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The Effects of Topographic Factors on Aboveground Biomass Production of Grasslands in the Atacora Mountains in Northwestern Benin

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The Atacora Mountain range is an important mountain chain in the West African landscape. It extends from northern Benin to Togo and Ghana. More and more cattle are starting to graze on the Beninese part of this range, although there is a

critical lack of basic data on its ecological function. The present study assesses the effects of topography and aspect on the grassland biomass production of these mountains. The results show that annual grassland biomass production

averages 5.29 tonnes dry matter (DM)/ha. This biomass production is significantly impacted by aspect (east facing versus west facing). Biomass is lower on east-facing sides (4.97 tonnes DM/ha) than on west-facing sides (6.10 tonnes DM/ha) and hilltops and valleys (6.24 tonnes DM/ha). This effect may be explained by direct exposure of east-facing sides to the harmattan, a northeast dry wind blowing from the Sahara Desert. No significant impact of topography on biomass production is observed.

Keywords: Grassland; topography; wind exposure; aboveground biomass; Atacora Mountains; Benin; West Africa.

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Introduction

The Atacora mountain range (400–600-m altitude in Benin) is an important mountain chain in West Africa. It extends from northwestern Benin to Togo and Ghana, where it can reach 800 m. It forms a special ecosystem in the West Africa Sudanian zone because of its hilly landscape and shallow soils, making it a fragile ecosystem. Because of its steep slopes and its relatively high altitudes compared to the surrounding plains regions, this mountain chain influences the dynamics of the West African monsoon, the most determinant factor in the climate of West Africa (Le Barbe et al 2002).

In its Beninese part, the vegetation in this mountain range consists of shrub and tree savannas, woodlands, and fallows (Sieglstetter and Wittig 2002; Tente and Sinsin 2002), and there is great variation in the species composition of the herbaceous layer (Müller 2007). The chain harbors 2 of Benin's endemic plant species *Cissus kouandeensis* and *Terminalia brownii* (Adjanohoun et al 1989; Adomou 2005). In the Sudanian zone of the country, where cattle rearing is an important economic activity, more and more cattle herds from the neighbouring regions are starting to graze on this range (Meurer 1994). Especially during the very difficult dry season, when fodder becomes rare in the surrounding plains regions because of overgrazing, local herders as well as transhumant Fulani herders coming from Sahelian countries (Burkina Faso and Niger) feed their cattle herds from herbaceous and tree

fodder (eg *Khaya senegalensis*, *Azelia africana*, *Pterocarpus erinaceus*) on this mountain chain (Meurer 1994).

Despite its ecological specificity and socioeconomic importance, basic scientific data on this mountain ecosystem are critically lacking to date (Adjanohoun et al 1989; Sene and Zingari 2001). A few recent studies have investigated the species diversity of the mountain chain (Sieglstetter and Wittig 2002; Tente and Sinsin 2002; Wala 2005). A few studies have also focused on the influence of the range on the regional climate, especially on the dynamics of the convective systems determining the climate of West Africa (Heinrich and Moldenhauer 2002; Le Barbe et al 2002). However, the ecological function of these mountains is little understood. For instance, little is known about the dynamics of species diversity, biomass production, and life forms in relation to topography, altitude, and exposure to winds. Also, the effects of grazing and recent growth of human settlements in the range have not yet been investigated. These data are critical to the sustainable management of the range. The aim of the present study is to: (1) estimate the aboveground herbaceous biomass production of the Atacora Mountains; and (2) determine the impact of topography and aspect on this biomass production.

Study area

The Benin portion of the Atacora Mountain range (Figure 1) is located in the large West Africa Sudanian

climatic zone, where rainfall usually ranges from 800 to 1000 mm (Houndenou and Hernandez 1998). However, the plains region surrounding this mountain chain shows special climatic features: Rainfall is higher because of the orographic effects and can reach 1300 mm per year instead of 800–1000 mm, as is common in the common Sudanian zone (Houndenou and Hernandez 1998; Heinrich and Moldenhauer 2002). Nonetheless, the area is becoming drier and drier because of climate change (Houndenou and Hernandez 1998, Heinrich and Moldenhauer 2002). Two seasons are distinguished: a rainy season (April to October) and a dry season (November to March). The average monthly temperature in the mountains over the past 35 years has ranged from 25.3–30.5°C, and the average relative humidity over the same period has ranged from 26.8% during the dry season to 80.5% during the wet season.

