Available online at http://www.ifgdg.org

Int. J. Biol. Chem. Sci. 13(6): 2433-2448, October 2019

ISSN 1997-342X (Online), ISSN 1991-8631 (Print)

International Journal of Biological and Chemical Sciences

Original Paper http://ajol.info/index.php/ijbcs http://indexmedicus.afro.who.int

Structural characterization and pod yields of populations of the fodder legumes trees *Piliostigma thonningii*. and *Prosopis africana* along the toposequence in western Burkina Faso

Souleymane OUEDRAOGO[1,3*], Lassina SANOU[2], Patrice SAVADOGO[2,4] and Chantal Yvette ZOUNGRANA/KABORE[3]

[1]*Centre National de la Recherche Scientifique et Technologique, INERA, Département Gestion des Ressources Naturelles (GRN)/Systèmes de Production (SP), 03 BP 7047, Ouagadougou 03, Burkina Faso.*
[2]*Centre National de la Recherche Scientifique et Technologique, INERA, Département Environnement et Forêts, 03 BP 7047, Ouagadougou 03, Burkina Faso.*
[3]*Université Nazi Boni, Institut du Développement Rural, BP 1091 Bobo-Dioulasso, Burkina Faso*
[4]*World Agroforestry (ICRAF), West and Central Africa Regional Office - Sahel Node, BP E5118, Bamako, Mali.*
[*]*Corresponding author; E-mail: osilamana@yahoo.fr*

ABSTRACT

Plant communities including fodder trees play an important role in livestock production in semi-arid zones of West Africa. This study was carried out at two sites of the western region of Burkina Faso and aimed to provide information on the current status of the natural savanna-woodland pastures and predict the pod production of *Piliostigma thonningii* and *Prosopis africana*, two key fodder species of these ecosystems. All woody species were systematically identified and their dbh and height were measured in plots along a toposequence. Pods were collected from 60 trees of *P. thonningii* and *P. africana* and the stem circumference at breast height and the crown diameter were also measured. To predict pod production, regression analysis was used to develop predictive allometric equations by selecting tree size variables for fitting to models. Results showed a total of 24 species belonging to 11 families and 22 genera were inventoried with clear tendency to shrub invasion of the toposequence locations. *P. thonningii* trees had a good regeneration status while *P. Africana individuals* were old. The two species had good potential for natural regeneration of the stands from seedlings. The pod production prediction equations for both species were significantly correlated to dendrometric traits ($P<0.0001$). They were species-specific, and the equations developed for each species were different. It is not advised to apply the same formula to predict pod production of fodder trees species at different savanna-woodland locations throughout West Africa.

Keywords: Browse species, dendrometric traits, class distribution, Fodder equation, Natural savanna-woodland pastures, Toposequence, West Africa.

INTRODUCTION

Globally, forest resource play a significant role in supporting the livelihoods of many people (Shackleton and Shackleton, 2000; Kristensen and Balslev, 2003; Sop and Oldeland, 2011; Laouali et al, 2014; Diatta et

DOI: https://dx.doi.org/10.4314/ijbcs.v13i6.1

al., 2016). In Africa, particularly in the continent's western regions, more than 90% of the population depend exclusively on forest and land resources for their livelihoods (Sop and Oldeland, 2011). The household daily needs included medicine, firewood, charcoal, and construction material for houses, food for human, fodder for livestock (herbaceous and woody species) along the natural pastures etc.

Forest resources, through their natural pastures, often support livestock breeding. Livestock feeding is mainly based on the exploitation of the natural pastures. This herbaceous layer accounts for 75-90% of the total annual phytomass of West African savanna-woodlands.

In the West African nation of Burkina Faso, natural pastures represent 90% of the herbivore diet. However, these pastures are nowadays degraded due to climate variability and increased livestock grazing. In addition, population pressure, fire, urbanization and hydro-agricultural development have profoundly changed the natural environment. Added to this, recurring droughts have led to fluctuating pasture productivity. During the rainy season, natural pastures are almost entirely dominated by annual grasses. This herbaceous layer constitutes an ephemeral fodder source because it has a short cycle of development which ends at the end of the rainy season. At this time, grasses are in the straw state with limited nutritional value. They can therefore not ensure livestock maintenance needs, much less those of animal production.

Given the fluctuating productivity of natural pastures and the shortage and absence of fresh herbaceous during dry season in Burkina Faso, their use for livestock production in this time requires supplementation of nitrogen, energy, vitamins and minerals. These nutrients that are available in agro-industrial products such as oilcakes of peanut and oilcakes of cotton for example in the context of Burkina Faso remain very high costs and limit their use by producers. The woody species of the savanna-woodlands therefore serve as a supplementary fodder source during the lean season. These woody species provide an important protein supplement for livestock during the dry season. They are rich in protein, vitamins and minerals, and therefore able to improve livestock diets during the dry season.

In Burkina Faso's savanna-woodlands, the biomass of the woody species accounts for 35% of the total ecosystem biomass. In some pastures, in the dry season, the woody species represent almost all of the available plant material. The relative scarcity of the fodder trees therefore raises the question of the optimal use of this resource. Livestock breeders often prune the trees to provide forage for their animals. This destructive action influences the woody fodder species' populations. Thus, there is a need to better understand the structural composition of the forage stands and their levels of foliage and/or fruit production. This knowledge will help in determining the optimal carrying capacity of the savanna-woodlands and thereby also inform improved pasture management in these ecosystems.

A number of previous studies have estimated the foliage biomass of the woody fodder species of West African savanna-woodlands (Navar et al., 2004; Savadogo, 2007; Bognounou et al., 2008; Ouédraogo-Koné et al., 2008). In Burkina Faso, allometric equations have been established for some species including *Afzelia africana* Sm., *Balanites aegyptiaca* (L.) Del., *Boscia angustifolia* A. Rich., *Ficus sur* Forssk., *Ziziphus mauritiana* Lam., *Acacia gourmaensis* A. Chev., *Acacia dudgeoni* Craib. ex Holl., *Acacia macrostachya* Reichenb. ex Benth., *Acacia seyal* Del., *Anogeissus leiocarpa* (DC.) Guill. & Perr., *Prosopis africana* (Guill. & Perr.) Taub., *Pterocarpus erinaceus* Poir. and *Pterocarpus lucens* Lepr. (Savadogo et Elfving, 2007; Ouédraogo-Koné et al., 2008; Sawadogo et al., 2010; Bognounou et al., 2013). Recent studies have also estimated the fruit production of the woody species *Carapa procera* DC., *Pentadesma butyracea* Sabine, *Afzelia africana* and *Ximenia americana* L., with the latter two species being major livestock fodder sources (Lankoandé et al., 2017; Nacoulma et al., 2017; Lompo et al., 2018). The development of these predictive equations aimed at optimizing their utilization for animal feed to ensure the sustainability of this practice.

The foliage and pods of the woody fodder species *Piliostigma thonningii* (Schum.) Milne-Redhead. and *Prosopis Africana* (Guill. & Perr.) Taub. are important sources of feed for ruminants grazing in the natural pastures of the western region of Burkina Faso. The sale of these species' pods in peri-urban and urban areas provides substantial income for rural households (Yelemou et al., 2007; Weber et al., 2008). Special attention should be given to understanding the structural composition and pod production of natural stands of these two species to propose strategies for facilitating their sustainable management by local communities. In this study, the aim was to assess the status of natural pastures in a savanna-woodland pastoral area managed by local communities in the western region of Burkina Faso.

