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Original Article

Evaluating Sorghum bicolor (L.) Moench (Sorghum) Vigour at Juvenile Stage in Agroforestry Parklands Systems According to a Climatic Gradient in Burkina Faso (West Africa)

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Droughts, Height, Humidity, Moisture, Wet.

ABSTRACT

Agroforestry parklands, due to their dependency on rainfall remain vulnerable to climate change. This research assessed a rainfall gradient effect on sorghum height to evaluate its vigour for formulating recommendations to maintain and/or improve crop productivity in agroforestry parklands under climate change. Studied agroforestry parklands consisted of an association of Sorghum with *Vittelaria paradoxa C. F Gaertn* (Karite) and *Parkia biglobosa (Jacq.) Benth* (Nere) at sites located in Burkina Faso's three climatic zones. Sorghum height was higher at lower rainfall. Higher sorghum height was associated with Karite at all the studied sites. It was higher at low rainfall for both tree species. Sorghum height increased from the zone under canopies to outside canopies associated with both tree species. For all zones, sorghum height was higher in association with Karite. The lowest sorghum height was in the first zone under canopies at all the studied sites, while for all zones, sorghum height was higher at low rainfall. The sorghum growth rate was higher in association with Karite, lower in the first zone under canopies and higher at low rainfall. The sorghum growth rate increased with the increase in the number of days after sowing at all the sites, in all the zones and under both tree species. The risk of sorghum production loss could be important in agroforestry parklands under high rainfall due to reduced vigour, and this risk could be reduced under low rainfall. Promoting Karite in agroforestry parklands could enhance sorghum vigour and reduce the risk of sorghum production loss under climate change in the Sahel. It could be recommended farmers avoid cultivating Sorghum in the zone nearest to the tree trunk in agroforestry parklands.

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INTRODUCTION

Selected agroforestry parklands systems play an important role in agricultural production in Burkina Faso (Bayala *et al.*, 2002) with the dominant tree species which are *Vitellaria paradoxa C. F Gaertn* (Karite), *Parkia biglobosa (Jacq.) Benth* (Nere) and *Adansonia digitata L.* (Baobab) (Nikiéma, 2005; Kindt et *al.*, 2008) and major cereal crops in an association which are *Sorghum bicolor* (L.) Moench (sorghum) (Boffa *et al*., 2000). This interest in agroforestry is due to the socioeconomic and environmental advantages that these systems provide to communities (Bayala *et al.,* 2002; Teklehaimanot, 2004). Many studies addressed the contribution of agroforestry practices in reducing the negative impacts of climate change on smallholders, but little research has been carried out to study the impact of that climate change on agroforestry systems (Watts *et al*., 2022). In the context of climate change, the Sahelian region in the tropics including Burkina Faso is expected to have warmer and drier environments, increasingly variable rainfall regimes, and more frequent climate extremes (Serdeczny *et al.*, 2017; Siyum, 2020). These manifestations of climate change are likely to have negative effects on crop productivity in agroforestry parklands systems (Watts *et al.*, 2022). The Sorghum is sometimes characterised by a low-level germinative vigour during the emergence resulting in a low vigour at the juvenile stage (Coulibaly, 2005), while a good vigour at the juvenile stage is an advantage for the future development of the crop in droughts conditions due to a good root anchorage at the beginning of the cycle allowing the crop better access to soil resources (Winkel & Do, 1992). The aim of this research was to investigate the effect of a climatic gradient on sorghum height to assess its vigour in agroforestry parklands with Karite and Nere as the dominating trees for formulating farmers' recommendations of parklands management to maintain and/or improve sorghum production in agroforestry parklands under climate change in Burkina Faso.

MATERIALS AND METHODS

Site Description

Field experiments were conducted at three 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 Sudano-Guinean savanna (southern part). The soils of the three sites are generally poor and have low Nitrogen (N), Organic Matters (MO) and Phosphorus (P) contents. In addition, they are weakly acidic with low Cationic Exchange Capacity (CEC) (*Table 1*). Average rainfall and temperature (the year 1980-2013) were 557 mm and 26.6 ºC in Tougouri, respectively, 859 mm and 25.7 ºC in Nobere, and 1061 mm and 25.1 ºC in Sokouraba (DGM, 2013). The average rainfall totalled 620, 775 and 927 mm, respectively, in Tougouri, Nobere and Sokouraba during the three years (2010, 2011 and 2012) of measurements.

