Effects of increasing rainfall gradient on sorghum Leaf Area Index (LAI) at juvenile stage in agroforestry parklands systems in Burkina Faso (West Africa)

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Abstract

LAI is defining key factor for sorghum productivity. However, few research investigated how it is affected under different rainfall conditions in agroforestry parklands. This research investigated the effect of an increasing rainfall gradient on sorghum LAI at juvenile stage for recommendations to maintain and/or improve sorghum productivity under climate change. Field experiments were conducted at three climatic zones in parkland systems consisted of an association of *Sorghum bicolor* (L.) Moench (sorghum) with *Vitellaria Paradoxa* C. F Gaertn (karité) and *Parkia biglobosa* (Jacq.) Benth (néré). The LAI was measured using the planimetric method with the ImageJ software. Sorghum LAI was higher in agroforestry parklands under low rainfall. The rainfall level affected differently sorghum LAI according to the associated tree species in agroforestry parklands. Promoting agroforestry with karité and néré trees in association with sorghum under reduced rainfall could contribute to maintain and/or improve sorghum productivity with climate change. Trees pruning could improve sorghum LAI and productivity associated with karité and néré trees in agroforestry parklands under increased rainfall with climate change.

Keywords: climate change, humidity, soil, karité, néré

Effets d'un gradient croissant de précipitation sur le Leaf Area Index (LAI) du sorgho au stade juvénile dans les systèmes parcs agroforestiers au Burkina Faso (Afrique de l'ouest)

Résumé

Le LAI est un facteur clé de la productivité du sorgho. Cependant, peu de recherches ont investigué comment il est affecté sous différentes conditions pluviométriques dans les parcs agroforestiers. Cette recherche a étudié l'effet d'un gradient croissant de précipitation sur le LAI du sorgho au stade juvénile pour des recommandations afin de maintenir et/ou améliorer la productivité du sorgho face au changement climatique. Des expérimentations étaient conduites dans trois zones climatiques dans des parcs agroforestiers constitués d'une association de *Sorghum bicolor* (L.) Moench (sorgho) avec *Vitellaria Paradoxa* C. F Gaertn (karité) et *Parkia biglobosa* (Jacq.) Benth (néré). Le LAI était mesuré avec le logiciel ImageJ. Le LAI du sorgho était plus élevé où les précipitations étaient faibles. Le niveau des précipitations a affecté différemment le LAI du sorgho selon les espèces d'arbres associées. Promouvoir l'agroforesterie avec le karité et le néré en association avec le sorgho dans des conditions de précipitations réduites pourrait contribuer à maintenir et/ou améliorer la productivité du sorgho avec le changement climatique. L'élagage

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des arbres pourrait améliorer le LAI et la productivité du sorgho associé au karité et au néré dans des conditions de précipitations accrues dans les parcs agroforestiers avec le changement climatique.

Mots clés : changement climatique, humidité, sol, karité, néré

Introduction

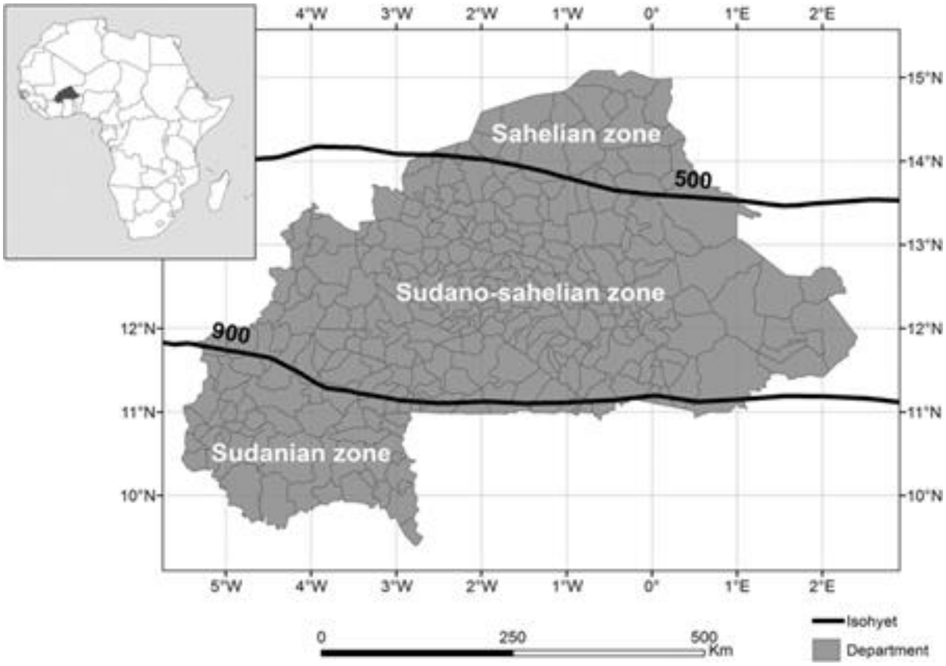
Agroforestry parklands systems with karité and néré trees are commonly used in the Burkina Faso agricultural production systems. That is because of goods and services provided by trees in these systems (BAYALA *et al.*, 2002 ; TEKLEHAIMANOT, 2004).

