicates of measurements for each provenance. On each tree, the gauge was installed on a stem with diameter in the recommended range according to gauge type. A section of 15 cm length, straight, smooth and free of structural defects was prepared on the stem selected for probe installation. Measurements were made every 1-minute and 10-minute mean values stored on a DL2e data logger (Delta-T Devices Ltd, UK). Each probe consisted of a pair of thermocouple needles that measure the temperature difference between the heated needle above and the sapwood ambient temperature measured by the reference needle below. Each gauge was placed on a tree stem and insulated against solar radiation, wind and rain by covering it with aluminum foil. The measurement on each replicate lasted for 48 hours before the equipment was moved to another replicate. Two sets of measurements were done at one month intervals.

3.4.3. Soil moisture

Changes in soil water content were monitored using Time Domain Reflectometry (TDR) (Diviner, Sentek Pty Ltd, Australia) with the same sample (i.e. the same 20 trees out the 25 forming the five replicates used for tree transpiration measurements). The area around each of the 20 sampled trees was subdivided into three concentric zones, which were laid out as follows:

Zone A - from the trunk of each tree up to 1 m away;
Zone B - from 1 m from the tree trunk to 2 m from the tree trunk;
Zone C - from 2 m from the tree trunk to 3 m from the tree trunk.

Due to a shortage of tubes only one tube of 1m length was installed in each concentric zone. The installation of the access tubes under each tree in the sample was done at three random positions. Subdividing the area into 16 smaller sections around each tree and selecting one section by means of random numbers determined the random position of a tube in each concentric zone. The access tubes were installed to a maximum of 1m using the equipment provided by the supplier and according to its recommendations. The measurement under each tree was done six times within a period of two weeks (5 to 20 November) at 10 cm interval depth to a maximum depth of 70 cm because of the bottom stopper and the top cap both reducing the measurable profile depth.

3.4.4. Data analysis

All data were entered or repackaged, summarized as Excel spreadsheets for analysis using Genstat 5 Release 7.1 (Rothamsted Experimental Station). Due to high level of losses that made the design unbalanced, REML was used for the analysis, the tests of effects have been Wald tests and the chi squared distribution which were used to calculate significance levels for all morphological data. ANNOVA was used for transpiration and leaf area data analysis. To take into account the variation of soil moisture both with the distance from tree trunk and soil depth, we considered the main effects of the provenance as well as all the interactions with the distance from tree trunk and soil depth and the data analyzed using REML analysis.

4. Results

4.1. Survival rates

The survival rate showed significant differences ($p<0.05$) in 1999 and 2001, and highly significant differences in 2000 ($p<0.01$) but these differences disappeared three years after planting (Table 2). Thus, the overall tree survival rate in January 2004 was lower than 60% with no significant difference between provenances. There was a clear decreasing trend for all provenances from the plantation date onward even though the survival rate was very variable within provenances (Table 2). Five years after planting, Botou provenance was superior though not significantly compared to the other provenances. In turn, Samacouta (Senegal) that showed the best survival rate during the planting year became the most poorly adapted to the area. The slight increase in the survival rates for Botou and Mali between 2002 and 2003 may have been due to either re-sprout from roots following the dieback of the aerial parts of some individuals or monitoring error.

4.2. Height growth

Significant differences ($p<0.001$) in height with time were observed between 1999 and 2004. In the fifth year after plantation two distinct groups were revealed (Table 2) with the provenances of Passoré (Burkina Faso), Djonon-Karaba (Mali), and Botou-Fada (Burkina Faso) showing the highest height whereas the provenances of Samacouta (Senegal) and Gonsé (Burkina Faso) performed poorly (Table 2).

4.3. Collar diameter

There were significant differences between provenances at three measurement dates (Table 2). The provenance of Passoré (Burkina Faso) had significantly ($p<0.001$) bigger collar diameter (2.3 cm) than the rest of the provenances in 2002. Botou-Fada (Burkina Faso), Djinon-Karaba (Mali), Samacouta (Senegal) and Gonsé were second, third, fourth and fifth respectively; however, the differences between them were not significant. In 2003, the best provenance was Mali followed by Passoré and again Senegal and Gonsé performed poorly. In 2004, Passoré provenance was the best followed by Mali. Therefore no consistent trend was observed for the best provenances in terms of diameter; nevertheless, Senegal and Gonsé performed consistently poorly (Table 2).