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Table 1: Soil characteristics in the three study sites

Parameter	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

The values are the average of top 50 cm soil layer.

Experimental design

The studied parkland systems consisted of an association of Sorghum with two native tree species: Nere and Karite. 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 was:

- 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.

This design was replicated eight times for each tree species at each site to give a total of sixty-four (= 8 reps x (2 species x 4 zones)) in Sokouraba, Nobere and Tougouri.

Data Collection

The parameter measured to assess the sorghum vigour were the growth rate and height. These parameters were measured every 7 days from the 34 days after sowing till 55 days after sowing in each of the concentric zones and the control plot associated with each tree species. The parameters were measured during three cropping seasons (years 2010, 2011 and 2012). The measurements have been done at the reproductive stage of sorghum development because it is at this stage that the maximum biomass is developed, as reported by Winkel et Do (1992) for the millet. For the measurements of these parameters, in each concentric zone and in the control plots, four sorghum plants were randomly selected, and the height was measured throughout each cropping season for each sorghum plant using a ruler. The Sorghum mean height in each of the concentric zones and in the control plot associated with the tree species was used for the statistical analysis. The sowing density of the Sorghum was the same in each zone and at each site.

Statistical Analysis

The difference between years was not statistically significant for the sorghum crop height, then the mean of the two years was used for the statistical analysis. The effect of an increase of precipitation along a climatic gradient (site), the effect of tree species and their interaction on sorghum crop height were tested using the general model of ANOVA. The effects of zones and their interaction with tree species and the increase of precipitation along a climatic gradient (site) were tested using the general model of ANOVA. The effect of days after sowing and its interaction with tree species, zones, and the increase of the precipitation along a climatic gradient (sites) 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%.