Crop performance is reduced under trees canopies in agroforestry parklands systems (BOFFA *et al.*, 2000 ; BAYALA *et al.*, 2002 ; TEKLEHAIMANOT, 2004 ; ZOMBOUBRE *et al.*, 2005 ; SANOU *et al.*, 2012). However, higher sorghum crop yield was reported under trees canopies in agroforestry parklands systems when rainfall increased (JONSSON *et al.*, 1999). LAI is a key parameter that determines crop productivity (MÜLLER *et al.*, 2005). LAI depends on soil water availability (KIRCHNER *et al.*, 2017). Sorghum LAI decreased under excessive soil water (KIRCHNER *et al.*, 2017) and under soil water deficit to adapt to droughts (NABINGER, 1997). Trees in agroforestry parklands systems improved soil humidity under canopies depending on species and canopies shape (ZOMBOUBRE *et al.*, 2005; SAIDOU *et al.*, 2012). It is not well established in the literature how sorghum LAI was affected by different rainfall conditions in agroforestry parklands. Climate change in the Sahel region is characterized by temperature increase and multiplication of extreme events as droughts and floods with droughts more recurrent in Burkina Faso (TRAORE *et al.*, 2013). Crop productivity in agroforestry parklands is then vulnerable to climate change due to the agricultural production systems dependency on rainfall in Burkina Faso (BOANSI *et al.*, 2019; LAUDIEN *et al.*, 2022). This research investigated the effect of an increasing rainfall gradient on sorghum LAI at juvenile stage for recommendations to maintain and/or improve sorghum productivity under climate change in agroforestry parklands systems.

1. Material and methods

1.1. Site description

Field experiments were conducted in Burkina Faso at 3 different sites along an increasing rainfall gradient: Tougouri located at 13° 18' 59'' latitude North and -3° 12' 1'' longitude West in the Sahelian zone (northern part); Nobere located at 11° 33' 29'' latitude North and -1° 12' 16'' longitude West in the Sudano-Sahelian savanna (central part) and Sokouraba located at 10° 51' 00'' latitude North and -5° 11' 00'' longitude West in the Sudanian savanna (southern part).



Map 1: Representation of the three climatic zones in Burkina Faso (Source: FLORENCE *et al.*, 2019)

The measurements of the soils characteristics during the experiments at the three sites showed that they are generally poor and have low Nitrogen (N), Organic Matter (MO) and Phosphorus (P) contents. In addition, they are weakly acidic with low Exchange Cationic Capacity (CEC) (Table I).

Table I: Soil characteristics in the sites.

Parameters	Tougouri	Nobere	Sokouraba
% Clay	42,6	33,8	56,1
% Silt	25	25,6	23,3
% Sand	32,4	40,6	20,6
CEC (meq/100 g)	10,13	5,81	9,34
Organic matter (%)	0,43	0,39	1,05
N content (%)	0,03	0,02	0,07
P content (P-Bray) (ppm)	2,2	9,56	5,38
pH	5,92	6,43	5,71

Average rainfall and temperature (year 1980-2013) were 557 mm and 26.6 °C in Tougouri respectively, 859 mm and 25.7 °C in Nobere, and 1061 mm and 25.1 °C in Sokouraba (DGM, 2013). The average rainfall totaled 620, 775 and 927 mm, respectively in Tougouri, Nobere and Sokouraba during the two years (2011 and 2012) of measurements.