4.4. Leaves

The observations of phenological changes of young karité trees showed four phases during the year (Figure 2). A phase of full leafing (August) followed by the beginning of leaf shading (November), a phase of leaf flush initiation in January and a leafless phase in March. Apart from three assessment dates, there were highly significant differences between provenances in the number of leaves for the remaining dates (Table 2). Passoré provenance showed the largest number of leaves during 5 monitoring dates out of 9 followed by Mali provenance and Gonsé provenance gave the lowest number of leaves during 6 measurement dates out of 9 (Table 2). These observations tended to be related to the mean area of the leaves of each provenance. It seemed that the smaller the leaf area the higher the number of leaves. Botou provenance showed the largest leaf area (136.18±9.00 cm^2) followed by Senegal (122.91±5.74 cm^2), Gonsé (115.01±6.41 cm^2) Passoré (112.38±5.76 cm^2) and Mali (102.93±3.96 cm^2) provenances, respectively. Differences between provenances with regard to leaf area were significant ($p<0.01$).

Table 2: Morphological parameters of five West African provenances of karité measured from November 1999 to October 2002 at Gonsé, Burkina Faso

Provenances Measurement dates	Botou-Fada (Burkina Faso)	Gonsé (Burkina Faso)	Djonon-Karaba (Mali)	Passoré (Burkina Faso)	Samecouta (Sénégal)	Standard Error of Means	Chi-sq probability
Survival rates (%)							
23/11/99	91.42	80.00	91.44	94.29	95.70	4.89	0.012
19/05/00	72.83	80.02	78.53	87.16	68.60	7.03	0.007
20/08/01	72.31	59.96	73.79	83.56	70.44	7.47	0.036
22/10/02	62.10	62.83	66.67	64.57	55.27	8.20	0.696
15/01/03	62.86	61.43	67.14	64.29	54.29	8.44	0.629
22/01/04	60.00	57.14	54.29	58.57	44.29	8.71	0.386
Height (cm)							
23/11/99	11.19	8.76	11.21	12.64	11.59	0.82	< 0.001
20/10/00	15.80	11.50	18.27	21.22	13.93	1.65	<0.001
20/08/01	15.94	10.76	17.49	22.24	13.50	2.41	<0.001
22/10/02	50.72	30.13	55.41	56.24	36.34	6.78	<0.001
15/01/03	31.80	17.90	38.01	35.81	20.01	5.82	<0.001
22/01/04	47.29	29.55	55.87	52.99	33.39	9.46	0.015
Collar diameter (cm)							
22/10/02	1.75	1.13	1.43	2.31	1.21	0.54	<0.001
15/01/03	1.25	0.83	1.45	1.41	0.87	0.21	0.003
22/01/04	1.74	1.14	1.87	1.91	1.21	0.31	0.026
Number of leaves							
20/12/99	4.64	5.15	4.9	5.34	5.35	0.61	0.727
20/03/00	1.97	2.14	2.06	1.79	1.31	0.39	0.207
21/08/00	12.34	8.62	14.48	17.84	12.35	1.56	<0.001
20/12/00	3.49	1.96	4.75	6.40	3.47	0.79	<0.001
03/01/01	7.88	6.14	11.86	14.93	10.11	1.66	<0.001
20/03/01	3.04	2.48	4.75	4.39	3.50	0.84	0.075
20/04/01	1.69	1.83	5.59	5.66	2.94	1.21	<0.001
22/08/01	13.86	11.57	19.21	19.90	14.37	2.41	<0.001
30/08/04	241.00	206.00	933.00	472.00	393.00	170.20	<0.001