MATERIALS AND METHODS

Description of study site

The study sites are Gombeledougou and Ouara villages, located in the western region of Burkina Faso (Figure 1). The villages are within the West Mouhoun District of the South Sudanian phytogeographical sector (Fontès et Guinko, 1995). The mean annual precipitation varies between 900 and 1,000 mm. During the last decades (1996-2016), the mean annual precipitation was 1065 mm ± 158.73 and the mean number of rainy days was 90 ± 7. Mean daily minimum and maximum temperatures ranged from 16 to 32 °C in January (the coldest month) and from 26 to 40 °C in April (the hottest month). The vegetation is characterized by the Sudanian species associated with Guinean species. The most common Sudanian species are *Isoberlinia doka* Craib & Stapf, *Vitellaria paradoxa* C.F. Gaertn., *Anogeissus leiocarpa, Terminalia laxiflora* Engl. & Diels, *Terminalia avicennioides* Guill. & Perr. and *Burkea africana* Hook. The grassy layer is dominated by *Andropogon gayanus* Kunth, *Andropogon pseudapricus* Stapf, *Andropogon ascinodis* C.B. Cl., *Cochlospermum planchonii* Hook. f. ex Planch., *Loudetia togoensis* (Pilger) C.E. Hubbard, *Pennisetum pedicellatum* Trin., *Rottboellia cochinchinensis* (Lour.) W.D. Clayton, *Diheteropogon hagerupii* Hitchc., *Microchloa indica* (L. f.) P. Beauv. and *Diheteropogon amplectens* (Nees) W.D. Clayton. Along the natural pastures at both sites, the relief is mainly characterized by three topographic positions that are low-lying, plateau, and slope) dominated by natural stands of *P. africana* and *P. thonningii*. The most frequently encountered soils are cambisols and lithisols. The study sites are used for agriculture, with cotton and maize being the most commonly cultivated crops (Bognounou et al., 2013).

Study species

The choice of the two fodder species (*P. thonningii* and *P. africana*) was based on their importance as browse species in the natural pastures of western Burkina Faso during the rainy and drought seasons. More broadly, these two species are important for farming and pastoralist communities throughout the West African Sahel. They provide a range of products and services to support these communities' livelihoods. These include wood, fuel, food, fodder, medicines and soil fertility improvements (Weber et al., 2008). Their flowers, fruits and pods are highly palatable for livestock. Faced with feed shortages and the high costs of supplementing livestock feed, the crushed pods of both of these fodder species are commonly mixed with corn bran or sorghum.

Piliostigma thonningii (DC.) Hochst. (Fabaceae-Caesalpinioideae) is a small tree (8–9 m) with an open crown. The leaves are drooping, alternate and conspicuously bi-lobed. The petioles are 1–3.5 cm long, and swollen at both ends. The leaf blades are 5–12 cm × 4–18 cm, cordate or rounded at the base, with lobes that are rounded or more or less cuneate, coriaceous, glabrous, greyish-green, and palmately veined with 8–11 basal veins. The species' fruit is an oblong pod 15–30 cm × 2.5–5 cm, straight, undulate or twisted, many-seeded. *Prosopis africana* (Guill., Perrott. & Rich.) Taub. (Fabaceae–Mimosoideae) is the only native *Prosopis* in Africa occurring from Senegal to Ethiopia throughout the Sudanian and Guinean ecozones (Bognounou et al., 2013). It is a small to large tree (4–20 m) with an open crown and slightly rounded buttress roots. The leaves are drooping, alternate and bipinnate, with rachis that are 10–15 cm long with 3–6 pairs of opposite pinnae (5–8 cm long); and 9–16 pairs of leaflets that are oblong-lanceolate, 12–30 mm and pubescent. The leaves typically have a gland between pairs of pinnae and leaflets. The pods are dark brown, cylindrical, thick and hard, shiny, up to 15 × 3 cm, with woody walls, compartmented; about 10 loose, rattling seeds per pod with a thin, intermarginal line around (Arbonnier, 2009; Bognounou et al., 2013).

Sampling design and data collection

A stratified-oriented sampling design was applied based on the occurrence and predominance of natural stands of *P. africana* and *P. thonningii* in Gombeledougou and Ouara villages. The inventories were carried out at the end of the rainy season when species can be easily identified and plots are easily accessible (Savadogo et al., 2007). For each species and each village, a total of 10 square sample plots (50 m × 50 m) were marked along each topographic position. The 50 m x 50 m observation plots were placed every 200 m according to a transect along the toposequence (Figure 2) found in the study sites. There are essentially three physical entities: the upper, the middle and the lower. The upper represents the highest points of sites and generally contains tropical ferruginous soils marked by the presence of rock outcrops that are often in the process of disintegration. The middle consists of the long slope that separates the upper from the lower. The soils are of variable depth and sandy-gravelly to sandy-silty structure. The lowland represents the lower part of the sites that is temporarily flooded during heavy rains. The soils are deep and clayey to silty-clayey in texture. Each plot was systematically surveyed, with all woody species marked and identified. All adult trees were identified and counted, their diameter at breast height (dbh) was measured by cross-calipering, and their height measured using a graduated pole (Savadogo et al., 2017). Seedlings were classed as individuals with a dbh of < 5 cm and height of < 2 m. All seedlings and shrubs were also identified, counted and their height measured. Identification of species and families of plant follows *The Plant List* (www.theplantlist.org).

Estimation of the production of *Piliostigma thonningii* and *Prosopis africana*

To estimate the two species' pod production, thirty adult individual per species bearing fruit have been chosen along the toposequence in each village. Before collection of the pods, the following dendrometric parameters were measured: the total height of the tree (i.e. the vertical distance between the ground level and the terminal bud) (Rondeux, 1999), the circumference at 20 cm and at 130 cm, the crown diameter in the directions North-South, East-West. This assessment was firstly made on an individual tree basis and then reduced to a per hectare value following the formula: Production (ha) = average production per individual tree × Number of plants produced per hectare. The pods were then put into labeled bags and brought to the laboratory for drying in an oven at 75 °C until a constant weight was obtained. The pods harvested per individual tree were weighed separately.

Calculations and data analysis

Population structures of Piliostigma thonningii and Prosopis africana

Structural characteristics (i.e. stem density, basal area, and diameter and height class distributions) were computed for each plot and averaged per toposequence unit for all individuals with a dbh ≥ 5 cm. To assess the horizontal and vertical structures of the adult populations of *P. thonningii* and *P. africana*, all individuals of both species were grouped into three height classes (2-4 m, 4-6 m and 6-8 m) and into six diameter classes (5-10, 10-20, 20-30, 30-40, 40-50, ≥ 50 cm). To evaluate β-diversity (similarity between the both sites), Jaccard's similarity index was computed based on presence/absence data of the species in the natural stands. This index potentially varies between 0 and 1, and a value close to 1 indicating greater similarity between patches, and hence low β-diversity (Krebs, 1999). When a significant difference was detected with seedling density and fructified trees of both species per toposequence, a pair-wise comparison was made using Tukey's test at the 5% level of significance.