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RESULTS

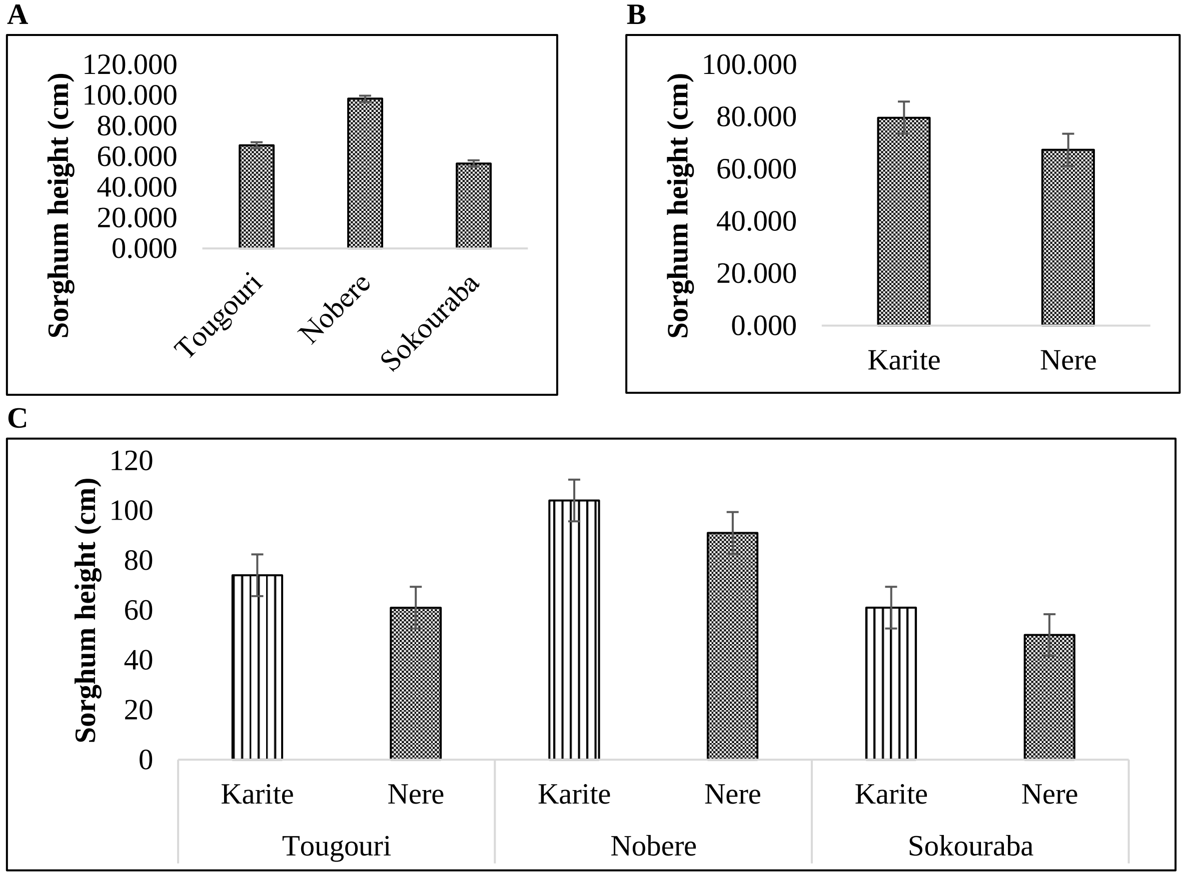
The results of ANOVA revealed a highly significant difference in sorghum height between sites (*Table 2*). The sorghum height was significantly higher at Tougouri and Nobere (*Figure 1A)*. The results of ANOVA showed a highly significant difference in sorghum height between tree species (*Table 2*). The sorghum height was significantly higher under Karite (*Figure 1B*). According to the results of ANOVA, the effect of interaction between sites and tree species on sorghum height was highly significant (*Table 2*). At the three sites, the sorghum height was significantly higher under Karite (*Figure 1C*). Under the Karite, the sorghum height was significantly higher at Tougouri and Nobere (*Figure 1C*). The same trend was observed regarding the sorghum height under Nere (*Figure 1C*).

Table 2: Results of ANOVA of the effect of sites, tree species and their interaction on sorghum height

Sorghum height	DDL	Sum of squares	Mean of squares	F	Pr > F
Sites	2	242270,668	121135,334	111,402	<0,0001
Species	1	29134,994	29134,994	21,357	<0,0001
Site*Species	5	271473,836	54294,767	51,546	<0,0001

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

Figure 1: (A) Sorghum crop height according to the sites, (B) Sorghum crop height according to the trees species and (C) Sorghum crop height according to the interaction between trees species and sites



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The results of ANOVA showed a highly significant difference in sorghum height between zones (*Table 3*). The sorghum height was significantly higher in the control zone and decreased from the control zone to zone A (*Figure 2A*). According to the results of ANOVA, the effect of interaction between zone and tree species on sorghum height was highly significant (*Table 3*). Under both Karite and Nere, sorghum height was significantly higher in the control zone and decreased from this control zone to zone A (*Figure 2B*). For all the zones, the sorghum height was significantly higher under Karite than Nere (*Figure 2B*). According to the results of ANOVA, the effect of the interaction between zones and sites on sorghum height was highly significant (*Table 3*). At Tougouri, the sorghum height was significantly higher in the control zone and lower in zone A (*Figure 2C*). At Nobere, it was significantly higher in Zone B and Zone C and lower in Zone A. At Sokouraba, it was significantly higher in the control zone and zone C and significantly lower in zone B and zone A (*Figure 2C*). For zone A, the sorghum height was significantly lower at Sokouraba compared to the other two sites (*Figure 2C*). The same trend was observed for the other zones (*Figure 2C*).