1.2. Experimental design

The studied parkland systems consisted of an association of Sorghum (Sariasso 14) with two native tree species: néré and karité trees. Sorghum was cultivated in concentric zones from the trunk of each tree species. The area around each of the sampled trees was split into three concentric tree influence zones and a control plot which were:

- Zone A - from tree trunk to half of the crown radius of the tree;
- Zone B - from half of the crown radius of the tree up to the edge of the crown;
- Zone C - from the edge of the tree crown up to 3 m away; and
- Zone H - a control plot for crop in monoculture which was an area of 4 x 4 m situated at least 40 m away from the edge of the crown and unshaded by any of the surrounding trees at any time of the day throughout the cropping season.

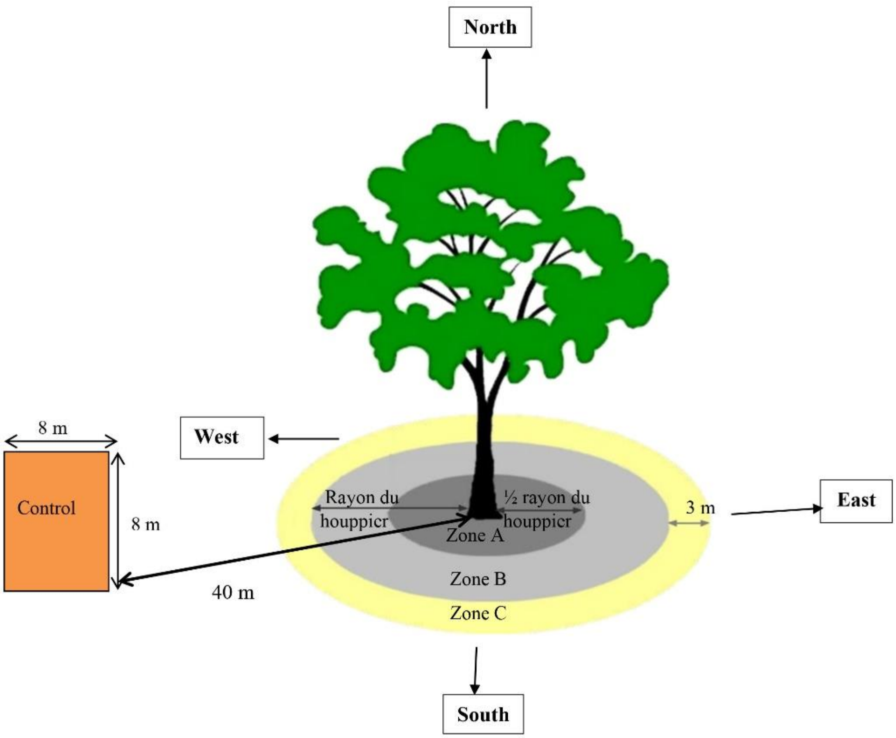


Figure 1: Experimental design indicating the different interactions zones A, B, C and Control

This design was replicated four times for each tree species at each site to give a total of thirty-two (= 4 reps x (2 species x 4 zones)) tree-by-zone sorghum LAI measurements in Sokouraba, Nobere and Tougouri. The sorghum was planted at the same dates in July 2011 and 2012 at all the sites and we did not provide fertilizers to the sorghum crop to be able to appreciate the contribution of the trees in improving the soil fertility. Also, the weeding occurs at the same dates in the different sites.

1.3. Data collection

Sorghum LAI was measured using the planimetric method with the ImageJ (NIH, USA, Freeware, Version 1.34s) software. Two sorghum plants were randomnly selected in each zone associated to each tree specie 30 days after sowing in 2011 and 2012 and all the leaves were collected and scanned. The total area of the leaves for each plant was generated with the ImageJ software and the mean area for the two plants for each zone was calculated. The sorghum LAI for each zone during each year of measurement was calculated by dividing the mean area (m^2) with a ground area of 1 m^2.