The topography of the mountain chain includes hilltops and plateaus, valleys, and hillsides with steep slopes (30–60%). Hillsides are generally either east facing or west facing. East-facing sides are mostly exposed to the *Harmattan*, a dry northeast wind that blows from the Sahara Desert during the dry season (Jenik and Hall 1966). West-facing sides are mostly exposed to West African moist monsoon, a southwest wind that blows from the Atlantic Ocean (Le Barbe et al 2002). Rocky and shallow soils are dominant, and sometimes sandy and clay soils with moderate stone content are found in seasonally wet or inundated valleys. Vegetation, which is still little known, consists of shrub, tree, and woodland savannas dominated by *Isobertinia doka*, *Daniellia oliveri*, *Vitex* spp., *Terminalia glaucescens*, *Parinari polyandra*, etc (Sieglstetter and Wittig 2002; Tente and Sinsin 2002; Wala 2005). The part of the mountain chain covered by this study stretches from Tanguieta city (10°37'N; 01°16'E) to Batia village on the borderline of the Biosphere Reserve of Pendjari (10°54'N; 1°29'E) (Figure 1).

Material and methods

A previous study identified 5 grassland types as the main representative grasslands in the study area (Avohou 2003):

- *Loudetia flavida* Stapf. grassland in *Burkea africana* shrub savannas, on the eastern sides of the mountains;
- *Andropogon schirensis* Hochst. grassland in *Burkea africana* shrub savannas, on the eastern sides of the mountains;
- *Andropogon tectorum* Schumach. & Thonn. grassland in *Isobertinia doka*, woodlands on the summits, the sides, and in the valleys of the mountain range;
- *Andropogon gayanus* Kunth. grassland in *Vitellaria paradoxa* or *Burkea africana* tree savannas or in old fallows (aged at least 2 years) at all topographic levels; and
- *Hypparrhenia involucreta* Stapf. grassland in *Detarium microcarpum* and *Burkea africana* tree or woody savannas, on the western sides of the mountains.

One protected plot of 10 m × 10 m was set up on the mountain range per grassland type, per topographic level (hilltop, middle side, lower side, and valley), and per mountainside aspect (east facing versus west facing). Seven 1-m² subplots were sampled randomly inside each protected plot. Maximum standing biomass was cut from these subplots and weighed at the end of the rainy season in 2003 in order to measure aboveground herbaceous dry biomass production. For each plot, 150 g of grass were sampled and oven-dried at 105°C for 3 days to determine dry matter (DM) content. The average biomass production was determined for each topographic level and for each type of aspect based on the biomass production of the 5 grasslands types. Soil depth from the topsoil to the parent rock was also measured for each plot, using 3 holes 5 m apart and dug in the surroundings of the plot. Soil texture was also noted. Data were analyzed through analysis of variance, and significance was assessed at the 0.05 level. STATISTICA software version 6.0 was used.

Results and discussion

The results show that the average aboveground herbaceous biomass production in the mountain range in the study area is 5.29 ± 0.47 tonnes dry matter (DM)/ha for the year of the study (Table 1). Biomass production is dependent on species composition ($F = 23.02$, $df = 4$, $P = 0.000$). *A. gayanus*, *H. involucreta*, and *L. flavida* grasslands show the highest biomass values, while *A. tectorum* and *A. schirensis* grasslands show the lowest biomass values. Biomass production is not significantly impacted by topography ($F = 1.94$, $df = 3$, $P = 0.1053$; Table 2). This result may be explained by the soil properties in relation to the mountain gradient. Soil depth and texture do not vary significantly according to topography (Table 2) because water runoff and soil erosion are very intense due to the steepness of the slopes (average gradient of 40%). Because of this hydrological erosion, the accumulation of soil particles is limited down the slopes. These particles are accumulated among rocks and stones, creating different kinds of microclimates. As soils are shallow and rocky at all topographic levels, they may experience important variations of temperature and evapotranspiration (Jenik and Hall 1966). These important variations in microclimatic parameters may better explain biomass production. This result is consistent with the observations by Jenik and Hall (1966) of the woody vegetation structure in the Togolese portion of the mountain range. These authors found that vegetation structure was little influenced by topography and altitude (Jenik and Hall 1966). Rather, soil depth and steepness of the slopes seem to have a greater influence on the vegetation structure (Jenik and Hall 1966).