Table 3: Results of ANOVA of the effect of zones and its interaction with tree species and sites on sorghum height

Sorghum height	DDL	Sum of squares	Mean of squares	F	Pr > F
Zones	3	70431,073	23477,024	17,871	<0,0001
Zones*Species	7	99828,71	14261,244	11,125	<0,0001
Zones*Sites	11	329322,322	29938,393	30,389	<0,0001

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

The results of ANOVA revealed a highly significant difference in sorghum height between the DAS (*Table 4*). The sorghum height was higher at the DAS-55 (*Figure 3A*). According to the results of ANOVA, the effect of the interaction between DAS and tree species on sorghum height was highly significant (*Table 4*). Under both Karite and Nere, the sorghum height was higher for DAS-55 (*Figure 3B*). For all the DAS, the sorghum height was significantly higher under Karite (*Figure 3B*). According to the results of ANOVA, the effect of the interaction between DAS and zones on sorghum height was highly significant (*Table 4*). For all the zones, the sorghum height increased with the increase of DAS (*Figure 3C*). For all the DAS, the sorghum height was significantly lower in zone A (*Figure 3C).* According to the results of ANOVA, the effect of the interaction between DAS and sites on sorghum height was highly significant (*Table 4*). At all three sites, the sorghum height increased with the increase of DAS and was significantly higher for DAS-55 (*Figure 3D*). The sorghum height for all the DAS were significantly lower at Sokouraba compared to the other two sites (*Figure 3D*).

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Figure 2: (A) Sorghum crop height according to the zones, (B) Sorghum crop height according to the interaction between zones and trees species and (C) Sorghum crop height according to the interaction between zones and sites

