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Optimal sowing periods and use of drought-resistant Sorghum varieties as an adaptation strategy to climate change in the Sudanian and Sahelian zones of Mali

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ABSTRACT

Description of the subject. A comparative trial of 3 varieties of sorghum sown at 3 different dates set up in Koulikoro (Sudanian zone) and San (Sahelian zone). The trial was conducted over two cropping seasons in 2018 and 2019.
Objective. The study was to determine the optimal sowing periods for good sorghum productivity in the two zones of Mali.
Methods. The experimental design was a split plot with three varieties (Fambè, Wassa, Jakumbè) as the primary factor and sowing date (secondary factor). The data collected were growth parameters (height velocity and diameter at the crown of the plants) and yield parameters (biomass and grain).
Results. The highest grain and biomass yields at the Koulikoro site were obtained with the Fambè variety (2.40 ± 0.02 t. ha^{-1}) and biomass of 6.40 ± 0.20 t. ha^{-1}. At the San site, the Wassa variety had the highest grain and biomass yields (2.44 ± 0.00 t. ha^{-1} and 9.22 ± 0.79 t. ha^{-1}). In the second year of testing, the variety Jakumbé also had the highest grain yields of 3.61 ± 0.14 t ha-^{1} and biomass of 12.00 ± 0.70 t ha^{-1} in Koulikoro. In San, the variety Fambè (3.03 ± 0.05 t. ha^{-1} and 12.50 ± 1.55 t. ha^{-1}). Overall, the first two planting dates in June resulted in higher yields in both zones. If rainfall starts on the right date, early July planting of the sorghum cultivar Fambè in the two study areas could be a good adaptation strategy to climate change.
Conclusion. This result could be proposed as an adaptation strategy to climate change for improving sorghum productivity and ensuring food security in the study area.

Keywords: sowing date, climate variability, climate resilience, water use efficiency, producer vulnerability.

RESUME

Périodes optimales de semis et utilisation de variétés de sorgho résistantes à la sécheresse comme stratégie d'adaptation au changement climatique dans les zones soudanienne et sahélienne du Mali
Description du sujet. Un essai comparatif de 3 variétés de sorgho semées à 3 différentes dates mises en place à Koulikoro (zone soudanienne) et à San (zone sahélienne). L'essai a été conduit pendant deux campagnes agricoles en 2018 et 2019.
Objectif. L'étude consiste à déterminer les périodes optimales de semis pour une bonne productivité du sorgho dans les deux zones du Mali.

Méthodes. Le dispositif expérimental était un split plot avec trois variétés (Fambè, Wassa, Jakumbè) comme facteur principal et la date de semis (facteur secondaire). Les données collectées étaient les paramètres de croissance (vitesse en hauteur et diamètre au collet des plants) et aux paramètres de rendements (biomasse et grains).

Résultats. Les rendements grains et biomasses les plus élevés sur le site de Koulikoro ont été obtenus avec la variété Fambè (2,40 ± 0,02 t. ha^{-1}) et biomasse de 6,40 ± 0,20 t. ha^{-1}. Au niveau du site de San avec la variété Wassa qui a présenté des rendements grains et biomasse les plus élevés soient 2,44 ± 0,00 t. ha^{-1} et 9,22 ± 0,79 t. ha^{-1}). Durant la deuxième année d'essai, la variété Jakumbé a présenté également les rendements grains les plus élevés de 3,61 ± 0,14 t ha^{-1} et biomasse de 12,00 ± 0,70 t. ha^{-1} à Koulikoro. Au niveau de San, la variété Fambè (3,03 ± 0,05 t. $ha-^{1}$ et 12,50 ± 1,55 t. $ha-^{1}$). En gros, les deux premières dates de semis du mois de juin ont induit des rendements meilleurs au niveau des deux zones. En cas de démarrage de pluie à bonne date, le semis en début du mois de juillet du cultivar de sorgho Fambè dans les deux zones d'étude pourrait constituer une bonne stratégie d'adaptation au changement climatique.

Conclusion. Ce résultat pourrait être proposé comme une stratégie d'adaptation au changement climatique pour améliorer la productivité du sorgho et assurer la sécurité alimentaire dans la zone d'étude.

Mots clés : Date de semis, variabilité climatique, résilience climatique, efficience de l'utilisation de l'eau, vulnérabilité des producteurs.

1. INTRODUCTION

Climate change is having a significant impact on agricultural production and the environment (Yan *et al.*, 2020), particularly in West Africa (Sultan and Gaetani, 2016). Climate variability are likely to affect the profitability of crop systems of great importance (such as sorghum) in maintaining food security for populations (Sultan and Gaetani, 2016). Indeed, these events related to climate variability have significant impacts on water resources and food security (Guo *et al.*, 2014). Climate variability is one of the most important factors influencing crop production from year to year in agricultural areas with the use of efficient technologies (Wei *et al.*, 2014).

In Africa south of the sahara in general and particularly in Mali, the agricultural sector is dependent on rainfall (Sissoko *et al.*, 2018). Production potential is determined very early on by the first rains and the optimal sowing dates of farmers (Soumaré *et al.*, 2008). This phenomenon results from the independence between the two events that are the beginning and end dates of the season (Traoré *et al.*, 2001). The droughts of the 1970s and 1980s caused a significant decrease in rainfall, but the consequences on the start and end dates of the season were smaller (Traoré *et al.*, 2001; Le Barbé *et al.*, 2002; Soumaré *et al.*, 2008). As a result, planting dates are subject to significant fluctuations due to the poor distribution of rainfall over time. This is why over the past 20 years, without a very pronounced drought, agricultural production has varied by a factor of two between the worst and best seasons (Sissoko *et al*., 2018). This interannual and inter-seasonal variability is one of the main factors of vulnerability for producers (Sissoko *et al*., 2018a; Teixeira *et al*., 2018).

All of this shows that agriculture in Mali is carried out under random climatic conditions with significant risks of drought, significantly affecting the yield of sorghum, which is a crop of high importance in maintaining the food security of populations (Traoré *et al*., 2021). Sorghum is one of the most consumed cereals in the communities' diet. However, sorghum yields remain low (less than 1 t. $ha-^{1}$) and this is due to abiotic constraints related to climatic variability (Kouressy *et al*., 2014; Sissoko *et al.,* 2018) and soil fertility status.

According to Marengo *et al.* (2011), climate change and its impacts on agriculture will be irreversible. The adoption of strategies to mitigate these impacts is crucial to ensure food and energy security in countries like Mali where agriculture is the main economic activity. Among these strategies, adjustments in agricultural practices are the most relevant. To this end, adaptation strategies related in particular to the use of resistant and short-cycle varieties or shifts in sowing dates (Rio *et al*., 2015) are often adopted by producers (Balogoun *et al*., 2013; Teixeira *et al*., 2018). For many authors, it is clear that the decline in rainfall has led to the adoption of short-cycle varieties by producers (Lacy *et al*., 2006). In Burkina Faso, for example, the cycle of sorghum varieties used by farmers has even decreased from 120-150 days to 70-90 days over the past 15 years (Ingram *et al.*, 2002, Kouressy *et al.*, 2008).

Risks due to climatic variations between seasons are often managed by shifting planting dates, fertilization practices, varietal choice or combining crop varieties in the rotation (Porter *et al*., 2014) which are short-term solutions whose sustainability over time is important to know. However, the study on the determination of optimal planting dates for drought-tolerant sorghum varieties in the more and less arid areas of Mali deserves to be updated in light of the evolving impact of climate change and predictions.

The objective of this study was to determine the optimal planting periods and climate-tolerant sorghum varieties for good productivity in the Sudanian and Sahelian zones of Mali as an adaptation strategy.