In contrast to topography, the side aspect has a significant impact on grassland biomass production

FIGURE 1 Map of Benin showing the location of the Atacora Mountain range. (Map by the authors)

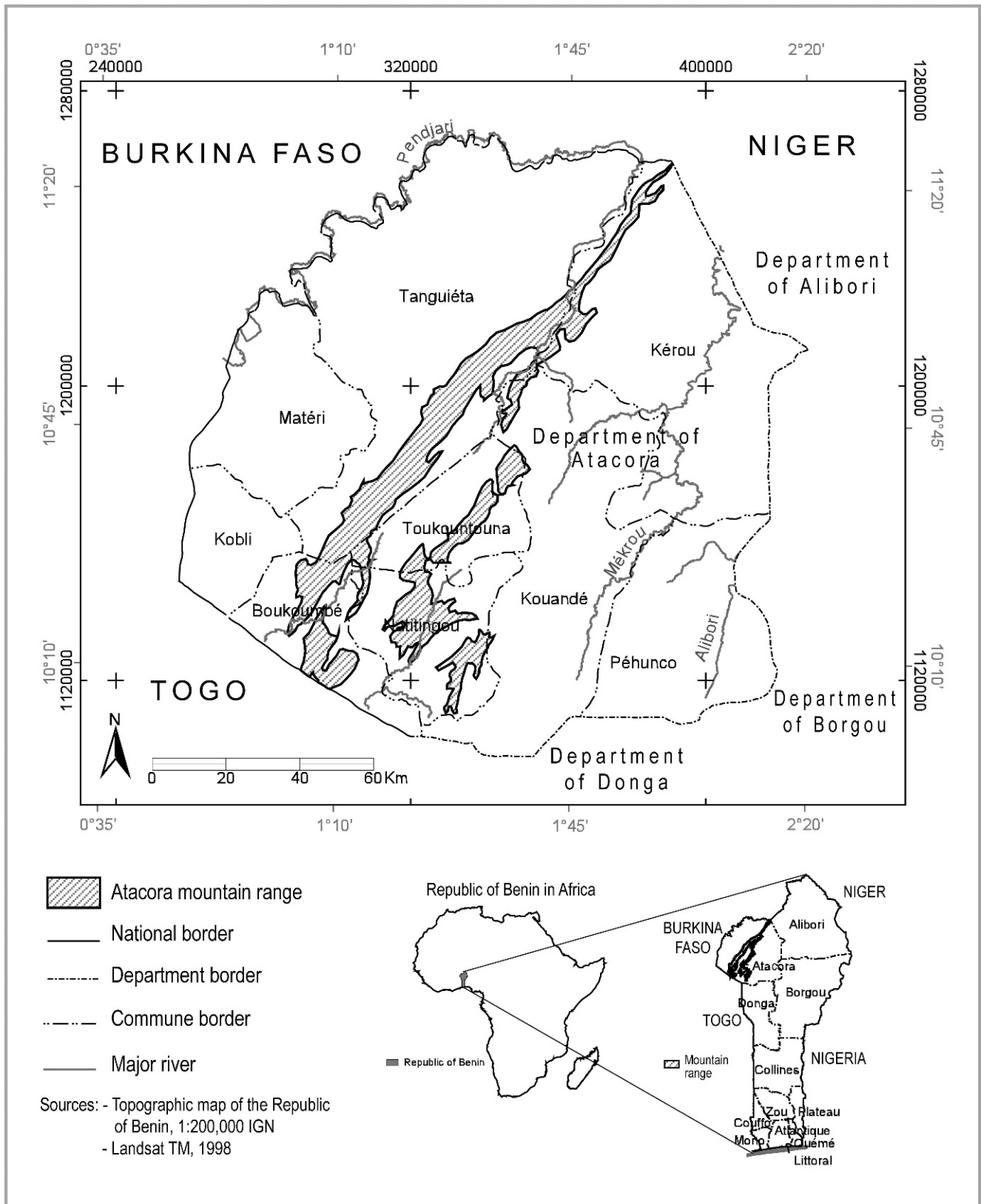


TABLE 1 Aboveground herbaceous biomass production of grasslands. Biomass production: $P = 0.000$. Values followed by the same letter (a, b) are not significantly different at 0.05 level based on Newman–Keuls test.