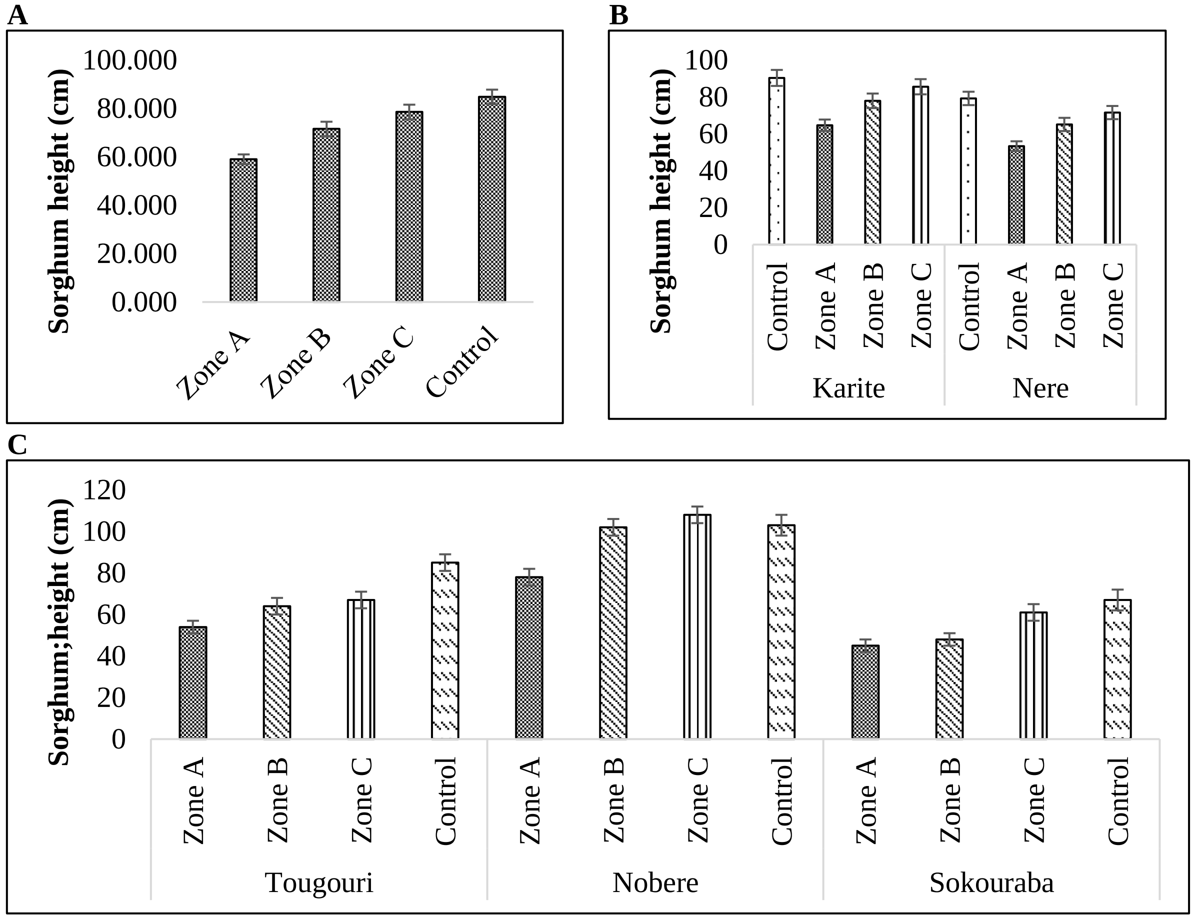
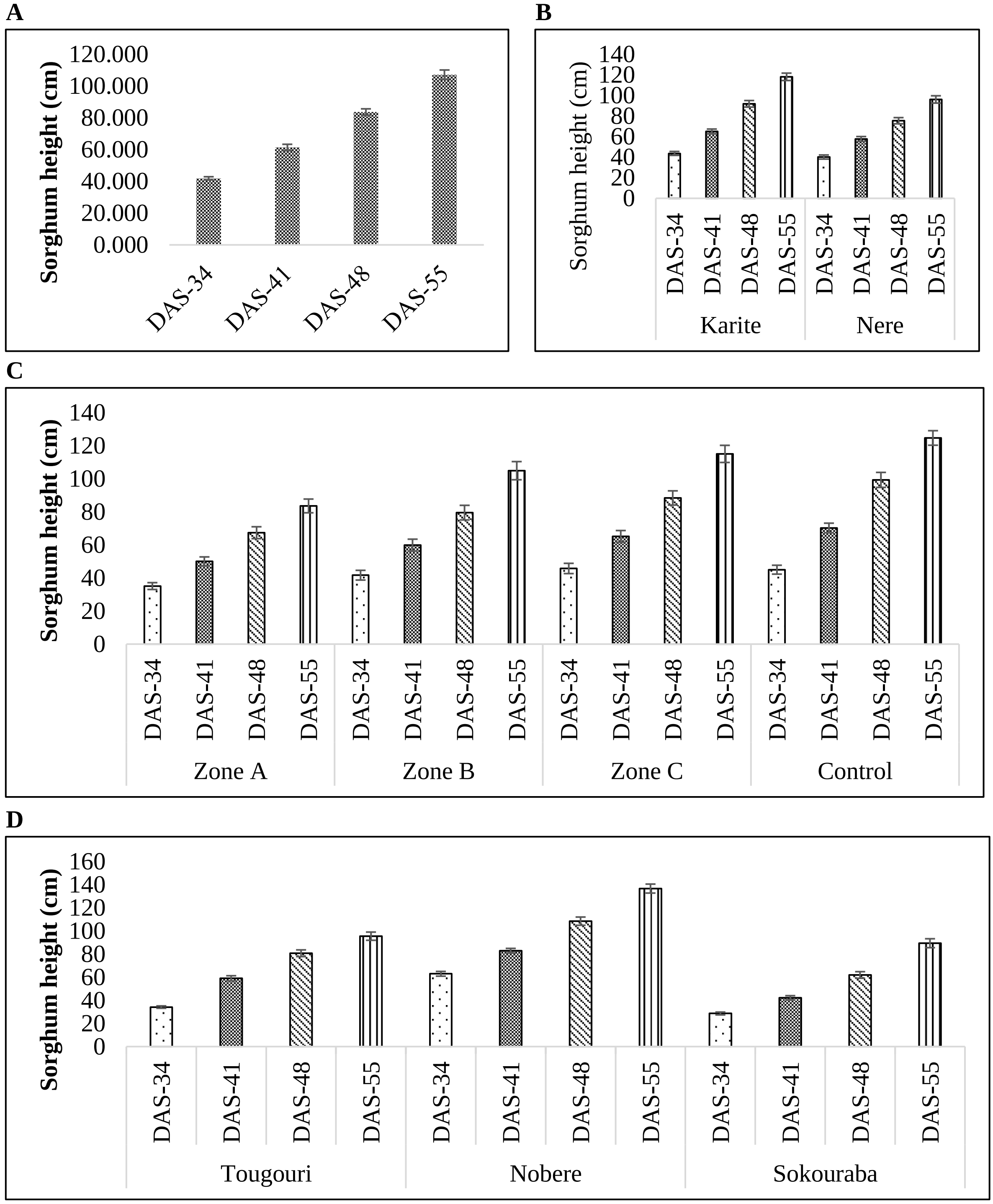