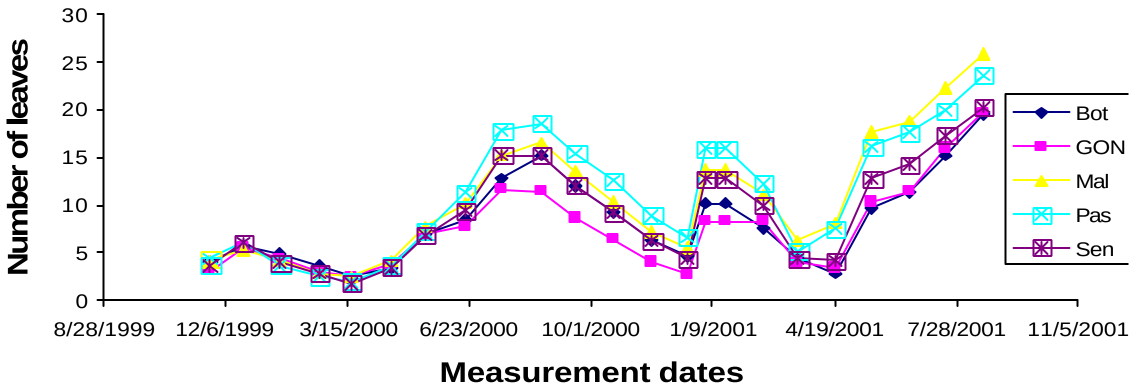

Figure 2: Leafing pattern of five West African provenances during 2000 and 2001 at Gonsé, Burkina Faso. Bot = Botou-Burkina Faso; GON = Gonsé-Burkina Faso; Mal = Mali, Pas = Passoré-Burkina Faso; Sen = Sénégal

4.5. Tree transpiration

Sap flow measurements were made simultaneously as described before allowing comparison between provenances. The diameters of the stems at the probes installation points were respectively 2.6, 2.7, 2.6, 2.6 and 2.5 for Botou, Gonsé, Mali, Passoré and Senegal provenances.

For the first measurement date in October 2004, mean transpiration rates per tree in the provenances were found to be significantly different ($p<0.001$) (Figure 3a.). Mali provenance displayed the highest daily transpiration rate (2.71 l $tree^{-1}$ day^{-1}) followed by Passoré provenance (2.25 l $tree^{-1}$ day^{-1}), Senegal provenance (1.43 l $tree^{-1}$ day^{-1}), Gonsé provenance (1.42 l $tree^{-1}$ day^{-1}) and Botou provenance (1.36 l $tree^{-1}$ day^{-1}). Similarly, the mean transpiration rates per unit area significantly differed between provenances ($p<0.001$). However, contrary to the transpiration per tree, Senegal provenance showed the highest transpiration per unit area with (0.31 l m^{-2} day^{-1}). This provenance was followed by Gonsé provenance (0.25 l m^{-2} day^{-1}), Mali provenance (0.21 l m^{-2} day^{-1}), Botou provenance (0.18 l m^{-2} day^{-1}) and Passoré provenance (0.18 l m^{-2} day^{-1}).

The second measurement that took place one month after the first, i.e. in November 2004, revealed significant differences between provenances in mean transpiration rates per tree ($p<0.001$) (Figure 3b.). Again Mali provenance displayed the highest daily transpiration rate (2.54 l $tree^{-1}$ day^{-1}) followed by Passoré provenance (2.18 l $tree^{-1}$ day^{-1}), Botou provenance (1.41 l $tree^{-1}$ day^{-1}), Gonsé provenance (1.36 l $tree^{-1}$ day^{-1}) and Senegal provenance (0.99 l $tree^{-1}$ day^{-1}). Gonsé provenance (0.26 l m^{-2} day^{-1}) and Senegal provenance (0.24 l m^{-2} day^{-1}) showed significantly higher transpiration rates per unit area compared to the rest ($p<0.001$). The figures were 0.20 l m^{-2} day^{-1} for Mali provenance, 0.19 l m^{-2} day^{-1} for Botou provenance and 0.17 l m^{-2} day^{-1} for Passoré provenance.

Therefore no significant changes were revealed in the transpiration rates of Gonsé, Mali and Passoré provenances between the first and the second measurement dates. In turn, an increase in both transpiration rates per tree and per unit area was noticed in Botou provenance whereas a decrease was observed in Senegal provenance (Figure 3).