1.4. Statistical Analysis

The effect of sites, zones and species and their interaction on sorghum LAI were tested using the general model of ANOVA. The analyses have been done using the software XLSTAT 2022. When the differences among the means were significant with ANOVA, they were separated by the test of Student-Newman Keuils at 5%.

2. Results

ANOVA test results did not show a significant difference in sorghum LAI between years for the data measured at each site. Then, the two years mean of sorghum LAI for each zone at each site was calculated and used for the statistical analysis. There is no significant difference of sorghum LAI among zones and between trees species (Table II). Likewise, there is no significant interaction between sites and zones, between trees species and zones (Table II).

ANOVA test results revealed a significant difference in sorghum LAI between sites (Table II). Sorghum LAI was significantly higher at Tougouri site (Figure 1). ANOVA test results showed a significant interaction between sites and trees species in sorghum LAI (Table II). The sorghum LAI was higher in association with karité trees at Sokouraba site while it was higher in association with néré trees at Tougouri site (Figure 1). The lower sorghum LAI in association with karité trees as well as in association with néré trees was observed at Sokouraba site (Figure 1).

Table II: Results of ANOVA of the effect of sites, zones, species and their interaction on sorghum LAI in agroforestry parklands systems in Burkina Faso (West Africa)

Sorghum LAI	DDL	Sum of squares	Mean of squares	F	Pr > F
Sites	2	0,294	0,147	5,051	**0,008**
Zones	4	0,198	0,049	1,607	0,179
Species	2	0,034	0,017	0,534	0,588
Sites*Species	5	0,368	0,074	2,515	**0,035**
Sites*Zones	12	0,529	0,044	1,481	0,147
Species*Zones	12	0,398	0,033	1,058	0,406

Significant = P < 0.05 very significant = P < 0.01 highly significant = P < 0.001

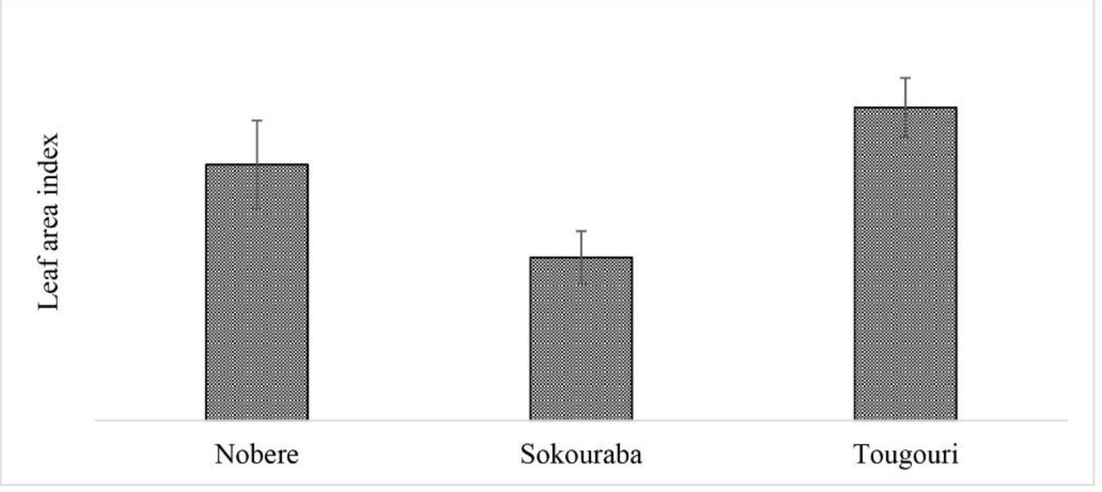


Figure 1: Sorghum LAI at 3 sites in Burkina Faso (West Africa)