Grassland type	Number of plots	Vegetation type	Woody cover (%)	Herb cover (%)	Biomass production (mean \pm SE tons DM/ha)
<i>Loudetia flavida</i>	4	Tree savannas	4	90	5.82 \pm 0.63 ^b
<i>Andropogon schirensis</i>	4	Shrub savannas	8	85	4.50 \pm 0.13 ^a
<i>Andropogon tectorum</i>	4	Woodlands	83	95	3.84 \pm 0.28 ^a
<i>Hyparrhenia involucrata</i>	5	Tree and shrub savannas	28	86	6.01 \pm 0.56 ^b
<i>Andropogon gayanus</i>	6	Fallow, tree savannas, woodlands	20	89	6.27 \pm 0.42 ^b
Overall mountain	23	–	–	–	5.29 \pm 0.47

($F = 4.47$, $df = 2$, $P = 0.0048$; Table 3). Herbaceous biomass is lower on east-facing sides (4.97 ± 0.37 tons DM/ha) than on west-facing sides (6.10 ± 0.59 tons DM/ha) and hilltops and valleys (6.24 ± 0.35 tons DM/ha), although soil properties do not differ according to the side (Table 3). This difference in biomass production may be explained by direct exposure of the east-facing sides of the range to a cold and dry wind called *harmattan*, making the east-facing sides drier than west-facing sides. The *harmattan* is a northeastern wind that brings dry air from the Sahara Desert (Jenik and Hall 1966; Tchamié and Bouraïma 1997). It has a desiccating effect on plants and contributes significantly to extension of bush fires (Schnell 1952: 80). This desiccating effect has been demonstrated by Jenik and Hall (1966) through studies of microclimatic parameters such as local temperature and evapotranspiration. These authors observed that steeper slopes facing east or northeast are covered by shrub steppe, while savanna woodland can be found on southwest- or west-facing slopes. They also reported that the total cover and the height of grasses and shrubs are lower on east- or northeast-facing sides than on southwest- or west-facing sides. This wind is normally experienced from November to March. Contrary to

northeast- and east-facing sides, southwest- and west-facing sides are more exposed to the monsoon, a wetter wind, and rainfall may be higher on these western sides during most of the rainy season (Le Barbe et al 2002). The effects of these convective systems on the ecological processes (eg species diversity, species distribution, life forms, tree growth, biomass production) of the mountain range need to be further investigated.

The ranges of biomass values obtained in our study are close to those obtained by other studies at similar latitudes. Afolayan (1978) recorded a grass biomass production ranging between 3.25 and 7.45 tons DM/ha in a Guinean savanna in northern Nigeria, where annual rainfall is between 1000 and 1200 mm and soils are moderately deep (at least 80 cm). Fournier (1983) found biomass yields ranging from 4.78 to 6.27 tons DM/ha in Sudanian savannas in Ouango-Fitini (9°35'N; 4°01'W, Ivory Coast) versus 3.84 to 6.27 tons DM/ha in the Atacora Mountains.

Conclusion

This study provides baseline data on biomass production in the Atacora Mountain range, one of the most important

TABLE 2 Variation of aboveground herbaceous biomass production according to topography. Soil depth: $P = 0.0000$; biomass production: $P = 0.1053$. Values followed by the same letter (a, b) are not significantly different at 0.05 level based on Newman–Keuls test.

Topography	Altitude (m)	Number of plots	Mean soil depth (cm)	Soil texture	Biomass production (mean \pm SE tons DM/ha)
Hilltop	347–518	5	22.0 ^a	Silty and sandy	6.51 \pm 0.34
Middle slope	325–455	8	13.5 ^a	Silty and sandy	5.29 \pm 0.37
Lower slope	280–429	7	14.3 ^a	Silty and sandy	5.84 \pm 0.84
Valley	347–367	3	33.9 ^{ab}	Silty and sandy	5.88 \pm 1.10

TABLE 3 Variation of aboveground herbaceous biomass production according to mountain side aspect. Soil depth: $P = 0.0001$; biomass production: $P = 0.0048$. Values followed by the same letter (a, b, c) are not significantly different at 0.05 level based on Newman-Keuls test.

Mountainside aspect	Altitude (m)	Number of plots	Mean soils depth (cm)	Soil texture	Biomass production (mean \pm SE tons DM/ha)
Hilltop and valley	350–450	8	24.9 ^a	Silty and sandy	6.24 \pm 0.35 ^a
East-facing sides	339–455	8	12.7 ^b	Silty and sandy	4.97 \pm 0.37 ^c
West-facing sides	280–429	7	15.9 ^b	Silty and sandy	6.10 \pm 0.59 ^a

mountain chains of West Africa. Herbaceous aboveground biomass production values obtained in this study were close to those recorded in other Sudanian regions. Biomass

production seems to be influenced by mountainside aspect. Large-scale studies are needed to investigate the ecological functioning of this range in greater detail.

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