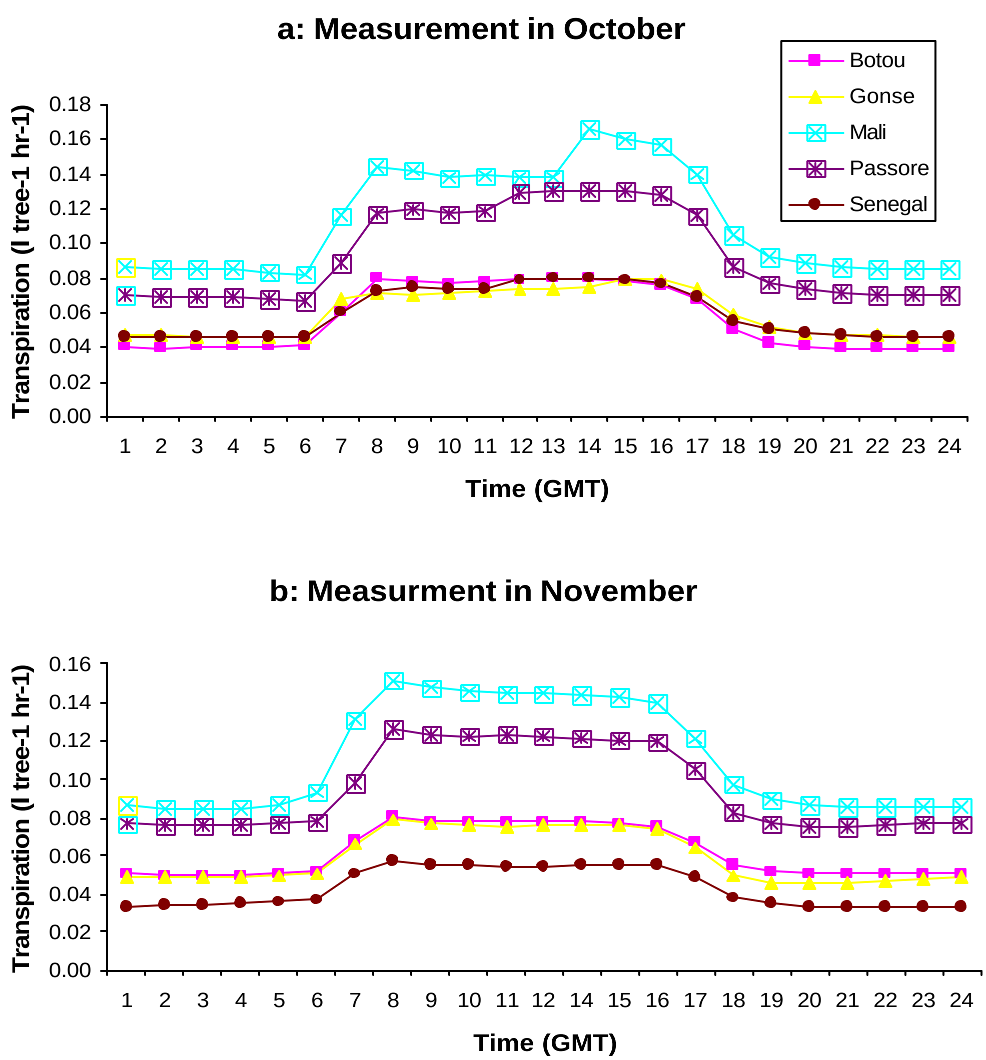

Figure 3: Transpiration rates of five provenances of karité (*Vitellaria paradoxa*) at Gonsé in 2004, Burkina Faso.

4.6. Soil moisture

Soil moisture was measured in the morning (between 6 and 8 h) and in the afternoon (between 17 and 18 h) with the idea to be able to work out the quantity of water depleted during the day. The two sets of data revealed significant provenance effect ($p<0.001$) with all the interactions that were also significant (all $p<0.001$ except for the interaction between zone and soil depth in the morning with $p<0.05$), apart from the interaction zone and soil depth in the afternoon (Table 3). The results showed no clear trend for all provenances according to the distance from tree trunk and with soil depth (Table 3a&b).

For the morning data we had a decreasing trend of soil moisture with soil depth in 8 cases out 15 combining the five provenances with the three zones (Table 3a).