2. MATERIAL AND METHODS

2.1. Study area

The trials were conducted in the districts of Koulikoro and San in Mali (Figure 1). The district of Koulikoro is located in the Sudanian zone 60 km from Bamako (political capital of Mali). It is located between longitude −8.9˚32' West and 12˚56' North latitude at an altitude of 332 m above sea level on the 900 mm isohyet (Traoré *et al*., 2021). The area is characterized by a Sudano-Sahelian climate with an average annual rainfall varying between 700 and 900 mm (Traoré *et al*., 2021). The growing season generally starts in early and June lasting in October. The district is an agropastoral zone, millet, sorghum, maize, rice, fonio and cowpea are the main food crops. Market gardening is also practiced. Cotton is the main cash crop. The vegetation of the zone is characterized by a savannah with trees and shrubs.

The herbaceous carpet is dominated by annual grasses with Combretum lecardii, *Combretum glutinosum, Guiera senegalensis, Prosopis africana, Sclerocarya birrea, Spondias monbin*, as dominant trees (Traoré *et al*., 2021). The main soil types encountered in the area are tropical ruby ferruginous soils. The district of San, however, is located in the Segou region in the Sahelian zone of Mali at West longitude −4˚9' and 13˚3' North latitude, altitude of 287 m above sea level. The average annual rainfall varies between 500 mm and 800 mm. The rainy season also start in mid-June and last in October. There is also a delay in the rainy season with an average of three months of rainfall (Traoré *et al*., 2021). Millet and sorghum are the main food crops. The vegetation is dominated by Faidherbia albida, Adansonia digitata, Vitelaria Paradoxa, Balanites aegyptiaca , Ceiba pentandra, Khaya senegalensis, Parkia biglobosa etc. The soils are clayey, sandy, lateritic and lateritic and gravelly.

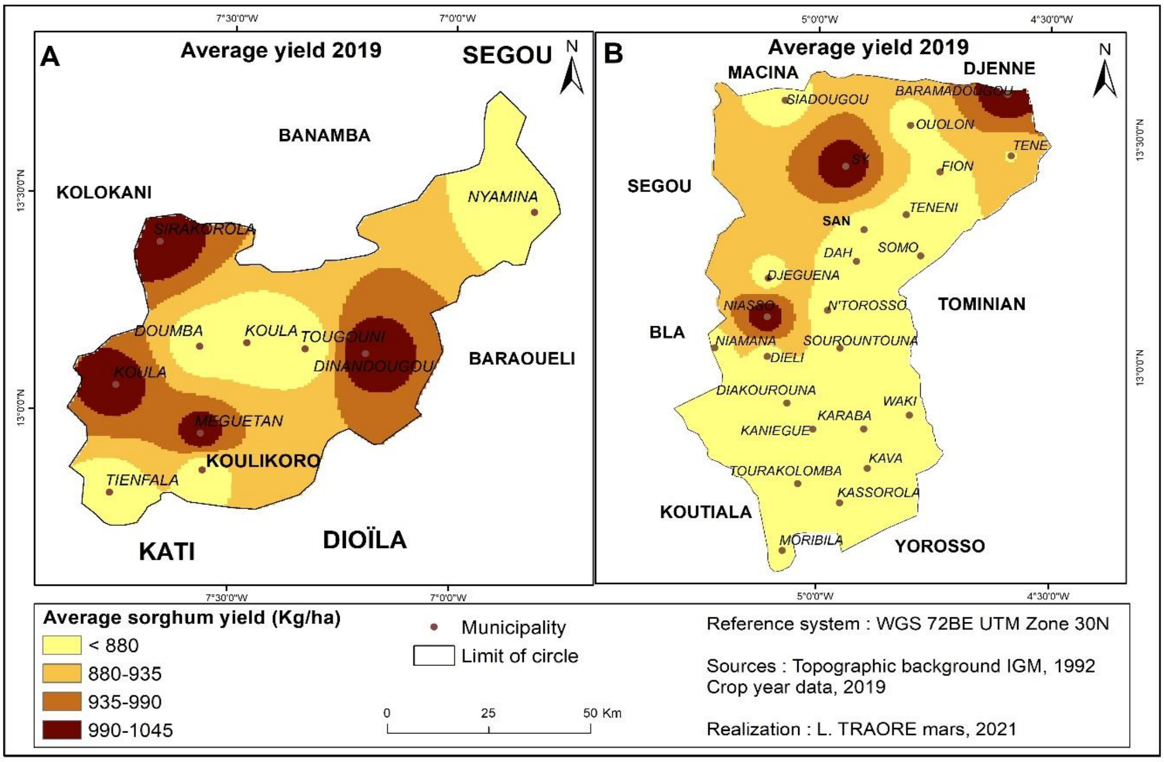


Figure 1. Presentation of the trial sites

2.2. Plant material

The plant material used consisted of three sorghum varieties: Fambè obtained from the Institut Polytechnic Rural de Formation et de Applied Research (IPR/IFRA) of Katibougou, and the Wassa and Jakumbé varieties obtained from the Institute Economic Rural (IER). The production cycle of these three varieties was 100 to 110 days with potential yields hovering around 2 t. ha^{-1} (Touré & Diallo, 2015). Table 16 presents the characteristics of each of these varieties.

Table 1. Characteristics of the three sorghum varieties tested in the trial

Varieties	Type	Cycle (days)	Grain color	Average yields (t. ha^{-1})
Fambè	Miksor 86-30-41	110	Translucent	2.5 – 3
Wassa	97-SB-F-5DT-63	105	White	2
Jakumbè	CSM 63-E	100	White	2

Experimental design and conduct of trials

The experimental design used was a split plot with four replications (Figure 2). The primary factor was the three sorghum varieties and the secondary factor was the variation in sowing dates and three sowing periods were observed according to the data in Table 02. The trials were conducted during two agricultural seasons (2018 and 2019) and the planting periods were observed at both sites. The sowing dates were identified taking into account the recommended sowing dates, i.e. between July 10 and 15. Thus, it was retained in addition to this recommended period, 10 days before and 10 days after taking into account the climatic variability observed nowadays where it does not rain over several days (Table 2).