Table 4: Results of ANOVA of the effect of Days After Sowing (DAS) and its interaction with tree species, zones, and sites on sorghum height

Sorghum height	DDL	Sum of squares	Mean of squares	F	Pr > F
DAS	3	456820,350	152273,450	188,465	<0,0001
DAS*Species	7	496116,746	70873,821	93,192	<0,0001
DAS*Zones	15	541898,402	36126,560	51,046	<0,0001
DAS*Sites	11	708115,241	64374,113	132,973	<0,0001

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

Figure 3: (A) Sorghum crop height according to the Days After Sowing (DAS), (B) Sorghum crop height according to the interactions between Days After Sowing (DAS) and trees species, (C) Sorghum crop height according to the interactions between Days After Sowing (DAS) and zones and (D) Sorghum crop height according to the interactions between Days After Sowing (DAS) and sites



DISCUSSION

The lowest sorghum height was observed at Sokouraba, which is the site with the highest level of precipitations. Also, the soils at Sokouraba are fertile due to the climatic conditions and good land management practices (Martin *et al.*, 2010; Mathayo *et al.*, 2016). But the sorghum height was

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significantly higher at the sites with low rainfall, which are Tougouri and Nobere. For all the zones, the sorghum height was higher at Tougouri and Nobere. Compared to Sokouraba, the soils of these sites are less fertile due to the high population, high population density, overgrazing, and low precipitation (Coulibaly *et al.,* 2020). The limited precipitations at these sites could have led to droughts at these sites during the crop-growing season, and the higher sorghum growth is an indicator of these droughts. The higher sorghum height observed at these sites with limited precipitations could be due to good root growth of Sorghum during the installation phase leading to a good starting vigour allowing Sorghum to resist droughts, as reported by Winkel et Do (1992).

In fact, this rapid growth reduces losses in soil water by evaporation but increases transpiration and biomass accumulation, which could guarantee production if this rapid growth has been used to build carbon reserves that can be remobilised to grains later (Winkel & Do, 1992). Then, applying water and soil conservation techniques could enhance trees' contribution to soil fertility and sorghum productivity in agroforestry parklands systems under drought conditions. The sorghum yields were improved through the use of water and soil conservation techniques (Bayen *et al.*, 2011). The sorghum height was influenced by tree species in agroforestry parklands with higher sorghum height under Karite. This result is in line with the results of many studies which have reported that crop yields are often better under Karite than Nere due to the improved availability of nutrients under the canopy of Karite (Kessler, 1992; Coulibaly *et al*., 2014). This better performance of crops under Karite may be explained by the open structure of the Karite canopy (Bazié *et al*., 2012), which would allow more light and more water to reach the soils under the canopy for crop growth.

In fact, Zomboudre *et al.* (2005) reported higher humidities under the open-structure canopy of Karite. The Karite could be the tree species to promote in agroforestry parklands for improving sorghum productivity under climate change. This recommendation is in line with our result, which showed that the sorghum height was higher under the Karite than Nere at all three study sites and with the results of the research work of Coulibaly *et al*. (2020). For each of the two tree species, the sorghum height was higher at the sites with low precipitations. On the one hand, this could be explained by a low development of the tree canopies at these sites due to the low precipitations received, allowing more light to reach plants enhancing photosynthesis and leading to the important sorghum growth. Coulibaly *et al.* (2014) reported better sorghum growth in agroforestry parklands with dynamic growth trees with low rainfall as a result of a low leaf area index of trees.