Predicting the pod production of Piliostigma thonningii and Prosopis Africana

For the analysis of fruit production, different types of regression equations, i.e. linear, logarithmic, exponential and power models, were applied by integrating several dendrometric parameters. Pod production (dry matter), dendrometric parameters (i.e. circumference, height, crown diameter) and model terms (i.e. predictor variables) were considered as dependent variables to compensate for the less consistent architecture and complicated branching patterns of trees in dry forest ecosystems that often make biomass predictions problematic (Cole et Ewel, 2006). An average was calculated by considering the fruit bearing per plot and per site. Production per hectare was obtained by the following equation: $P(ha) = PmoyxN$.

Where P (ha) = Production per hectare; Pmoy = mean Production per individual tree; and N = Number of individual tree bearing pods per hectare.

We retained only the best models, being those with a high R^2, a significant probability ($P<0.05$) and that during the reliability tests of the model, the predicted values from each model were plotted against the observed values. All of the analyses were performed using the statistical software SAS version 9.1.

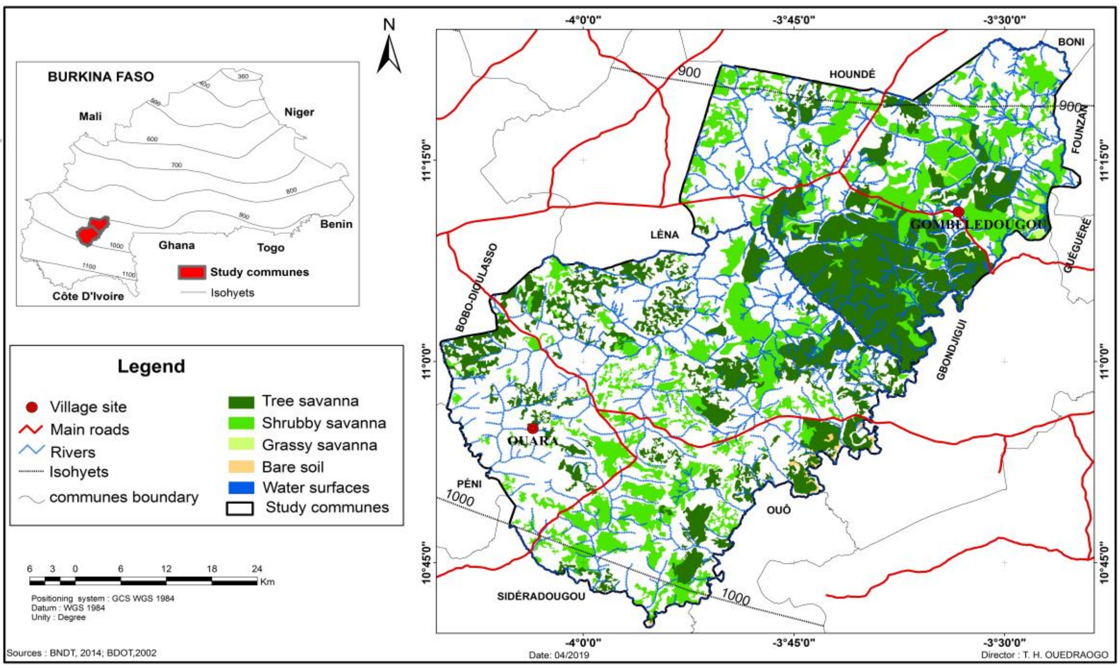

Figure 1: Study site location.

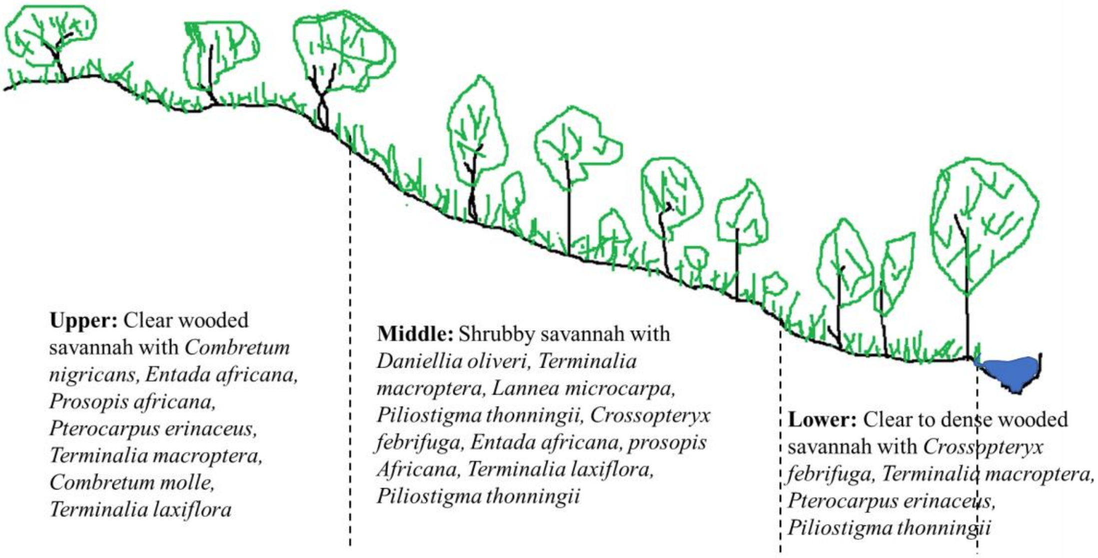

Figure 2: Transect along the toposequence of the study sites.

RESULTS

Woody species composition in western natural pastures

A total of 24 species belonging to 9 families and 22 genera are associated with *P. africana* in Ouara, compared to 11 species belonging to 7 families and 11 genera identified in Gombeledougou. In these areas, the dominant family is Fabaceae-Caesalpinioideae. In Ouara, Fabaceae-Caesalpinioideae represents 30.41% of all families with 8 species. The most represented species were *Burkea africana* (9.28%), *Isoberlinia doka* (8.76%) and *Daniellia oliveri* (Rolfe) Hutch. & Dalz. (5.15%). Other common families in Ouara are Sapotaceae (17.01%), represented by the single species *Vitellaria paradoxa*, Fabaceae-Mimosoideae (35.05%), with 3 species of which *Parkia biglobosa* (Jacq.) R. Br. ex G. Don f. (5.15%) was the most represented, and the families of Combretaceae and Ebenaceae which accounted for 8.24%, with 6 species for Combretaceae and one species for Ebenaceae. At Gombeledougou, Fabaceae-Caesalpinioideae are followed by Fabaceae-Mimosoideae (36.93%), Fabaceae-Mimosoideae (36.63%), Meliaceae (4.95%), with 2 species of which *Azadirachta indica* A. Juss. is the most represented (3.96%), and Malvaceae (3.96%) represented by the single species (Table 1). However, Jaccard's index of similarity ranged from 44 to 82% and 19 to 60% at Gombeledougou and Ouara, respectively. There are high similarities in species composition between the plateau and slope locations. The lowest values (19% and 44%) of similarity were observed between the low-lying and plateau locations, and the low-lying and slope locations (Table 2).