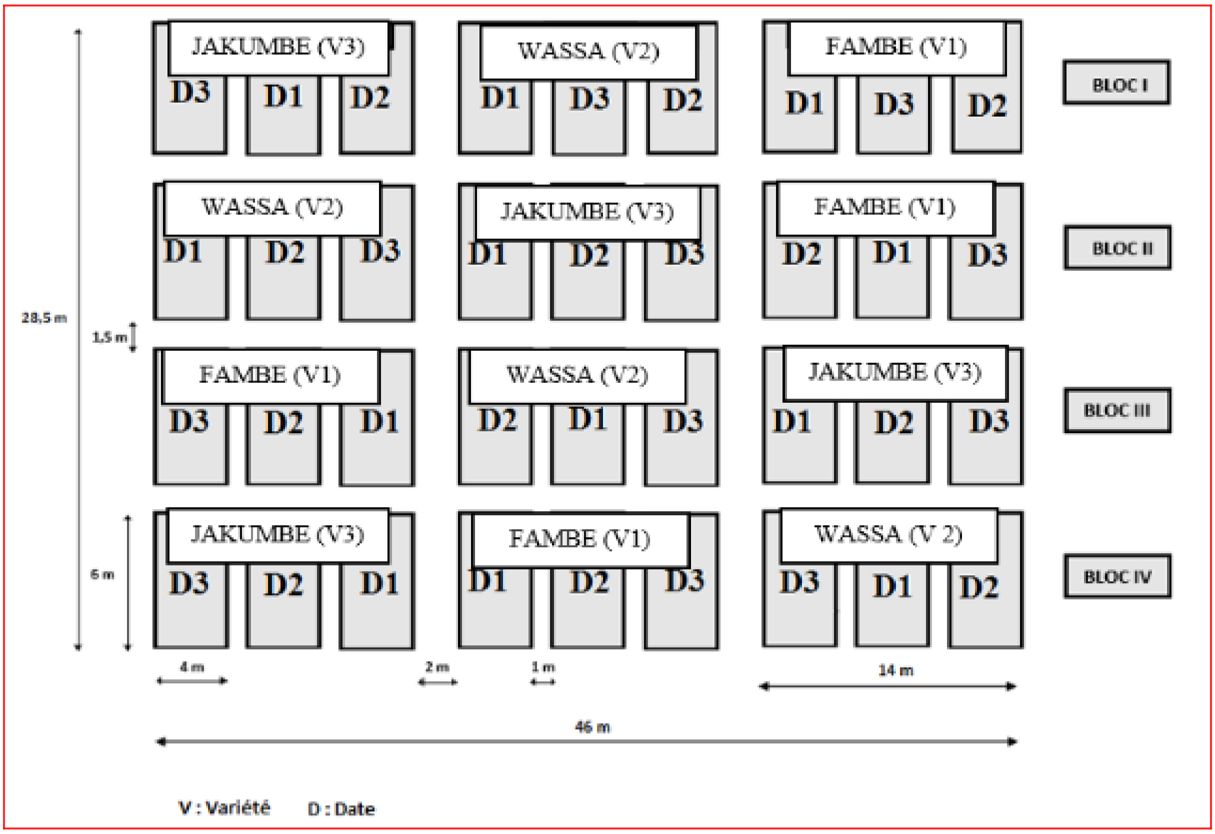


Figure 2. Trial layout

Table 2. Different planting times for sorghum in the two years (2018 and 2019) of cultivation at the two trial sites.

Sowing date	Years			
	2018		2019	
	Koulikoro	San	Koulikoro	San
Date 1 (D1)	01 July	06 july	30 june	05 july
Date 2 (D2)	11 july	16 july	10 july	15july
Date 3 (D3)	21 july	26 july	20 july	25 july

The surface area of the elementary plots was 6 m × 4 m, i.e. 24 m² with 1.5 m as an alley between the blocks and 1 m between the elementary plots. Sowing was done at a distance of 75 cm between rows and 40 cm between plants with two plants per hole, i.e. a sowing density of 66667 plants ha-^{1}. Soil preparation consisted of a flat ploughing followed by a weeding during the second weeding.

Two weeding operations were carried out, on the 15th day after sowing (DAS) and on the 45th day after sowing (before application of the second urea application). The fertilizers used were Diammonium Phosphate (DAP 18-46) at a rate of 100 kg/ha combined with urea (46 % nitrogen) at a rate of 50 kg/ha (MA-ASS, 2010). PROFEBA containing 21.07 % C; 1.57 % N; 8.78 % P2O5; 1.76 % K2O; 2.42% Ca; 1.12 % Mg; 49.5 % Zn; 41.12 % Mn; 246.93 Fe; and 29.02 Cu at a rate of 2000 kg.ha-^{1} was applied as a basal fertilizer at planting. Urea for both trials was applied as a cover manure with ploughing in a pellet about 10 cm from the crown of the sorghum plant in two identical fractions at 15 and 45 days after planting.

Prior to crop establishment, soil samples were taken with a Dutch auger on the diagonals, medians and sides of each unit plot at depths of 0-20 cm and 20-40 cm. Composite samples were made up following each depth. These composite mixtures were dried in the laboratory of the Institut Polytechnic Rural of Formation and Applied Research (IPR/IFRA) of Katibougou and placed in the appropriate bags and then transported to the Laboratory of soil sciences, Water and Environment of the Agricultural Research Center (CRA-Angonkanmey) of the National Agricultural Research Institute of Benin (INRAB) for physico-chemical analyses. These analyses consisted of the determination of pH(water) (by the potentiometric method in a soil/solution ratio of 1/2.5), organic carbon (by the Walkey and Black method, in a potassium dichromate solution), assimilable phosphorus (by the Bray 1 method, in a solution of ammonium molybdate with ascorbic acid and then the determination is done by colorimetry at a wavelength of 660 nm), total nitrogen (by the Kjeldahl method, digestion in concentrated sulfuric acid in the presence of a selenium-based catalyst), exchangeable bases (K+, Ca2+ and Mg2+) by the Metson method with ammonium acetate at pH 7, the determination of Ca2+ and Mg2+ is done using the atomic absorption spectrophotometer and that of K+ using the flame photometer.

Soil moisture was monitored using the granulometric method by taking soil samples from the elementary plots using an auger following the diagonals. Sampling was carried out every decade from the 7th day of the month. The samples were placed in tared metal boxes. The fresh weight (FW) was obtained by weighing immediately at the laboratory of the Institute Polytechnic Rural, of Formation Applied research (IPR/IFRA) of Katibougou with a MEMMERT precision balance. Then, the samples were put in an oven at 105°C for 24 hours to obtain the dry weight (DW). The weight humidity (Hp) was calculated using the following formula (Ollier and Poirée, 1981): Hp (%) = 100 x (FP-DW)/DW.

The data collected during the trials concerned growth parameters (plant height, collar diameter) and yield parameters (biomass and grain yields, 1000 grain weight). Plant height and crown diameter were taken at 30, 45, 60 and 75 days before harvest. Plant height growth rate was calculated according to the formula (ΔH)/t with ΔH the difference in height between two catches and t the time interval between two measurements (15 days in this study). Sorghum was harvested at physiological maturity after perfect drying of the sorghum panicles at the interpretable surface after removal of rows and border plants. Threshing was done after drying the panicles and then the weight of the grains was taken. Biomass was weighed after panicle harvest. The stems were cut flush with the ground. The entire biomass was weighed using a scale. Grain and biomass yields were determined according to the formula:

Grain or biomass yield (kg.ha-^{1}) = S * P * SI /1000

S = area (ha);

P = plot yield (kg.ha-^{1});

SI: Interpretable area (m²).

From the yield data, the harvest index and water use efficiency were determined. The harvest index was considered in this study, as the ratio of grain yield to the sum of grain and straw yields according to the following formula (Baba *et al.*, 2018): IR = (Grain yield)/(Grain yield + Biomass yield) with IR: harvest index. Water use efficiency was determined by the formula (Blanney and Criddle, 1950): WUE (t.mm-1 of water) = (Grain yield/FTE).

Where WUE = water use efficiency of sorghum grain during the five months of the trial and PTE = potential evapotranspiration.

PTE was calculated by the formula: PTE = 0.254.x K.x (1.8t + 32) x P

K = Blaney-Criddle coefficient. It is a function of the crop and the region considered in this study we used 0.77 for this coefficient.

t = average temperature in °C during the period considered.

P = percentage of the average day length according to the latitude.

2.3. Statistical analysis

The collected data were entered into the Excel spreadsheet version Office 2013. SAS software was used for statistical analyses. These analyses consisted of a three-factor analysis of variance (variety, sowing date, and year). The Student Newman-Keuls test was used for the separation of means at the 5 % threshold.

3. RESULTS

3.1. Physico-chemical characteristics of the soils and climatic parameters of the test sites

The physico-chemical characteristics of the soils of the sites are presented in Table 18. Most of the soils have a silty-sandy texture. The C/N ratio was less than 12, which indicates a good level of soil fertility. The soils were slightly acidic. The exchangeable K+ values as well as the CEC are low. Assimilable phosphorus in the soils ranged from 14 $mg.kg^{-1}$ (in Koulikoro) to 84 $mg.kg^{-1}$ (in San). In general, the soils at the test sites have a relatively low level of fertility.