The effect of distance from tree trunk showed that Passoré and Senegal provenances showed higher water content in zone B compared to the two others whereas Gonsé and Mali showed the reverse. Botou provenance only displayed a decreasing trend of soil water content going from the tree trunk to the open area. The trends mentioned above were maintained in the afternoon except for Senegal provenance that displayed an increasing trend of soil water content going from tree trunk to the open area (Table 3b). The mean water content of zones and soil depth showed higher soil water content under Gonsé provenance followed by Senegal, Mali, Botou and Passoré provenances both in the morning and in the afternoon (Table 3). It was not possible to work out the daily water loss using the afternoon and morning data since on average the figures of the afternoon were higher than those obtained in the morning (Table 3).

Table 3: Soil moisture (%) under five provenances of karité (*Vitellaria paradoxa*) according to the distance from tree trunk (zones) and soil depth at Gonsé in 2004, Burkina Faso.

a: Morning measurement

Zone	Depth	Botou	Gonsé	Mali	Passoré	Senegal	Mean General
A	0-10	7.50	7.11	5.02	6.77	6.92	6.76
	10-20	7.68	8.82	7.23	6.68	7.15	7.51
	20-30	8.15	9.11	7.27	6.43	7.24	7.64
	30-40	9.68	10.65	9.31	7.96	9.38	9.40
	40-50	10.65	13.72	12.73	11.08	11.27	11.82
	50-60	13.39	17.47	13.23	13.98	14.28	14.52
	60-70	20.66	17.36	14.78	12.52	17.07	16.31
Mean A		10.37	12.03	9.94	9.23	10.28	10.40
B	0-10	6.66	4.96	6.44	6.63	6.39	6.21
	10-20	7.11	5.48	7.07	6.44	7.33	6.70
	20-30	6.97	5.59	7.21	6.87	7.81	6.92
	30-40	8.45	8.34	7.61	8.41	9.37	8.52
	40-50	10.50	11.58	11.21	11.57	13.98	11.92
	50-60	13.19	15.20	13.72	14.95	14.92	14.43
	60-70	12.98	16.54	12.76	15.32	14.99	14.55
Mean B		9.41	9.67	9.43	9.56	10.42	9.74
C	0-10	6.43	6.86	5.64	5.62	6.08	6.15
	10-20	7.33	7.46	7.54	5.81	6.57	6.90
	20-30	7.38	7.34	8.00	6.52	8.47	7.56
	30-40	9.17	9.84	9.71	8.69	10.95	9.73
	40-50	9.90	13.94	12.24	11.41	13.49	12.26
	50-60	10.36	16.50	14.82	14.31	17.18	14.66
	60-70	10.39	19.77	15.85	12.48	18.42	15.29
Mean C		8.71	11.18	10.54	9.26	11.59	10.30
Mean General		9.47	10.95	9.97	9.34	10.78	10.15

b: Afternoon measurement

Zone	Depth	Botou	Gonsé	Mali	Passoré	Senegal	Mean General
A	0-10	7.74	7.16	5.11	6.93	7.08	6.90
	10-20	7.94	8.95	7.47	6.90	7.40	7.73
	20-30	8.31	9.25	7.42	6.59	7.40	7.80
	30-40	9.69	10.81	9.47	8.05	9.47	9.50
	40-50	10.62	13.77	12.83	11.08	11.34	11.85
	50-60	13.41	17.52	13.34	13.99	14.29	14.56
	60-70	20.48	17.51	15.04	12.62	17.19	16.42
Mean A		10.45	12.14	10.10	9.33	10.40	10.51
B	0-10	6.80	5.04	6.55	6.79	6.50	6.33
	10-20	7.29	5.62	7.25	6.63	7.59	6.89
	20-30	7.15	5.75	7.30	7.02	7.90	7.05
	30-40	8.56	8.49	7.63	8.51	9.36	8.60
	40-50	10.50	11.58	11.10	11.57	13.92	11.89
	50-60	13.21	15.06	13.59	14.92	14.83	14.36
	60-70	13.00	16.46	12.84	15.34	15.00	14.55
Mean B		9.50	9.71	9.46	9.65	10.47	9.80
C	0-10	6.49	7.12	5.68	5.68	6.25	6.27
	10-20	7.40	7.78	7.58	5.97	6.75	7.05
	20-30	7.47	7.49	7.93	6.70	8.54	7.65
	30-40	9.15	9.90	9.67	8.81	10.98	9.77
	40-50	9.83	13.85	12.21	11.45	13.53	12.24
	50-60	10.27	16.57	14.76	14.25	17.22	14.64
	60-70	10.33	19.74	15.82	12.15	18.42	15.19
Mean C		8.70	11.29	10.52	9.29	11.67	10.34
Mean General		9.53	11.04	10.03	9.42	10.86	10.22