Population structures of *Piliostigma thonningii* and *Prosopis africana*

A total of 7,330 individuals were encountered at both study sites, of which 43% were individuals with a dbh of <5 cm (considered as an understory plant or seedling/sapling). Excluding this understory and considered only the adults of both species, we observed a significant difference between the densities of *P. thonningii* and *P. africana*, depending on the toposequence ($P<0.05$). The highest densities of *P. thonningii* (213±8.85) and *P. africana* (410±4.83) were found on the plateau followed by the densities on the slope. The densities of both species were lowest on the low-lying (Table 3). In addition, the highest proportion of fructified trees of *P. thonningii* and *P. africana* was found on the slopes.

The diameter class distribution of *P. thonningii* trees along the toposequence produced a reverse "J"-shaped curve. Most individuals (i.e. 52% in the low-lying, 54% in the plateau and 35.35% in the slope) were in the 5-10 cm dbh class. The diameter class distribution of *P. africana* produced different curve forms along the toposequence. We observed the "J"-shaped curve at the low-lying, where 100% of the individuals were in the last class (i.e. dbh of ≥ 50 cm). At the plateau, the diameter class distribution was characteristic of populations with the same age. The different diameter classes had near the same proportions. At the slope, the diameter class distribution showed a reverse "J"-shaped curve (Figure 3). The individuals of *P. africana* with the largest diameter (dbh = 86.62 cm) and height (12.3 m) were found at the low-lying. In addition, the height class distribution of *P. thonningii* trees produced a negative exponential curve. The distribution was a skewed bell-shaped curve for *P. africana* at the low-lying and slope locations, while its distribution was a negative exponential curve at the plateau (Figure 4).

Density of seedling populations of *Piliostigma thonningii* and *Prosopis africana*

Seedling populations of *P. thonningii* decreased significantly along the toposequence (P<0.05). This was different to the average densities of seedling populations of *P. africana* (Table 4). The results showed that regeneration of *P. thonningii* is highest on the low-lying, with an average density of 310±155 small individuals/ha, followed by the plateau (241±158 small individuals/ha). The highest density of seedling populations of *P. africana* was found on the slope (87±8 small individuals/ha), following by the plateau (31±3 small individuals/ha). The proportion of these individuals represents 43% of the total individuals of *P. thonningii* and *P. africana* recorded in Gombeledougou and Ouara.

Estimation of the pod production of *Piliostigma thonningii* and *Prosopis africana*

The models to predict the pod production of the two fodder species contained different structural parameters related to trees. Pod production by *P. africana* was positively correlated with crown cover (North-South) and the circumference at 130 cm, while pod production of *P. thonningii* was highly correlated with crown cover (East-West), the circumference at 130 cm and the total height (Table 5). For these structural parameters, the R^2 values varied to one species to other. The R^2 values of fruit prediction models of *P. africana* varied from 0.31 to 0.44 with the significant probabilities (P<0.0001). The best fit prediction model for the pod production of *P. africana* is the linear regression, while the equation coefficients were different. The highest mean pod production of *P. africana* was 287.84 kg DM/ha in the low-lying and 94.52 kg DM/ha in the slope. Considering the toposequence, the mean pod production per tree of *P. thonningii* was 2.56±1.88 kg. The highest mean pod production of *P. thonningii* (559.44 kg DM/ha) was found at the plateaus. This production is supported by the polynomial equation, $Y=ax^b$, with a high correlation coefficient (R^2 =0.86). The pod production of *P. thonningii* could be estimated using the height. The goodness of fit model was exponential regression, with R^2=0.96. The values of R^2 were significant for the tree circumference at 130 cm and crown (North-South, East-West).

Table 1: List of Woody species (dbh < 5 cm), families and species and family dominance at Gombeledougou and Ouara.

Location	Families	Species	D S (%)	D F (%)
Gombele-dougou	Malvaceae	*Bombax costatum*	3.96	3.96
	Fabaceae-Caesalpinioideae	*Cassia sieberiana*	0.99	47.52
		Daniellia oliveri	11.88	
		Detarium microcarpum	4.95	
		Isoberlinia doka	29.70	
	Combretaceae	*Terminalia laxiflora*	1.98	1.98
	Meliaceae	*Azadirachta indica*	3.96	4.95
		Khaya senegalensis	0.99	
	Fabaceae-Mimosoideae	*Parkia biglobosa*	5.94	36.63
		Prosopis africana	30.69	
	Polygalaceae	*Securidaca longipedunculata*	2.97	2.97
	Sapotaceae	*Vitellaria paradoxa*	1.98	1.98
Ouara	Anacardiaceae	*Lannea microcarpa*	4.64	4.64
	Malvaceae	*Bombax costatum*	0.52	0.52
	Fabaceae-Caesalpinioideae	*Afzelia africana*	0.52	30.41
		Burkea africana	9.28	
		Cassia siberiana	1.03	
		Daniellia oliveri	5.15	
		Detarium microcarpum	1.03	
		Isoberlinia doka	8.76	
		Pterocarpus erinaceus	3.61	
		Tamarindus indica	1.03	
	Combretaceae	*Anogeissus leiocarpus*	1.55	4.12
		Combretum molle	0.52	
		Combretum nigricans	0.52	
		Pteleopsis suberosa	0.52	
		Terminalia laxiflora	0.52	
		Terminalia macroptera	0.52	
	Ebenaceae	*Diospyros mespiliformis*	4.12	4.12
	Fabaceae-Mimosoideae	*Acacia polyacantha*	0.52	35.05
		Entada africana	1.03	
		Parkia biglobosa	5.15	
		Prosopis africana	28.35	
	Ochnaceae	*Lophira lanceolata*	2.58	2.58
	Rosaceae	*Parinari curatellifolia*	0.52	0.52
	Sapotaceae	*Vitellaria paradoxa*	17.01	17.01

DS: Species dominance; DF: family dominance.

Table 2: Jaccard's index of similarity at Gombeledougou (A) and Ouara (B) in natural stands of *Piliostigma thonningii* and *Prosopis Africana.*

A. Gombeledougou

	Low-lying	**Plateau**	**Slope**
Low-lying	1		
Plateau	0.44	1	
Slope	0.44	0.82	1

B. Ouara

	Low-lying	**Plateau**	**Slope**
Low-lying	1		
Plateau	0.19	1	
Slope	0.20	0.60	1

Table 3: Density and proportion of fructified trees of *Piliostigma thonningii* and *Prosopis Africana.*

Toposequence	***Piliostigma thonningii***	**Proportion**	***Prosopis africana***	**Proportion**
Low-lying	99±4.57b	19%	89.81±2.81b	25%
Plateau	213±8.85a	31%	410±4.83a	39%
Slope	105±10ab	34%	217±4.94ab	34%

Means with different letters are significantly ($P<0.05$) different base on Tukey's HSD test.