Table 3: Physico-chemical properties of soils from the test sites during the two years of experimentation

Characteristics	Years						
	2018			2019			
	Koulikoro		San	Koulikoro		San	
Depths (cm)	0-20	20-40	20-40	0-20	20-40	0-20	20-40
% Clay	6,31	10,76	8,55	9,52	12,76	5,61	18,31
% Silt	20,4	20,59	5,01	21,2	29,6	5,76	5,49
% Sand	73,3	68,64	86,45	69,77	57,65	88,62	76,2
Texture	Silty-Sandy	Silty-Sandy	Sandy-Clay	Silty-Sandy	Silty-Sandy	Sandy	Sandy-Silty
C ($g.kg^{-1}$)	7,0	6,7	4,3	6,4	6,4	6,4	6,3
N ($g.kg^{-1}$)	0,7	0,7	0,55	0,5	0,8	0,53	0,6
C/N	10	10	8	13	8	12	11
pH (eau)	4,98	4,80	4,19	5,73	5,71	6,04	6,28
$K^{+}_{éch}$ ($cmol.kg^{-1}$)	0,29	0,24	0,46	0,11	0,09	0,23	0,21
CEC ($cmol.kg^{-1}$)	4,80	6,24	4,92	7,4	8,640	5,6	10,52
P ($mg.kg^{-1}$)	21	14	28	44	26	84	59

The rainfall amounts as well as the number of rainy days recorded (Table 4) in both areas showed that 2019 was wetter than 2018 in Koulikoro while rainfall amounts were higher in 2018 in San compared to 2019.

Table 4: Rainfall during the two agricultural seasons in the study area

Sites	**Koulikoro 2018**						**Total**	**San 2018**						**Total**
Month	May	June	July	August	Sept	Oct		May	June	July	August	Sept	Oct	
Rainfall (mm)	119	184	206	207	184	0	900	19,3	137,3	163,5	216,8	288	18,6	843,5
Number of rainy days	5	7	12	12	11	0	47	4	7	13	13	19	2	58
	Koulikoro 2019						Total	San 2019						Total
Rainfall (mm)	80,1	103	123,2	386	245,9	74,2	1012,4	43	144	81	230	139	12	649
Number of rainy days	5	10	16	20	17	8	76	4	9	9	13	12	3	50

These rainfall amounts were recorded after 47 days of rain in the districts Koulikoro and San 58 days of rain in 2018. 76 rainy days were recorded in Koulikoro and 50 rainy days in San in 2019. Also, temperatures for both sites ranged from 22 to 37°C. High maxima were noted in Koulikoro. These amounts of rainfall are sufficient for a 105-day cycle sorghum variety.

3.2. Effect of variation in sowing dates on plant growth parameters of sorghum varieties

Tables 5 and 6 show the growth rates in height and diameter at the collar of sorghum plants according to the different sowing dates at the Koulikoro and San sites, respectively. The growth rate in height as well as that of the diameter at the crown of the plants varied significantly ($p< 0.001$) according to the sites, the sowing dates and the sorghum varieties used. Similarly, the interaction between sowing dates and sorghum varieties had a significant ($p < 0.001$) influence on growth parameters. At the Koulikoro site (Table 5), the highest growth rates in height were obtained with the Fambè (8.6 cm.day-1) and Wassa (7.5 $cm.day^{-1}$) varieties at the first two sowing dates for both years of the trials. The same observation was made for the growth rate of the diameter at the collar for this site. At the San site (Table 6), the varieties Fambè (7.8 $cm.day^{-1}$) and Jakumbè (7.01 $cm.day^{-1}$) showed the highest growth rates in height when sown at dates D1 and D2 (beginning of July), regardless of the year. The first two sowing dates are those that offer a good growth of sorghum plants, whatever the site.

Table 5. Effect of sowing dates on the speed (mean values ± standard errors) of growth in height and diameter at the crown of sorghum plants at the Koulikoro experimental site

Varieties	Sowing dates	Growth rate (cm. Days-^{1}) at 45 DAS		Growth rate (cm. Days-^{1}) at 60 DAS		Growth rate (cm. Days-^{1}) at 75 DAS		Diameter at the collar (cm. Days-^{1}) at 60 DAS		Diameter at the collar (cm. Days-^{1}) at 75 DAS	
		2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
	D1	5,1±0,59a	4,1±0,87a	6,7±0,37a	4,5±0,83b	4,6±0,61a	8,8±2,22a	0,2±0,02a	0,2±0a	0,1±0,02a	2,5±0,11a
(Fambè)	D2	5±0,44a	4,3±0,45a	6,4±0,16b	5,6±0,7ba	2,0±0,4b	11,0±0,4a	0,1±0a	0,0±0,2a	0,1±0a	2,2±0,07a
	D3	4,9±0,51a	3,4±0,26a	5,6±0,24b	7±0,17a	1,5±0,4b	5,9±2,04a	0,125±0,02a	0,1±0a	0,1±0a	1,9±0,11b
	Moyenne	5±0,27A	4,1±0,31B	6,3±0,22B	5,9±0,3BA	2,7±0,47A	8,6±1,1A	0,2±0,01A	0,1±0,0BA	0,09±0,0A	2,16±0,09A
	D1	5,9±0,41a	6,4±1,14a	7,4±0,62a	2,4±1,36b	3,5±1,10a	10,7±3,36a	0,1±0a	0,2±0,02a	0,1±0,02a	2,5±0,07a
	D2	6±0,37a	4,7±0,74a	6,6±0,54a	4,5±0,69ba	2,4±0,33a	7,9±0,74ba	0,2±0,02a	0,1±0,04b	0,1±0,02a	2,3±0,02b
(Wassa)	D3	5±0,24a	4,5±0,2a	6,2±0,53a	6,7±0a	1,9±0,55a	3,9±0,60b	0,2±0,02a	0,1±0ba	0,1±0a	1,9±0,07c
	Moyenne	5,7±0,22A	5,2±0,48A	6,7±0,3BA	4,5±0,70B	2,6±0,44A	7,5±1,3A	0,2±0,01A	0,1±0,02B	0,1±0,01A	2,3±0,0B
	D1	6,2±0,39a	4,6±0,70a	8,4±0,79a	5,7±0,64a	1,8±0,42a	8,9±1,30a	0,1±0a	0,2±0,05a	0,07±0,04a	2,9±0,05a
	D2	5,4±0,33ba	4,6±0,30a	7,8±0,64a	6,4±0,43a	1,9±0,61a	6,8±1,97a	0,1±0a	0,1±0a	0,2±0,02a	2,7±0,2a
(Jakumbè)	D3	4,4±0,45b	3,9±0,45a	6,6±0,48a	7,5±0,55a	1,5±0,25a	4,6±1,19a	0,1±0,04a	0,2±0,02a	0,2±0,02a	2,2±0,12b
	Moyenne	5,3±0,30A	4,4±0,28BA	7,6±0,40A	6,5±0,36A	1,7±0,24A	6,8±0,96A	01±0,01A	0,2±0,02A	0,2±0,01A	2,6±0,09B

Means followed by the same alphabetical letters are not significantly different ($p > 0.05$) according to the Student Newman-Keuls test. Koulikoro 2018- D1: 01/07; D2=11/07; D3= 21/07; 2019- D1: 30/06; D2:10/07; D3: 20/07; San: 2018- D1: 06/07; D2: 16/07; D3: 26/07; 2019: D1: 05/07; D2: 15/07/2019; D3: 20/07

Table 6. Effect of sowing dates on the speed (mean values ± standard errors) of growth in height and diameter at the crown of sorghum plants at the San