On the other hand, the higher sorghum height observed for each of the two tree species at the sites with low precipitations could be explained as a mechanism to resist droughts under tree canopies, probably because of low water reaching the soil due to the low precipitations received. Also, the increase in light under the tree canopies as a result of the low development of tree leaf area index due to the low precipitations received could increase evapotranspiration and lead to a water deficit under the trees. Bayala *et al.* (2008) reported significant evapotranspiration under Karite, which resulted in significant root development of Sorghum in the topsoil layers to cope with this water deficit, and this resulted in improved sorghum performance under the Karite. The sorghum height decreased from the control plot to zone A near the trunk of the trees, and this trend was observed under Karite as well as under Nere. These findings corroborate those of Bazié *et al.* (2012), who reported reductions in crop performance under a tree canopy. This low performance of crops under tree canopies in spite of improved soil fertility under trees in agroforestry parklands (Bayala *et al.*, 2006, 2014; Pane, 2005) has been explained by light reduction under trees (Bayala *et al.*, 2008; Bazié *et al.*, 2012) and by belowground tree crop competition for access to soil nutrients resources (van Noordwijk & Cadish, 2002; Bayala *et al.*, 2004).

The higher height for all zones was observed under Karite, probably due to better root development during the installation phase (Winkel & Do, 1992), and this could be explained in addition to a mechanism to resist a water deficit under this tree species as a result in a reduction in competitions under Karite. Bayala *et al.* (2008) reported a reduction in competition under Karite due to better development of the crop roots at the surface of the soil. Sorghum height increased from zone A to the control zone at all the studies sites confirming that light would be one of the major factors limiting crop growth in agroforestry parklands (Bayala *et al.*, 2008; Bazié *et al.*, 2012). The growth rate to appreciate sorghum vigour at the juvenile stage through the measurement of the height in relation to the number of days after sowing (Brétaudeau *et al*., 1989) showed a good vigour in general at the juvenile stage of Sorghum due to an increase of sorghum height at all the number of days after sowing, in all the zones, at all the studied sites and both under Karite and Nere. This vigour at the juvenile stage allows plants to cope with later droughts (Winkel & Do 1992). Bationo *et al.* (1999) showed that early plant vigour, due to good phosphorus nutrition, provides the plant with a higher degree of soil cover, resulting in less water loss through evaporation at the soil level.

For all the number of days after sowing, the sorghum height was higher under Karite than Nere, reflecting a faster growth under Karite than Nere and then a good vigour at the juvenile stage under Karite than Nere. This result could therefore give a greater ability of Sorghum to resist droughts under Karite, as reported by Brétaudeau et al. (1989). Sorghum vigour was reduced in zone A because, for all the number of days after sowing, the lowest sorghum height was observed in this zone. This weak vigour in this zone could increase the risk of obtaining very low yields of Sorghum. Coulibaly (2014), Boffa *et al.* (2000), and Bayala *et al.* (2002) reported lower grain and biomass yields in the zones under canopies near the tree trunk. This low vigour observed in this zone A could be explained by increased competition for access to light in this zone (Sanou *et al.*, 2012). The lowest sorghum height for all the number of days after sowing was observed at Sokouraba, reflecting rapid sorghum growth and then good vigour at sites with low and moderate rainfall that can be considered as a mechanism to resist water stress (Winkel & Do 1992).

CONCLUSION

The risk of sorghum production loss could be important in agroforestry parklands under high rainfall due to reduced vigour, and this risk could be reduced under low rainfall. Promoting Karite in agroforestry parklands could enhance sorghum vigour and reduce the risk of sorghum production loss under climate change in the Sahel. It could be recommended farmers avoid cultivating Sorghum in the zone nearest to the tree trunk in agroforestry parklands.

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