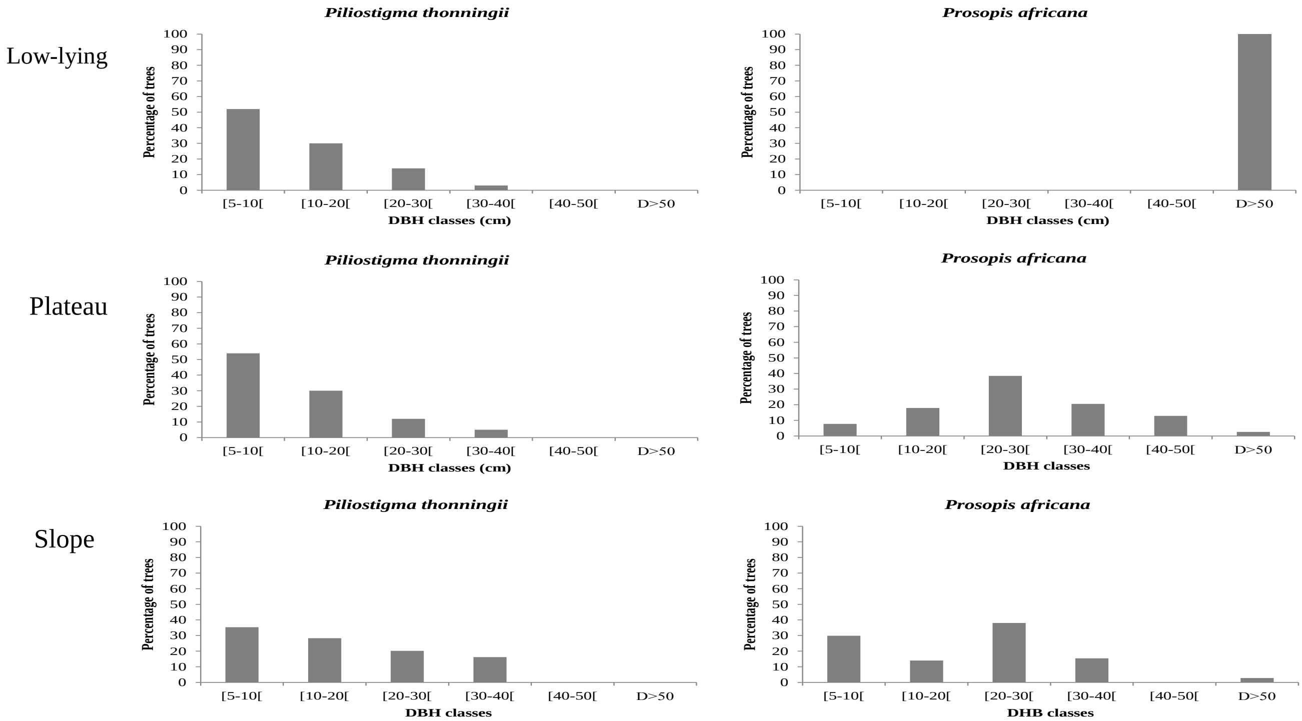

Figure 3: Diameter class distribution of *Piliostigma thonningii* and *Prosopis africana* along a toposequence in western region of Burkina Faso.

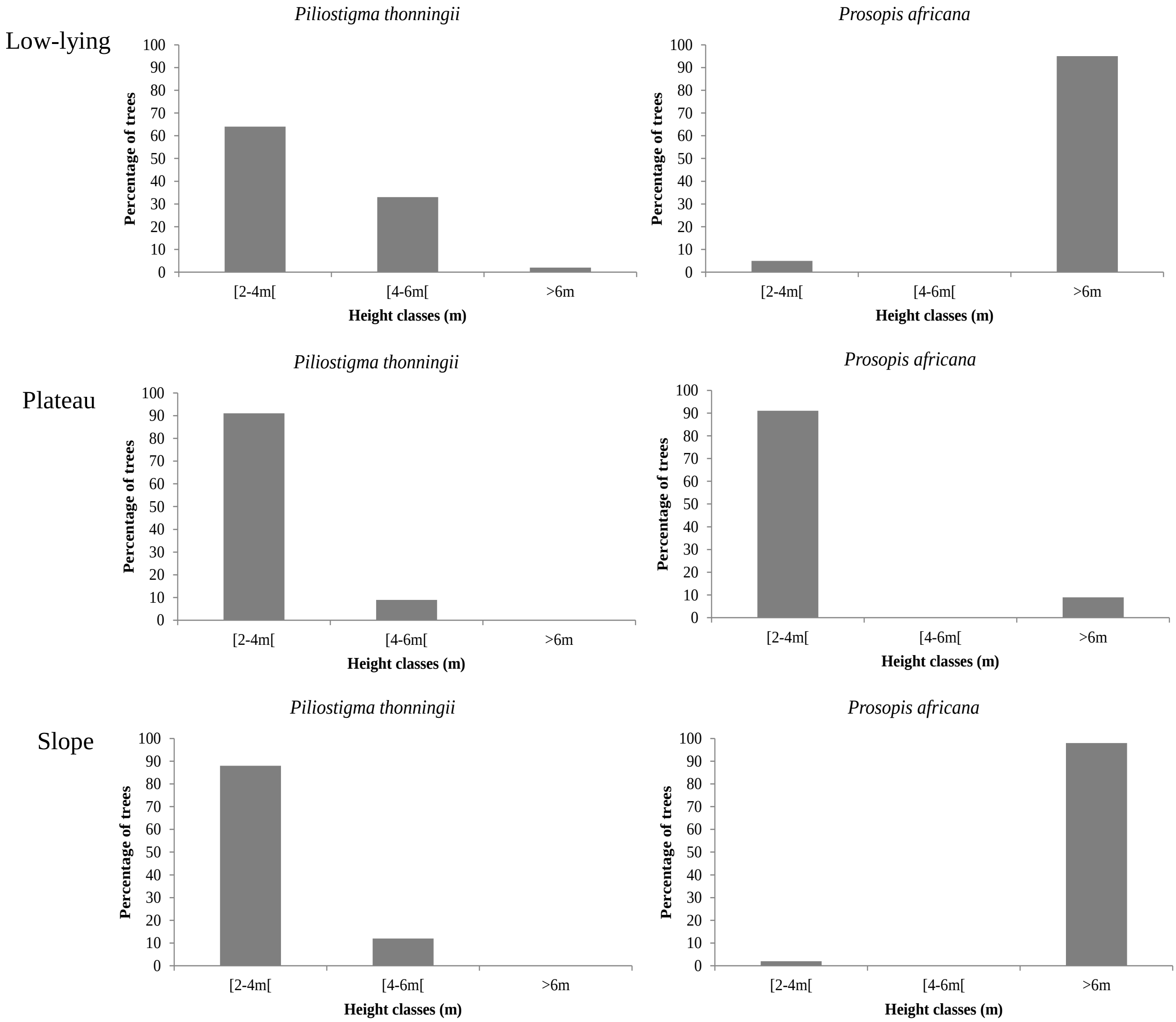

Figure 4: Height class distribution of *Piliostigma thonningii* and *Prosopis africana* along a toposequence in western region of Burkina Faso.

Table 4: Seedling density of *Piliostigma thonningii* (Gombeledougou) and *Prosopis africana* (Ouara).

Toposequence	Gombeledougou	Ouara
Low-lying	310±155a	15±2ab
Plateau	241±158ab	51±3ab
Slope	94±8b	87±8a

Means with different letters are significantly (P<0.05) different base on Tukey's HSD test.