Varieties	Sowing dates	Growth rate (cm. Days-^{1}) in heigth at 45 DAS		Growth rate (cm. Days-^{1}) in height at 60 DAS		Growth rate (cm. Days-^{1}) in heigth at 75 DAS		Diameter at the collar (cm. Days-^{1}) at 60 DAS		Diameter at the collar (cm. Days-^{1}) at 75 DAS	
		2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
	D1	1,6±0,04a	4,3±0,11a	3,8±0,07a	6,7±0a	6,8±0,52a	9,2±1,48a	0,3±0,06a	0,3±0,0a	0,1±0a	3,22±0,04a
(Fambè)	D2	3,5±0,04b	4,4±0,16a	3,5±0,33a	5,9±0,50a	6,2±0,46a	6,8±0,29a	0,3±0,06a	0,2±0,0b	0,1±0a	2,5±0,25b
	D3	1,02±0,09c	3,1±0,55b	2,87±0,38a	4,35±0,68b	4,87±0,6b	7,22±1,33a	0,3±0,04a	0,1±0b	0,1±0a	2,07±0,2b
	Moyenne	1,4±0,07B	3,9±0,24A	3,4±0,1C	5,7±0,39A	5,9±0,3A	7,8±0,6A	0,3±0,0A	0,2±0,0A	0,1±A	2,6±0,1A
	D1	2,1±0,16a	4,2±0,30a	4,7±0,20a	6,1±0,67a	5,6±0,41a	6,8±0,96a	0,3±0,04a	0,3±0,0a	0,1±0a	3,0±0,13a
	D2	1,7±0,08a	3,65±0,16a	4,8±0,26a	6,07±0,70a	5,25±0,53a	6,72±2,08a	0,22±0,04a	0,12±0,0a	0,1±0a	2,45±0,16b
(Jakumbè)	D3	1,2±0,18b	2,6±0,50b	4,3±0,17b	3,9±0,76a	3,8±1,00a	7,6±1,15a	0,2±0,04a	0,1±0,0a	0,1±0a	2,1±0,11b
	Moyenne	1,65±0,13A	3,46±0,26A	4,6±0,13B	5,32±0,48A	4,86±0,4A	7,01±0,8A	0,2±0,02A	0,13±0,0A	0,1±0A	2,48±0,1A
	D1	1,7±0,07a	4,4±0,14a	8,5±0,28a	6,7±0a	8,3±0,90a	6,4±0,64a	0,2±0,02b	0,2±0,11a	0,1±0a	2,7±0,02a
	D2	1,4±0,02b	4,3±0,27a	8,2±0,31a	5,7±0,18a	6,6±1,73a	6,0±0,37a	0,2±0,02b	0,1±0a	0,1±0a	2,5±0,11a
(Wassa)	D3	0,9±0,05c	2,2±0,40b	5,7±0,35b	4,5±0,66b	6,9±1,82a	6,9±0,89a	0,4±0,08a	0,2±0,05a	0,1±0a	1,9±0,0b
	Moyenne	1,3±0,10B	3,7±0,33A	7,5±0,40A	5,7±0,34A	7,3±0,83B	6,4±0,37	0,3±0,03A	0,2±0,03A	0,1±0A	2,4±0,1A

Means followed by the same letters are not significantly different ($p > 0.05$) according to the Student Newman-Keuls test. Koulikoro 2018- D1: 01/07; D2=11/07; D3= 21/07; 2019- D1: 30/06; D2:10/07; D3: 20/07; San: 2018- D1: 06/07; D2: 16/07; D3: 26/07; 2019: D1: 05/07; D2: 15/07/2019; D3: 20/07

3.3. Effect of variation in sowing dates on yield parameters of different sorghum varieties at the two study sites

Figures 5, 6 and 7 show the effect of variation in sowing dates of different sorghum varieties on grain and biomass yields during the two years of cultivation at the experimental sites. The results of the analysis of variance showed that grain and biomass yields varied significantly ($p < 0.001$) according to varieties and sowing dates considering the sites. In addition, there was significant variation ($p < 0.001$) in yield from one agricultural season to another. Analysis of Figures 7 and 8 shows that the highest grain and biomass yields were obtained at the first sowing date (D1, sowing in early July) regardless of variety. The highest grain and biomass yields at the Koulikoro site were obtained with the Fambè variety (2.40 ± 0.02 t. ha-^{1}) and a biomass yield of 6.40 ± 0.20 t. ha-^{1}, followed by the Wassa variety (2.16 ± 0.07 t. ha-^{1}) and a biomass yield of 9.36 ± 0.80 t. ha-^{1}. The same trend was observed at the San site with the Wassa variety showing the highest grain and biomass yields of 2.44 ± 0.06 and 9.22 ± 0.79 t. ha-^{1}, followed by the Jakumbé variety (1.97±0.01 t. ha-^{1}) and (5.27±0.14 t. ha-^{1}).

In the second year of testing, the Jakumbé variety also had the highest grain yields of 3.61 ± 0.14 t ha-^{1} and biomass of 12.00 ± 0.70 t ha-^{1}, followed by the Fambè variety with grain yields of 2.88 ± 0.14 t ha-^{1} and biomass of 6.80 ± 0.25 t ha-^{1} in Koulikoro. In San, the variety Fambè (3.03 ± 0.05 t. ha-^{1} and 12.50 ± 1.55 t. ha-^{1}) followed by the variety Jakumbè had the highest grain and biomass yields (2.45 ± 0.04 t. ha-^{1} and 6 ± 0.91 t. ha-^{1}) for the second year of the trial for the first sowing date in June and the second sowing date in June. But on average the variety Fambé performed better with grain yields of 2.30 ± 0.11 t. ha-^{1} and biomass of 6.32 ± 0.27 t. ha-^{1}, followed by the variety Jakumbé with 2.17 ± 0.020 t. ha-^{1} in Koulikoro, while in San, the Wassa variety had the highest grain yields and biomass (1.84 ± 0.09 and 7.66 ± 0.45 t. ha-^{1}), followed by the Jakumbé variety with the lowest yields and biomass (1.80 ± 0.10 and 4.95 ± 0.23 t. ha-^{1}) for the second year of the trial for treatments D1 and D2. In sum, the first two sowing dates (sown at the beginning of July) showed better yields in both zones.