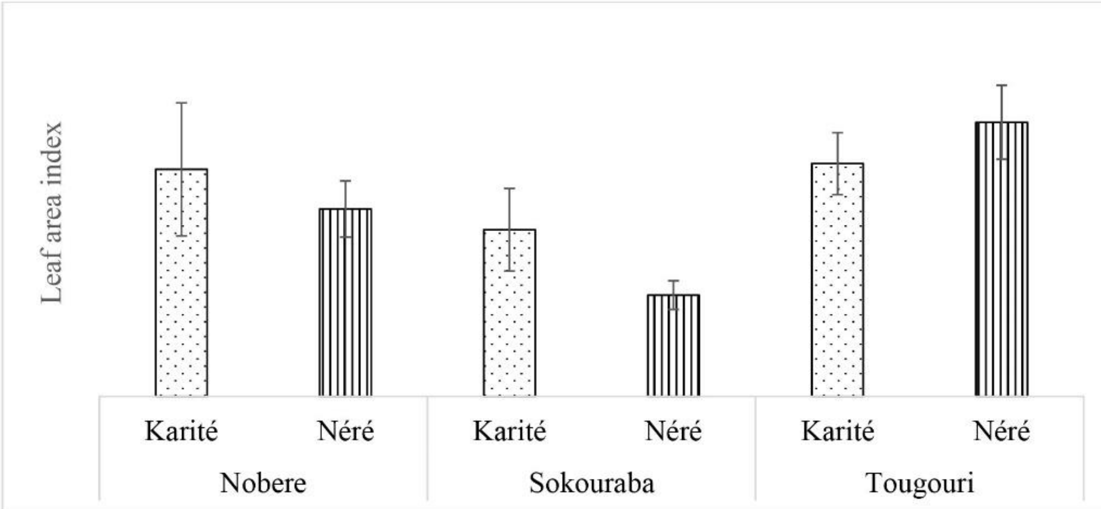


Figure 2: Sorghum LAI in association with karité and néré trees at 3 sites in Burkina Faso (West Africa)