DISCUSSION

Species composition of the natural pastures

A total of 24 species belonging to 11 families and 22 genera were inventoried. The families Fabaceae-Mimosoideae, Fabaceae-Caesalpinioideae and Combretaceae were dominant. This result corroborated the findings of several authors who have assessed the composition of savanna-woodlands in Burkina Faso (Sawadogo, 2009; Savadogo et al., 2017). Also, according to Sawadogo (2009), these families are typically found in the North Sudanian zone and most woodland mosaics. We found a greater species richness than that recorded by Savadogo et al. (2017), probably because these authors focused their study on the degraded land where sensitive or intolerant species to edaphic conditions were naturally eliminated.

The floristic composition varied along the toposequence. The results showed a low species richness in the low-lying at both study sites and a great similarity in species composition between the plateaus and slopes. The difference in species composition may be due to micro-climatic factors because the growth of trees in semi-arid ecosystems is mainly determined by moisture, soil characteristics and landscape position (Bognounou et al., 2009). Also, differences in floristic composition would arise from human pressures (Bellefontaine et al., 2000) and deteriorating weather conditions that reduce the chances of maintenance and the potential for regeneration of some species. For example, in our study sites, the inter-monthly and inter-annual rainfall variability in recent years impacted seriously on diversity of seedling populations. Also, tree mutilations (i.e. trunk cutting for firewood and construction materials, pruning for livestock) suffered by certain species such as *Afzelia Africana* Sm. ex Pers., *Burkea africana* Hook., *Combretum glutinosum* Perr. ex DC., *Daniella oliveri* (Rolfe) Hutch. & Dalziel Show, *Detarium microcarpum* Guill. & Perr., *P. thonningii* (Schum.) Milne-Redh. and *P. africana* (Guill. et Perr.) Taub. found in Ouara and Gombeledougou, along with annual burning and overgrazing are the determining factors that can influence the floristic composition of plant communities.

Population structures of *Piliostigma thonningii* and *Prosopis africana* and their regeneration potential

The diameter class distribution of *P. thonningii* trees along the toposequence produced a reverse “J”-shaped curve and at the slope, the diameter class distribution of *P. africana* also showed a reverse “J”-shaped curve (Figure 3), indicating that most of the individuals are found in the first dbh class. In savanna-woodlands of Burkina Faso, many authors have found the same form of diameter class distribution (Savadogo et al., 2007; Bognounou et al., 2009). The reverse “J” shape of the cumulative diameter class distribution is an indication of good regeneration status (Zegeye et al., 2006). This is because the small individuals were abundant than the old individuals. In addition, the seedlings of *P. thonningii* are more abundant in the low-lying and the plateau locations compared to the slope. This result is consistent with Razanamandranto et al. (2004), who reported that *P. thonningii* and *P. reticulatum* are usually found along the water course, supporting the hypothesis of endozoochorous or hydrochorous seed dispersal in savanna woodlands (Savadogo et al., 2007). Note that in the context of West African savanna-woodlands increasingly subject to many disturbances and climatic variability, the transition from seedling population to sapling , shrub and tree populations takes a long time and depending also on many biotic and abiotic factors (Tabuti et Mugula, 2007; Gnoumou et al., 2011). Our results are contrary to those of Niang-Diop et al (2010) who found that *P. africana* is a species characterized by low natural regeneration despite high in situ germination capacity due to low young plant survival in Senegal.

The diameter class distribution of *P. africana* at the low-lying produced a “J”-shaped curve where 100% of the individuals were in the last class (dbh of ≥ 50 cm). There was minimal regeneration of this species in the low-lying compared to the seedling densities at the plateau and slope locations (Table 5). This result showed that on the one hand, *P. africana* is not well-adapted to the hydromorphic soil conditions present at the low-lying where the humidity is often high, especially during the rainy season. The moisture conditions also limit the germination of the seeds and growth of other species that are intolerant of this edaphic condition. On the other hand, the seedlings/saplings of *P. africana* that are considered the most easily accessible and palatable fodder are severely grazed by livestock. Also, fire is a frequent disturbance factor in the savanna-woodlands and can result in the loss of sensitive species. According to Sanou et al. (2018), tree seedlings being grazed and browsed or trampled by livestock can lead to failures in their regeneration patterns. However, at the plateau, the diameter class distribution of *P. africana* showed the presence of a considerable number of species in the different dbh class indicating that it is well-adapted in this toposequence unit. Despite the continual browsing in the study sites, the optimal proportion of small individuals of both fodder species gives them a good regeneration status.

Prediction model to evaluate pod production of *Piliostigma thonningii* and *Prosopis africana*

Methods to efficiently evaluate the fodder production potential of shrubs or trees often use dendrometric traits (i.e. basal diameter, diameter at breast, total height and crown cover and volume) (Savadogo and Elfving, 2007; Bognounou et al., 2008; Sawadogo et al., 2010). In our study, these dendrometric traits are also used to estimate the pod production of *P. thonningii* and *P. africana* (Table 5).

Thus, for *P. africana*, the crown cover according to two cardinal directions (North-South and East-West) produced the best predictor of pod production of this species. This result is in part corroborated with the findings of Bognounou et al. (2013), who found that the best equation to predict the biomass production of *P. africana* used crown cover and basal area. The R^2 values of the different model predictions for this species are inferior to 0.50. This situation is probably due to human pressures on the species (i.e. repetitive harvesting during the dry season, annual fire in savanna-woodlands) and environmental conditions (i.e. climatic and edaphic conditions). According to Bognounou et al. (2013), climatic conditions and anthropogenic disturbances such as fire, animal breeding and other pressures generate unusual shrub or tree shapes making the development of prediction equations difficult. In that way, Larwanou et al. (2010) observed that *P. afriana*'s fruit production is not related to the size of the tree in the central part of Niger (500 mm rain fall/year).

The repetitive cutting of fodder trees influenced the pod production (Bode, 2004). The models to predict the pod production of the two fodder species contained different structural parameters related to trees and have different equation coefficients. This result indicated that dendrometric traits of trees have a variable influence on fruit production. The pod production of *P. africana* on the slopes and plateaus is lower than its pod production in the low-lying locations. This could be explained by the fact that the low-lying retain moisture for longer periods than the slopes and plateaus. However, *P. africana* is a species that naturally occurs in areas with an average annual rainfall that is greater than 1000 mm, while in the Ouara area, in recent decades there has been an average annual rainfall of below 1000 mm. This assertion is supported by several authors who have confirmed that rainfall shortages and drying winds have induced fruiting abortions that have directly reduced fruit production (Okullo et al., 2004; Berjano et al., 2006).