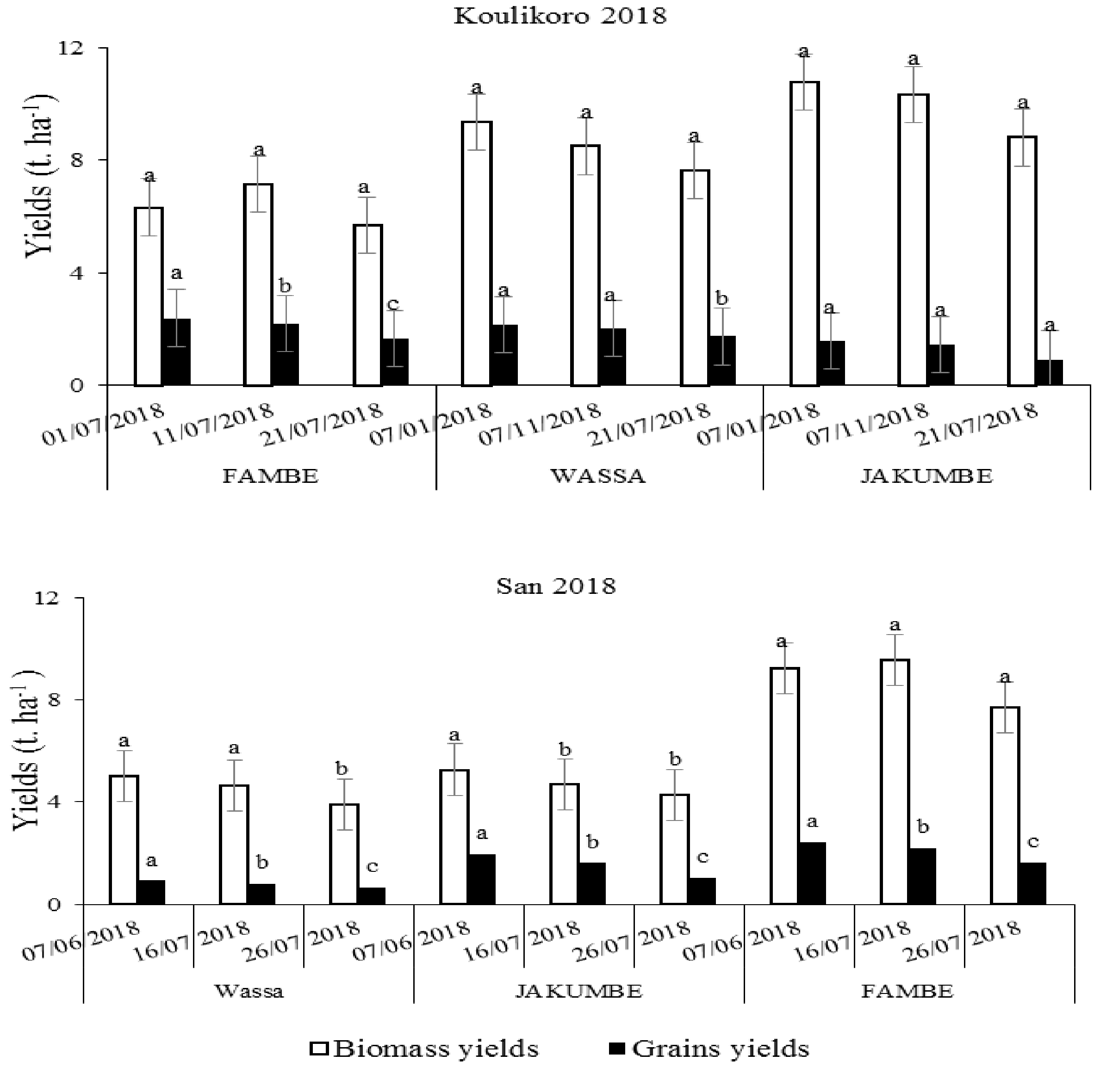


Figure 5. Effect of sowing date variation on grain and biomass yields (mean values ± standard errors) of sorghum varieties at the experimental sites of Koulikoro in the Sudanian zone and San in the Sahelian zone in 2018

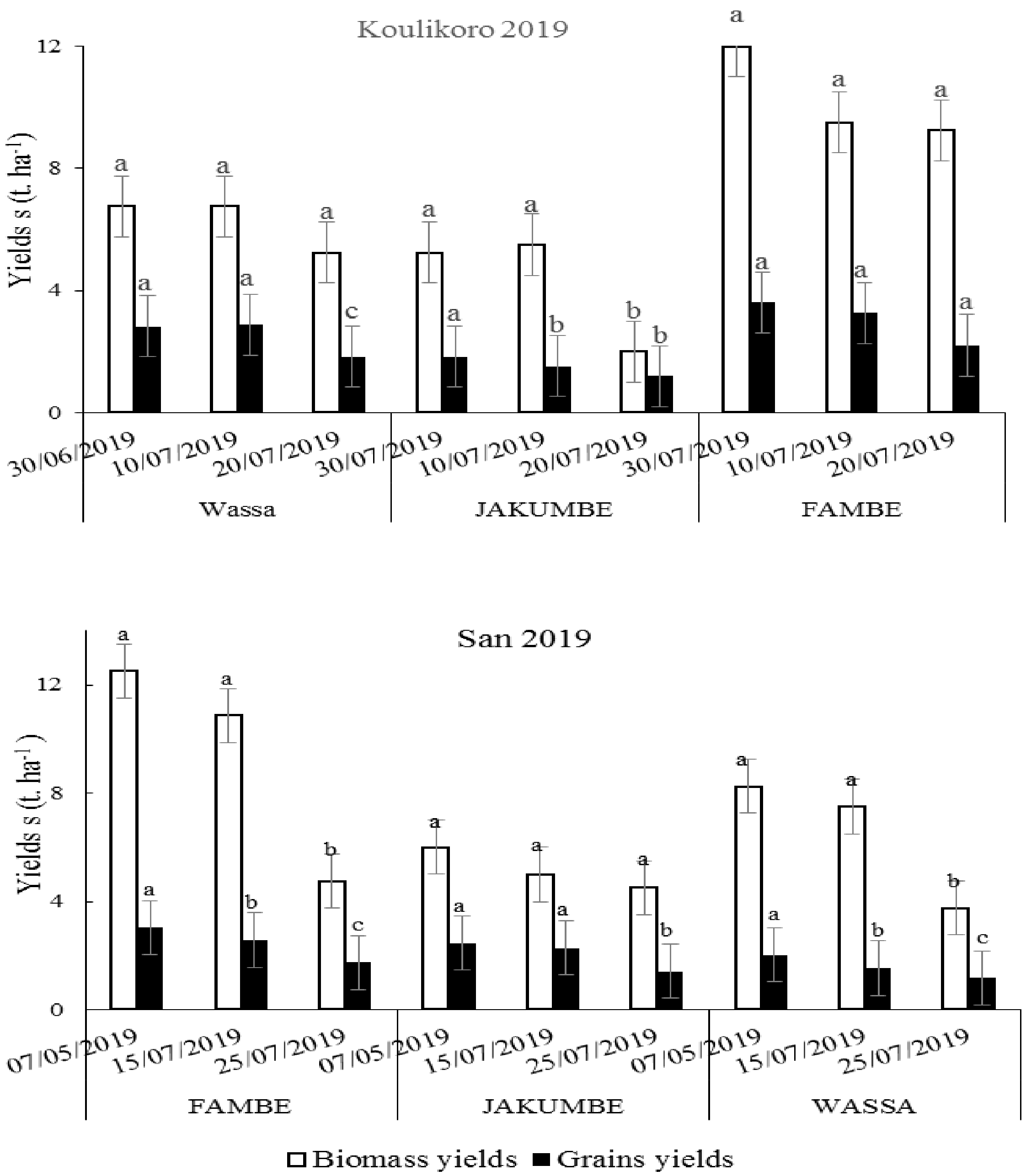
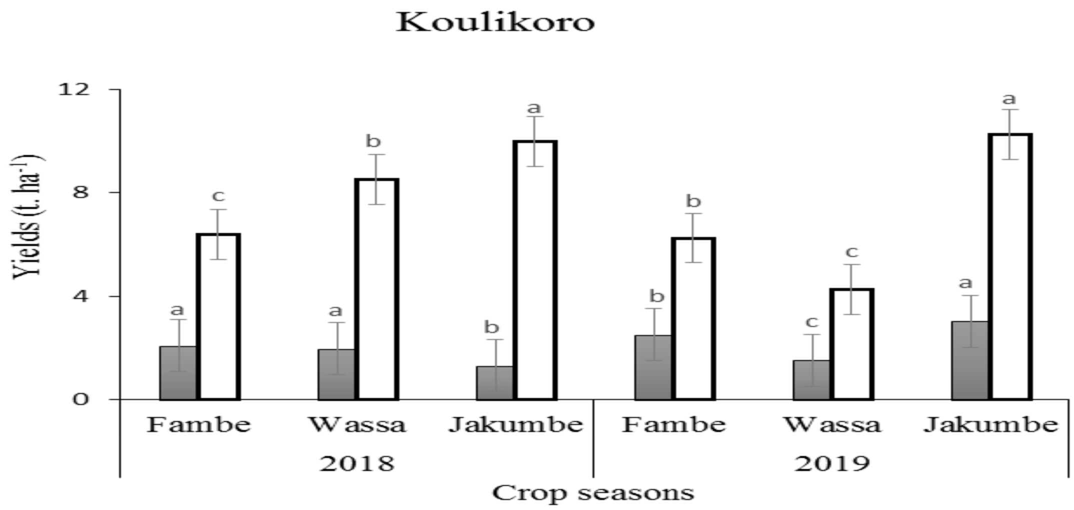


Figure 6. Effect of sowing date variation on grain and biomass yields (mean values ± standard errors) of sorghum varieties at the experimental sites of Koulikoro in the Sudan zone and San in the Sahel zone in 2019