3. Discussion

Sorghum LAI in the studied agroforestry parklands systems did not reveal significant difference between the zones under trees canopies and the control zones outside trees canopies. Also, there were not a significant difference of sorghum LAI between zones at each study site and for each zone between the sites. These results corroborate SANOU *et al.*, (2012) who showed that there was not a significant difference of millet LAI between the zones under trees canopies compared to the zones outside trees canopies. Despite of this no significant difference of sorghum LAI between zones under canopies compared to the zones outside canopies, the yields of cereal crops including sorghum are in general reduced under trees canopies compared to the zones outside trees canopies in agroforestry parklands (BAZIÉ *et al.*, 2012). The LAI being a parameter that defines crop productivity (MULLER *et al.*, 2005), then the reduced yields of sorghum observed under tree canopies are probably due to a reduction in the light quantity and quality necessary for crops photosynthesis under tree canopies (BAYALA *et al.*, 2008; BAZIÉ *et al.*, 2012). Indeed, several authors reported a reduction of light quality and quantity received under tree canopies (BOFFA *et al.*, 2000; BAYALA *et al.*, 2002). In agroforestry parklands, it could be concluded that light would not influence sorghum LAI and that sorghum performance depends on the light intercepted for photosynthesis. Then, it could be suggested tree pruning in agroforestry parklands which allows improving light quantity and quality received under trees canopies enhancing crop photosynthesis and increasing crop yields because crops will benefit from ecosystem services provided by the trees (BAYALA *et al.*, 2014). For each associated zone, sorghum LAI was not significantly different between karité and néré trees. Also, the sorghum LAI was not significantly different between zones in association with each tree species. However, several authors reported sorghum grain yield reduction under néré trees than karité trees (BAYALA *et al.*, 2002; BAZIÉ *et al.*, 2012; SANOU *et al.*, 2012; COULIBALY *et al.*, 2014). Then, this difference of sorghum grain yield performance under néré trees compared to karité trees could be associated to a different allocation of assimilate produced through photosynthesis. The assimilate allocation during the growing season was reported as a key factor in sorghum yield establishment and is under the influence of environmental factors (COULIBALY *et al.*, 2014). Several authors reported different environmental conditions under karité and néré trees canopies in agroforestry parklands. Indeed, it has been reported different soil fertility improvement under karité and néré trees canopies (SANOU, 2010; COULIBALY, 2014) and different light quantity and quality received under karité and néré trees canopies (BAYALA *et al.*, 2002) in agroforestry parklands. Also, it has been reported different soil humidities under canopy of the same tree species depending on the shape of the canopy in agroforestry parklands (ZOMBOUDRE *et al.*, 2005). The results of ANOVA revealed a significant difference of sorghum LAI according to the sites. The sorghum LAI was significantly higher at the site of Tougouri. This result shows that sorghum LAI is under the influence of rainfall and corroborates KIRCHNER *et al.*, (2017) who showed that LAI variation of different sorghum species for fodder production was intrinsically linked to water availability. The results of our research revealed that higher sorghum LAI was obtained at the site with the lowest rainfall. These results contradict NABINGER (1997), who reported that the plant first strategy for adapting to drought conditions is to reduce LAI. This higher sorghum LAI obtained at Tougouri site with the lowest rainfall could be explained by a good starting vigour of sorghum at this site probably due to a good root development as a mechanism for adaptation to the water deficit. WINKEL et DO (1992) reported that a good plant starting vigour, due to a good root system development during the installation phase of the plant allow to maintain a good subsequent growth of the aerial part of the plant in case of water deficit. This result corroborates COULIBALY *et al.*, (2014) who reported higher sorghum harvest indexes in agroforestry parklands with karité and néré trees at the site with the lowest rainfall level in a similar study. This good development of sorghum LAI in agroforestry parklands observed at the site with the lowest rainfall level could ensure production. Analyses showed a significant interaction between sites and trees species on sorghum LAI. The sorghum LAI was higher in association with karité trees at the sites of Nobere and Sokouraba while it was higher in association with néré trees at Tougouri site. This could be explained by different environmental conditions obtained under the canopies of the two tree species because of the different rainfall amount obtained at the different sites. In fact, the highest sorghum LAI obtained in association with karité trees at the site with high precipitation could be explained by higher soil humidity obtained with karité trees than néré trees. The karité trees with the open structure of its canopy (BAZIÉ *et al.*, 2012) allows more precipitation reaches the soil under the trees leading to high soil humidity allowing sorghum to take advantage of the soil fertility under trees through improved foliar and aerial growth and consequently improved LAI. However, at the site of Tougouri with the lowest rainfall, the higher LAI was obtained under néré trees. This may be due to higher soil humidity with this specie at this site with low rainfall because of the reduced evaporation due to the dense and compact canopy of this specie (SANOU, 2010). BAYALA *et al.,* (2004) reported an increase in evaporation under karité trees canopies because of the open architecture of its canopy which allows more radiation to pass through. Then, the low sorghum LAI in association with karité trees observed at this site with low rainfall could be due to a water deficit and this reduction of sorghum LAI in association with karité trees at this site could be considered as a strategy of adaptation to the water deficit as it has been reported by NABINGER (1997). The lower sorghum LAI in association with karité trees as well as in association with néré trees was observed at Sokouraba site with the highest rainfall probably due to a water deficit created under both trees species due to a significant interception of rainfall because of a significant development of the trees canopies with the importance of precipitation. This important interception of precipitation by the trees canopy could have leaded to a water deficit under the canopies resulting in a reduction of the sorghum LAI as an adaptation strategy to droughts. COULIBALY *et al.,* (2014) reported an increase in tree canopy through a significant development of the trees LAI when tree growth is dynamic under increased precipitation.

Conclusion

LAI, a key parameter for sorghum productivity, was higher in agroforestry parklands under low rainfall conditions, probably due to a good plant starting vigour. The rainfall level was a key factor influencing sorghum LAI in agroforestry parklands according to the associated tree species because of different environmental conditions created under trees canopies. Promoting agroforestry with karite and nere in association with sorghum under reduced rainfall could contribute to maintain and/or improve sorghum productivity with climate change. Trees pruning increasing soil humidity, light quality and quantity under trees could improve sorghum productivity in agroforestry parklands under increased rainfall with climate change.

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