Compared to *P. africana* where the best-fit models are produced by using the crown and circumference parameters, for *P. thonningii* the total height produces the best-fit model with a value of R^2 close to 1 (0.96). Also, Lompo et al. (2018) found a best-fit model to predict fruit production of *Ximenia americana* used tree height. The production per individual tree of *P. thonningii* is greater than those obtained by Kima (2008) and Sanou (2005). This difference could be explained by the high density of the adult individuals of the species at Gombeledougou. Indeed, the high density of individuals in an area leads to strong competition for nutrients, resulting in a decrease in production. The savanna-woodlands of Burkina Faso are strongly characterized by different regimes and frequencies of disturbances (i.e. fire, cutting, pruning of fodder tree species, and conversion of forest space to agriculture land) and environmental conditions (i.e. rainfall variability drying winds, low soil fertility) (Sawadogo et al., 2010). Thus, in the light of these biotic and abiotic factors, it seems difficult and not recommended to apply the same formula to predict pod production of fodder trees species at different savanna-woodlands location throughout West Africa (Bognonou et al., 2013). According to Bognonou et al. (2013), the application of the same formula may either over- or under-estimate the biomass, depending on species attributes.

Table 5: Allometric equations relating species-specific pods productions (PP) to the circumference at 1.30 m (Circ), crown cover (Cover) and height (H) of *Piliostigma thonningii* and *Prosopis Africana*.

Species	**Location**	**Allometric equations**	**R^2**	**P**
Prosopis africana	Ouara	PP = - 28.67+5.25 (Cover_E-W)	0.31	P<0.0001
		PP = -29.41 + 5.24 (Cover_ N-S)	0.42	P<0.0001
		PP = -23.53 +36.46(Circ)	0.44	P<0.0001
		PP = -37.57 + 0.13 (Cover_E-O) + 3.64 (Cover_ N-S) +24.95 (Circ_1.30)	0.50	P<0.0001
Piliostigma thonningii	Gombeledougou	$PP=0.5606Circ^{0.7531}$	0.86	P<0.0003
		$PP=2.0536e^{0.1267H}$	0.96	P<0.0001

E-W: East-West, N-S: North-South.

Conclusion

This study examined the species composition, population structure and pod production of the two fodder species *Piliostigma thonningii* and *Prosopis africana* along a toposequence at two sites in western Burkina Faso. The results showed differences in species composition depending on the topographic position and that the species have different site preferences. *Piliostigma thonningii* has a better regeneration status than *P. africana*, based on its diameter class distribution and densities of seedling populations. A low similarity in tree species composition between the toposequence sites (plateaus versus low-lying, low-lying versus slope) showed a high beta diversity and reflects differences in habitat conditions, topography and distances between sites. For the prediction of pod production, the results revealed that the equations varied within species, depending on the different regimes and frequencies of disturbances and environmental conditions. Pod production of *P. thonningii* and *P. africana* was successfully predicted based on the stem circumference and total height, and crown cover and circumference, respectively. These dendrometric traits that can facilitate fodder availability evaluations should receive greater consideration in the management of natural pastures throughout West African savanna-woodlands.

COMPETING INTERESTS

The authors declare that there are no competing interests.

AUTHORS' CONTRIBUTIONS

SO and LS conceived the research idea, collected the data, analyzed the data and wrote the draft. PS and CYKZ made valuable comments on the manuscript.

ACKNOWLEDGEMENTS

The authors thank the Institute of Environment and Agricultural Research for their support during data collection. We would also like to extend our gratitude to the anonymous reviewers for their valuable comments and suggestions made to help improve the manuscript.

REFERENCES

Arbonnier M. 2009. Arbres, arbustes et lianes des zones sèches d'Afrique de l'Ouest, 3e Ed., QUAE/MNHN.

Barminas JT, Maina HM, Ali J. 1998. Nutrient content of *Prosopis africana* seeds. *Plant Food Hum. Nutr*, **52**: 325-328. DOI: https://doi.org/10.1023/A:1008045218320.

Bellefontaine R, Gaston A, Petrucci Y.2000. Management of natural forests of dry tropical zones. (Conservation guide 32) Food and Agriculture Organization of the United Nations (FAO). Rome, Italy, 318.

Berjano R, De Vega C, Arista M, Ortiz PL, Talavera S. 2006. A multiyear study of factors affecting fruit production in *Aristolochia paucinervis* (Aristolochiaceae). *Am. J. Bot.* **93**(4): 599-606. DOI: https://doi.org/10.3732/ajb.93.4.599.

Bode S. 2004. Pratiques pastorales et biodiversité des parcours dans le canton de Dantchandou (Fakara). Mémoire de D.E.S.S., Université Abdou Moumouni, Niger. p59.

Bognounou F, Ouédraogo O, Zerbo I, Sanou L, Rabo M, Thiombiano A, Karen H. 2013. Species-specific prediction models to estimate browse production of seven shrub and tree species based on semi-destructive methods in savannah. *Agrofor. Syst.*, **87** (5) : 1053-1063. DOI: https://doi.org/10.1007/s10457-013-9620-2.

Bognounou F, Savadogo M, Boussim, IJ, Guinko S. 2008. Equations d'estimation de la biomasse foliaire de cinq espèces ligneuses soudaniennes du Burkina Faso. *Secheresse* **19**: 201–205. DOI: https://doi.org/10.1684/sec.2008.0137.

Bognounou F, Thiombiano A, Savadogo P, Boussim JI, Oden PC, Guinko S. 2009. Woody vegetation structure and composition at four sites along a latitudinal gradient in Western Burkina Faso. *Bois For. Trop.*, **300**: 30–44. DOI: https://doi.org/10.19182/bft2009.300.a20412.

Cole TG, Ewel JJ. 2006. Allometric equations for four valuable tropical tree species. *For. Ecol. Manage.*, **229**: 351-360. DOI: https://doi.org/10.1016/j.foreco.2006.04.017.

Diatta AA, Ndour N, Manga A, Sambou B, Faye CS, Diatta L, Goudiaby A, Mbow C, Dieng SD. 2016. Services écosystémiques du parc agroforestier à *Cordyla pinnata* (Lepr. ex A. Rich.) Milne-Redh. dans le Sud du Bassin Arachidier (Sénégal). *Int. J. Biol. Chem. Sci.*, **10**(6): 2511-2525. DOI: http://dx.doi.org/10.4314/ijbcs.v10i6.9.

Fontès J, Guinko S. 1995. Carte de la végétation et de l'occupation des sols du Burkina Faso. Ministère de la Coopération Française :projet campus (88 313 101), 67p.

Gnoumou A, Bognounou F, Hahn K, Thiombiano A. 2012. A comparison of Guibourtia copallifera Benn. stands in South West Burkina Faso-community structure and regeneration. *J. For. Res.* **23**: 29–38. DOI: http://dx.doi.org/10.1007/s11676-012-0116-0.

Kima S. 2008. Valorisation des gousses de Piliostigma thonningii (Scuhm.) en production animale et étude de l'infestation par des insectes. Mémoire d'ingénieur IDR/UPB, p 84.

Krebs CJ. 1999. Ecological Methodology. 2nd Edition, Benjamin Cummings, Menlo Park, 620 p.

Kristensen M, Balslev H. 2003. Perceptions, use and availability of woody plants among the Gourounsi in Burkina Faso. *Biodiv. Conserv.*, **12**(8): 1715-1739. DOI: https://doi.org/10.1023/A:1023614816878.

Lankoandé B, Ouédraogo A, Boussim IJ, Lykke AM. 2017. Natural stands diversity and population structure of Lophira lanceolata Tiegh. ex Keay, a local oil tree species in Burkina Faso, West Africa. *Agrofor. Syst.* DOI: https://doi.org/10.1007/s10457-016-9913-3. 1-14.