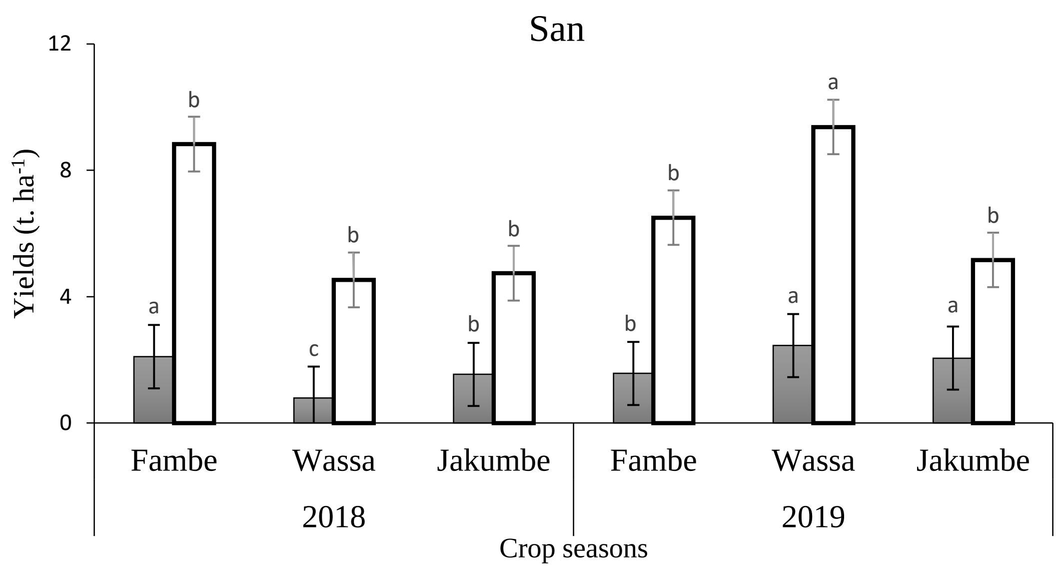


Figure 7. Effect of variation in sowing dates on average grain and biomass yields of sorghum varieties at the Koulikoro and San experimental site in the Sudan zone during the two agricultural seasons

Table 7 presents the results of the three-factor analysis of variance (sowing dates, varieties and sites) performed on the biomass and grain yields of sorghum. From this table, it appears that grain and biomass yields vary very significantly ($p<0.001$) according to variety and from one sowing date (sowing period and year) to another and from one site to another (Table 07). The same is true for the interactions Varieties*sowing dates and Sites*varieties*sowing dates ($p<0.001$).

Table 7. Analysis of variance (Fisher's value) of yields of different varieties by year and by site

Source of variation	Degree of freedom	Fisher's value	
		Biomass yields	Grain yields
Sites	1	15,16***	85,81***
Varieties	2	47,34***	17,17***
Dates	5	13,54***	136,63***
Blocks	3	0,35ns	2,18ns
Sites*varieties	2	10,58***	36,79***
Sites*dates	5	4,69***	0,55ns
Varieties*dates	10	5,04***	15,32***
Sites*varieties*dates	10	15,16***	55,39***

ns: P > 0.05; ***: P < 0.001

The results of the Student Newman Keuls test are presented in Table 7. Analysis of this table reveals that the first sowing date of 2019 induced the highest grain yields (p < 0.05) for the varieties Fambè and Jakumbè while the first sowing dates induced the highest grain yields for the variety Wassa (2.26±0.14 t/ha) regardless of site. Similarly, the Fambè and Jakumbè varieties (2.25±0.07 t/ha) also recorded the highest grain yields (p < 0.05) at the Koulikoro site, while the Jakumbè and Wassa varieties (1.82±0.11 t/ha) had the highest yields at the San site. In general, yields were better (p < 0.05) in the Koulikoro district than in San (Table 8).

Table 8. Effect of sowing dates on yields (mean ± standard error) of varieties at the two sites

Sites	Varieties	Sowing dates	Biomass yields (kg/ha)	Grain yields (kg/ha)
Koulikoro	Fambè	01 july 2018	6,40±0,20ba	2,40±0,02 ab
		11 july 2018	7,16±0,80a	2,19±0,04 ab
		21 july 2018	5,80±0,41ba	1.68±0,04b
		30 june 2019	6,80±0,90ba	2,82±0,29a
		10 july 2019	6,80±0,25ba	2,88±0,14a
		20 july 2019	5,25±1,03b	1,84±0,26b
		Average	6,32±0,27B	2,30± 0.11A
	Wassa	01 july 2018	9,36±0,80a	2,16±0,07a
		11 july 2018	8,50±0,98a	2,01±0,03ab
		21 july 2018	7,64±0,71ba	1,75±0,08bc
		30 june 2019	5,25±0,94b	1,83±0,30abc
		10 july 2019	5,50±1,84b	1,53±0,20c
		20 july 2019	2,00±0,40c	1,19±0,30d
		Average	6,37±0,63B	1,74±0.08B
	Jakumbè	01 july 2018	10,77±0,92ba	1,57±0,09d
		11 july 2018	10,33±1,39ba	1,44±0,04d
		21 july 2018	8,81±0,86b	0,94±0,07e
		30 june 2019	12,00±0,70a	3,61±0,14a
		10 july 2019	9,50±1,25ba	3,20±0,12b
		20 july 2019	9,26±1,31ba	2,20±0,10c
		Moyenne	10,11±0,47A	2,17±0,020A
	GENERAL AVERAGE		7,60±0,34X	2,07±0,08X
San	Fambè	06 july 2018	5,02±0,26b	0,92±0,06d
		16 july 2018	4,64±0,24b	0,80±0,05de
		26 july 2018	3,92±0,20b	0,67±0,02e
		05 july 2019	12,50±1,55a	3,03±0,05a
		15 july 2019	10,87±0,92a	2,57±0,05b
		20 july 2019	4,75±0,47b	1,75±0,06c
		Average	6,95±0,76A	1,62±0,19B
	Jakumbè	06 july 2018	5,27±0,14ba	1,97±0,01b
		16 july 2018	4,68±0,12ba	1,62±0,20c
		26 july 2018	4,26±0,13b	1,03±0,03d
		05 july 2019	6,00±0,91a	2,45±0,04a
		15 july 2019	5,00±0,70ba	2,29±0,09a
		20 july 2019	4,50±0,64b	1,42±0,09c
		Average	4,95±0,23B	1,80±0,10A
	Wassa	06 july 2018	9,22±0,79ab	2,44±0,00a
		16 july 2018	8,25±0,62ab	2,21±0,02b
		26 july 2018	7,71±0,40b	1,65±0,02d
		05 july 2019	9,57±0,87a	2,02±0,07c
		15 july 2019	7,50±0,64b	1,53±0,07d
		20 july 2019	3,75±0,25c	1,17±0,03e
		Moyenne	7,66±0,45A	1,84±0,09A
	GENERAL AVERAGE		6,52±0,33Y	1,75±0,07 Y

Means followed by the same alphabetical letter of the same character and for the same factor are not significantly different (P > 0.05) according to the Student Newman-Keuls test.

Table 9 presents the effect of sowing dates of the different sorghum varieties on harvest indices and water use efficiency at the two experimental sites. The results of the analysis of variance showed that sowing dates and varieties significantly ($p < 0.001$) affected the harvest index and water use efficiency at each site. Similarly, these parameters varied significantly ($p < 0.001$) from year to year. Analysis of the results in Table 9 shows that the highest harvest indices and water use efficiency were obtained with the earliest sowing dates regardless of variety. The highest harvest index and water use efficiency (WUE) for the Koulikoro site were observed with the Fambè variety followed by the Wassa variety for the first two planting dates. The same observations were made at the San site for the second year of the trial. Overall, sowing at the beginning of the rainy season (July) provides the best harvest indices and water use efficiency by the plant.