5. Discussion and conclusions

The variable trend of the survival rate within each provenance is characteristic of geophytic species in their initial stage with the aboveground part that dies during the dry season and re-sprouts during the following wet season. Karité being a Sahelian species, undergoing fire and the long dry season, may have developed strategies to avoid natural stresses. By eliminating the aboveground part during the dry period, the plant allocates more carbohydrates to the belowground part allowing young individuals to survive the harsh climatic conditions. This reserve part is progressively replaces by deep root at age range between 4 to 8 (Piot, 1979). In a system where the occurrence of the stresses is reduced as in managed plantation in the actual case, the death causes become homogenous explaining why there was no-significant difference amongst provenances.

Mean annual increments of growth parameters were lower than those reported by Delolme (1947). This author reported an annual increment in height of 21.9 *vs* 4.0 cm in the present study and annual increment in collar diameter of 11.9 *vs* 0.5 cm. The better growth performance of the individuals in the experiment reported by Delolme (1947) may be due to differences in environmental conditions and/or genetic characteristics. In turn, mean annual increment in diameter in the present study is higher than the values of 0.45, 0.37 and 0.25 mm $year^{-1}$ reported by Mahamane (1996), Picasso (1984) and Devineau (pers. Com.), respectively.

Vegetative phenology showed a seasonality common in tropical species (Patel, 1997). Leaf shading happened during the dry season and showed similar pattern to mature individuals (Bayala, 2002). Passoré and Mali provenances displayed higher number of leaves and longer length of leafing phase as shown in Figure 2. These two parameters may be the most appropriate to discriminate provenances for the initial growth phase because of the evident link between longer vegetative phase and higher capacity of photosynthesis. Higher capacity of photosynthesis is synonymous to higher production of growth substrates which induces higher survival rate and better growth of the individuals. Thus, Passoré and Mali provenances showed the highest transpiration rate per tree (Figure 3) and probably the highest nutrients consumption. As a consequence Passoré provenance displayed the highest soil water depletion capacity while the depletion capacity was medium under Mali provenance (Table 3). However, the quantity of water transpired per unit area was the lowest in Passoré provenance and medium in Mali provenance. Therefore, these two provenances may have a better water use efficiency making them more suitable for semi-arid regions of West Africa. The fact that Botou provenance showed higher transpiration at the second measurement date may be to new leaves emerging corroborating the findings of Tschaplinski and Blake (1995) who found an increase of 31% in stomatal conductance in pruned hybrid poplar trees compared to the shoots of unpruned trees due to the emergence of news leaves. In reverse, the decrease in the transpiration rate of Senegal provenance is due to more leaves getting aged and therefore were shed, resulting in a reduction in whole plant transpiration (Arndt *et al*., 2001). The daily transpiration rates of five years old *V. paradoxa* provenances in the present were close to those of two years old trees of *Grevillea robusta* (2.62 l $tree^{-1}$ day^{-1}), *Alnus acuminate* (2.55 l $tree^{-1}$ day^{-1}) and *Paulownia fortunei* (0.60 l $tree^{-1}$ day^{-1}) as found by Muturi (2004) in a semi-arid zone of Kenya. Even though these two studies were carried out in semi-arid zones, the trees in this latest study are fast-growing species and the atmospheric evaporative demand is lower in East Africa compared to the conditions in semi-arid zone of West Africa (Figure 1). These reasons may explain why two-year old trees transpired similar quantities to five-year old trees.