Larwanou M, Yemshaw Y, Saadou M. 2010. Prediction models for estimating foliar and fruit dry biomasses of five Savannah tree species in the West African Sahel. *Int. J. Biol. Chem. Sci.*, **4**(6): 2245-2256. DOI : http://dx.doi.org/10.4314/ijbcs.v4i6.64943.

Laoualia Dan Guimbo I, Larwanou M, Inoussa MM, Mahamane A. 2014. Utilisation de *Prosopis africana* (G. et Perr.) Taub dans le sud du département d'Aguié au Niger : les différentes formes et leur importance. *Int. J. Biol. Chem. Sci.,* **8**(3): 1065-1074. DOI: http://dx.doi.org/10.4314/ijbcs.v8i3.20.

Lompo O, Lykke AM, Lankoandé B, Ouédraogo A. 2018. Influence of climate on fruit production of the yellow plum, Ximenia americana, in Burkina Faso, West Africa. *J. Hort. For.*, **10**(4): 36-42. DOI: https://doi.org/10.5897/JHF2017.0517.

Nacoulma BIM, Lykke AM, Traoré S, Sinsin B, Thiombiano A. 2017. Impact of bark and foliage harvesting on fruit production of the multipurpose tree Afzelia africana in Burkina Faso (West Africa). *Agrofor. syst*. DOI: https://doi.org/10.1007/s10457-016-9960-9.

Navar J, Mendez E, Najera A, Graciano J, Dale V, Parresol B. 2004. Biomass equations for shrub species of Tamaulipan thornscrub of North-eastern Mexico. *J. Arid. Environ.*, **59**: 657-674. DOI : https://doi.org/10.1016/j.jaridenv.2004.02.010.

Niang-Diop F, Sambou B, Lykke AM. 2010. Contraintes de régénération naturelle de *Prosopis africana* : facteurs affectant la germination des graines. *Int. J. Biol. Chem. Sci*., **4**(5): 1693-1705. DOI: http://dx.doi.org/10.4314/ijbcs.v4i5.65578.

Okullo JBL, Hall JB, Obua J 2004. Leafing, flowering and fruiting of Vitellaria paradoxa subsp. nilotica in savanna parklands in Uganda. *Agrofor. Syst.*, **60**:77-91. DOI: https://doi.org/10.1023/B:AGFO.0000009407.63892.99.

Ouédraogo-Koné S, Kaboré-Zoungrana, CY, Ledin I. 2008. Importance characteristics of some browses species in an agrosilvopastoral system in West Africa. *Agrofor. Syst.*, **74**: 213-221. DOI: https://doi.org/10.1007/s10457-007-9095-0.

Razanamandranto S, Tigabu M, Neya S, Odén PC. 2004. Effects of gut treatment on recovery and germinability of bovine and ovine ingested seeds of four woody species from the Sudanian savanna in West Africa. *Flora*., **199** : 389–397. DOI : https://doi.org/10.1078/0367-2530-00167.

Rondeux J. 1999. La mesure des arbres et des peuplements forestiers. Les Presses Agronomiques de Gembloux (Belgique), p 531.

Sanou L, Zida D, Savadogo P, Thiombiano A. 2018. Comparison of aboveground vegetation and soil seed bank composition at sites of different grazing intensity around a savanna-woodland watering point in West Africa. *J. Plant. Res.*, **131**(5):773-788. DOI: https://doi.org/10.1007/s10265-018-1048-3.

Sanou S. 2005. *Piliostigma reticulatum* (D.C) Hoscht : Potentialités fourragères et essai d'amélioration de la valeur nutritive des gousses. Mémoire de fin d'études IDR/UPB, p 57.

Savadogo P. 2007. Dynamics of Sudanian Savanna-Woodland Ecosystem in

Response to Disturbances. Doctoral Thesis N.2007:64. Faculty of Forest Sciences.

Savadogo P Elfving B. 2007. Prediction models for estimating available fodder of two savanna tree species (Acacia dudgeoni and Balanites aegyptiaca) based on field and image analysis measures. *African J. Range For. Sci.* **24**: 63-71. DOI: https://doi.org/10.2989/AJRFS.2007.24.2.2.156.

Savadogo P, Sanou L, Dayamba SD, Bognounou F, Thiombiano A. 2017. Relationships between soil seed banks and above-ground vegetation along a disturbance gradient in the W National Park trans-boundary biosphere reserve, West Africa. *J. Plant Ecol.* **10** (2): 349–363. DOI: https://doi.org/10.1093/jpe/rtw02.

Savadogo P, Tigabu M, Sawadogo L, Oden PC. 2007. Woody species composition structure and diversity of vegetation patches of a Sudanian savanna in Burkina Faso. *Bois For. Trop.*, 5-20. DOI: https://doi.org/10.19182/bft2007.294.a20333.

Sawadogo, L. 2009. Influence de facteurs anthropiques sur la dynamique de la végétation des forêts classées de Laba et de Tiogo en zone soudanienne du Burkina Faso. Thèse d'Etat. Université de Ouagadougou, p 142.

Sawadogo L, Savadogo P, Tiveau D , Dayamba SD. 2010. Allometric prediction of above-ground biomass of evelen woody tree species in the Sudanian savanna-woodland of West Africa. *J. For. Res.*, **21**(4):475-481. DOI: https://doi.org/10.1007/s11676-010-0101-4.

Shackleton C, Shackleton SE. 2000. Direct use values used in woodlands. *In The Souther African Forestry Hanbook*, Owen DL (ed). Forestry Institute: Pretoria, South African; 635-641.

Sop T K, Oldeland J. 2011. Local perceptions of woody vegetation dynamics in the context of a 'Greening Sahel': a case study from Burkina Faso. *Land Degrad. Dev.*, **24**(6): 511-527. DOI: https://doi.org/10.1002/Idr.1144.

Tabuti JRS, Mugula BB. 2007. The ethnobotany and ecological status of Albizia coriaria Welw. ex Oliv. in Budondo Subcounty, eastern Uganda. *Afr. J. Ecol.*, **45**: 126–129. DOI: https://doi.org/10.1111/j.1365-2028.2007.00869.x.

Weber JC, Larwanou M, Abasse T, Kalinganire A. 2008. Growth and survival of Prosopis africana provenances tested in Niger and related to rainfall gradient in the West African Sahel. *Forest Ecology and Management*, **256**(4): 585-592. DOI: https://doi.org/10.1016/j.foreco.2008.05.004.

Yelemou B, Bationo BA, Yaméogo G, Millogo-Rasolodimby J 2007. Gestion traditionnelle et usages de Piliostigma reticulatum sur le plateau central du Burkina Faso, *Bois For. Trop.*, **291**: 55-65. DOI :https://doi.org/10.19182/bft2007.291.a20356.

Zegeye H, Teketay D, Kelbessa E. 2006. Diversity, regeneration status and socio-economic importance of the vegetation in the islands of Lake Ziway, south-central Ethiopia. *Flora*, **201**(6): 483-498. DOI : https://doi.org/10.1016/j.flora.2005.10.006.