The results of soil water content showed lower values both for the morning and for the afternoon measurements under the provenances that displayed the best growth performance, i.e. Passoré, Botou and Mali provenances (Tables 2 & 3). These findings corroborate the results of Muthuri (2004) who found that *Grevillea robusta*, growing faster than *Alnus acuminata*, was more competitive with crops for soil moisture. The higher values of soil water in the afternoon compared to those obtained in the morning may be due to hydraulic lift occurring in this geophytic species (Ludwig *et al*., 2003). Such type of species is use to partition more growth substances to the below-ground parts, thus ensuring a good a root system capable to go deep allow the trees to access to the ground-water and thus to withstand the water stresses (Jones, 1992).

The fact that two of the provenances from Burkina Faso were amongst the three provenances along with provenance that performed better is in agreement with the findings of Maranz *et al*. (2003). These authors, based on oil content and oil chemical characteristics, located a major centre of karité domestication on the Mossi Plateau of Burkina Faso. The potential existence of centers for domestication for savanna agroforestry species has not been really considered by researchers. Selection based on both growth and fruit quality characteristics could help transform indigenous and sustainable agroforestry practices to more profitable enterprises.

In conclusion, five years after plantation, observations of the morphological characteristics, transpiration and soil water content indicate that the best provenances are Passoré (Burkina Faso), Djonon-Karaba (Mali) and Botou-Fada (Burkina Faso). Nevertheless, further research is required to determine the long-term effects of these provenances on soil water balance (as well as nutrients) and their fruit production before reliable recommendations can be made to farmers.

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Annex:

Administrative report

The activities planned within the framework of the IFAR grant were to:

1. compile relevant morphological and climatic data already recorded at the research site:
2. collect data on physiological characteristics:
   - soil moisture using Diviner 2000;
   - leaf hydraulic potential using a pressure chamber;
   - transpiration using Dynagauges
3. model the long term functioning of the provenances with WaNuLCAS using long-term Sahelian rainfall data.
4. prepare a draft manuscript for a journal article on research methods and results.

The proposal has been revised by ICRAF headquarter scientists before it was sent to the sponsor for approval. Since the approval I have been assisted by ICRAF staff members both in Nairobi and Bamako to handle the grant and organize my stay at Nairobi. The field work was carried out as planned followed by a stay at the headquarters of ICRAF at Nairobi. This stay took place from the 26 November to 12 December 2004. During this stay, a first meeting was held on the 29 November 2004 with Chin Ong, Catherine Muthuri and Janet Awimbo to discuss the progress of the field work and the writing of the final report to be submitted by the end of December 2004 to the sponsor.

Concerning the progress of the field work, the leaf hydraulic potential was the only parameter not yet monitored. This parameter will be measured and the assessment of the other parameters needs to be continued to take into account the variability linked to the different phenological phases. The modeling part was not presented in the present report due to lack of time, this part will be done in the near future.

For the report it was decided that a first draft needed to be produced based on the advice of Richard Coe for statistical analysis. Thus, a second meeting was held with Richard Coe to discuss the statistical analysis issues. This was a useful meeting because of the high level of losses of plants making the experimental design unbalanced and more difficult to analyze with the traditional tools. Therefore, it was suggested by Richard Coe to use the REML that can accommodate with such complications occurring in the run of an experiment.

Based on all the above discussions a draft was produced and passed on the 7 December 2004 to ICRAF staff members involved in the project for their amendments and comments. Besides the report, I have done some literature review on the topic using the facilities offered by the library of ICRAF.

During my stay at ICRAF, I got opportunity to interact with other scientists not involved the present project. I want to mention:

- Mr. Christian Thine who is also an IFAR grantee to discuss how to exchange experience in the future ;
- Dr. Julia Wilson of the University of Edinburgh who was visiting ICRAF at the same period. With her we discussed some issues of an EU project (UBENEFITS) in which we are both involved. We also discussed the possibility to develop a new proposal for the coming call for proposals of EU;
- A PhD student of Chin Ong registered at the Jomo Kenyatta University of Agriculture and Technology who is about to start is work on Bamboo tissue culture. I visited the greenhouses and the work this student is doing on tissue culture at the JKUAT.

In line with the objectives of the IFAR foundation, we look forward to continuing the collaboration established through the implementation of the activities of the present grant. That implies the development of other sponsorship initiatives to continue the fieldwork and the exchange of experience. Amongst the possibilities a renewal of the grant with IFAR if such possibility exists and also the development of team IFS proposal involving INERA, ICRAF and JKUAT.

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