Table 9. Effect of sowing dates and varieties on harvest indices and water use efficiency (mean values ± standard errors) at the two trial sites during the two years of experimentation

Sites	**Varieties**	**Sowing dates**	**Harvest index**		**Water use efficiency (t.mm^{-1} of water)**	
			2018	2019	2018	2019
Koulikoro	FAMBÈ	D1	0,3±0,00a	0,4±0,03a	0,05±00a	0,03±0,00a
		D2	0,3±0,01a	0,4±0,01a	0,01± 00b	0,03±0,00a
		D3	0,3±0,01b	0,3±0,02a	0,02±00a	0,01±0,00b
		Average	0,3±0,00A	0,3±0,01AB	0,2±0,00A	0,0±0,00A
	WASSA	D1	0,2±0,01a	0,3±0,04a	0,02±00a	0,02±0,00a
		D2	0,2±0,01a	0,3±0,07a	0,02±00a	0,02±0,00a
		D3	0,2 ±01a	0,4±0,04a	0,01±0,00b	0,01±00b
		Average	0,2±0,00B	0,4±0,03A	0,0±0,00A	0,0±0,00B
	JAKUMBÈ	D1	0,2±0,00a	0,3±0,01ba	0,01±00a	0,01±00a
		D2	0,2±0,01a	0,3±0,02a	0,01±00a	0,01±00a
		D3	0,2±0,01a	0,2±0,00b	0,01±00a	0,01±0,00a
		Average	0,2±0,00C	0,3±0,01B	0,0±0B	0,0±0,00A
		X	0,2±0,00A	0,3±0,01A	0,0±0,00A	0,01±0,00A
SAN	WASSA	D1	0,2±0,00a	0,3±02b	0,01±00a	0,01±0,00a
		D2	0,2±0,00a	0,2±0,01b	0,01±00a	0,01±00a
		D3	0,2±0,01a	0,3±0,01a	0,00±0,00b	0,01±00b
		Average	0,2±0,00C	0,22±0,01B	0,00±0,00B	0,01±0,00A
	JAKUMBÈ	D1	0,3±0,00a	0,4±0,03a	0,02±00a	0,02±00a
		D2	0,3±0,01a	0,4±0,02a	0,01±00b	0,02±00a
		D3	0,2±0,00b	0,3±0,01a	0,01±00b	0,01±00b
		Average	0,3±0,01A	0,3±0,01A	0,0±0,00A	0,0±0,00AB
	FAMBÈ	D1	0,3±0,01a	0,3±0,01ab	0,02±00a	0,02±00a
		D2	0,2±0,01a	0,2±0,01b	0,02±00a	0,02±00a
		D3	0,2±0,00a	0,3±0,01a	0,01±00b	0,01±00b
		Average	0,2±0,00B	04±0,01B	0,0±0,00A	0,0±0,00B
		X	0,2±0,00A	0,3±0,01B	0,0±0,00A	0,0±0,00B

Means followed by the same alphabetic letters and the same character are not significantly different ($P > 0.05$) according to the Student Newman-Keuls test

Legend: Koulikoro 2018- D1: 01/07; D2=11/07; D3= 21/07; 2019 - D1: 30/06; D2:10/07; D3: 20/07; San: 2018- D1: 06/07; D2: 16/07; D3: 26/07; 2019: D1: 05/07; D2: 15/07/2019; D3: 20/07

4. DISCUSSION

4.1. Soil fertility status, climatic characteristics of the test sites and sorghum productivity in the study area

The analysis of the results of the physico-chemical properties of the soils before the installation of the trials showed that the soils of the two sites are acid with a good level of soil fertility. In general, the sum of exchangeable bases and the CEC are low, which translates into a low cation exchange capacity in the soil. This result corroborates that obtained by Adjanohoun *et al.* (2011) in Benin. Imbalances between the levels of calcium, magnesium and phosphorus in the soil were noted. These results show that it is necessary to provide nutrients to these soils because they cannot continuously meet the needs of crops in general and sorghum in particular (Yallou *et al.,* 2010, Saidou *et al.,* 2012). In sum, this low level of soil fertility could also explain the low levels of sorghum yield observed in the zone. This is accentuated by high variability in rainfall patterns.

Similar results were obtained by Haro & Traoré (2016) in Burkina Faso, Kanté (2001), Traoré *et al.* (2013) who concluded that the low productions recorded in the zone were mainly due to the low level of soil fertility (Bado, 2002) and precisely their deficiency in nitrogen and phosphorus (Sanchez *et al.,* 2012) and to the low rainfall. The amount of rainfall recorded during the two years in the study area was over 800 mm in the Koulikoro circle and 600 mm in the San circle. This means that the amount of water that fell during the two trial years was sufficient to sustain the water supply of the sorghum crop. This observation is consistent with that reported by Sene (1995). According to the author, a well-distributed rainfall (between 500 and 600 mm) is required for good growth of a short-cycle variety, 650 to 800 mm for a medium-cycle variety, and 950 to 1100 mm for a long-cycle variety if optimum yields are to be achieved under good soil fertility conditions. Maximum and minimum temperatures varied during the two cropping seasons at both sites, confirming the observations of our previous study (Traoré *et al*., 2021).

4.2. Evolution of harvest indices and water use efficiency of sorghum varieties according to different sowing dates

Average values of harvest indices in 2018 ranged from 0.10 to 0.28 in Koulikoro and from 0.16 to 0.27 in San. In 2019, harvest indices ranged from 0.19 to 0.39 and from 0.17 to 0.32 in Koulikoro and San, respectively. These results corroborate with those of Chantereau *et al.* (1998) in Mali, Somé & Ouattara (2005) in Burkina Faso (harvest index varying between 0.37 and 0.49), Ganyo *et al*. (2018) in Senegal (harvest indices varying between 0.32 and 0.79). The variation in harvest index over the two cropping seasons indicates an improvement in yield levels over the two seasons.

With respect to water use efficiency in 2018, it ranged from 14 to 16 $kg.mm^{-1}$ of water and from 16 to 30 $kg.mm^{-1}$ of water in 2019 in Koulikoro and from 14 to 16 kg.mm-^{1} of water in San for both years. This result is very high compared to the values recorded by Kouyaté &Wendt (1991) (3.52 to 6.72 $kg.mm^{-1}$ of water) in Mali. However, our results corroborate Daroui *et al.* (2011) in Morocco (5 and 14.57 $kg.mm^{-1}.ha$-^{1}). This could be explained by the good rainfall recorded during the period of the trials. The improved water use efficiency in 2019 could also explain the better yields obtained in this year.

Monitoring of soil moisture content over the two production cycles showed fluctuations from year to year. This result is in agreement with those observed by Traoré (2016) in Mali. According to Nadjem (2012) in Algeria, these variations are the result of the interaction of the "rain, temperature, wind and solar radiation" component with the development stage of the crop. The variations of these soil moisture values are also a function of the complex interaction between the hydraulic mechanisms of the soil (capillary rise, percolation, drainage) on the one hand and the development of the root system on the other. All this can explain the variations in the level of yield noted at our experimental sites.

4.3. Efficiency of the optimal sowing date and varietal choice on the level of sorghum yield as an adaptation strategy to climate change

The yields obtained (grain and biomass) are significantly different from one cropping season to the next, which shows that inter- and intra-annual variations in rainfall and the number of rainy days have an impact on sorghum yields. This finding corroborates that of Soumaré (2004) who observed that in tropical zones, rainfall is random at the beginning of the season. On the same site, the onset of the rainy season can vary by 30 days from one year to the next. Thus, the study of the beginning and end of the rainy season and the variation is essential to better adjust the length of the crop cycle to the current rainfall. This knowledge also helps to determine the irrigation period, sowing and harvesting dates, the water rationing period as well as the quantification of the water needs of a crop (Kouassi *et al.,* 2018).

Regarding sowing dates, our results showed that early sowing induced better grain and biomass yield ($p < 0.05$) compared to late sowing. These results are consistent with those found by Verma (2011). They also corroborate those obtained by de Salem *et al*. (1991) and Soumaré (2004) who showed that the adaptation of crops to aridity conditions is linked to an efficient use of available water and this is possible thanks to the control of the crop sowing period. The first rains are of paramount importance in determining the level of crop yield. The highest average grain yields are obtained for plantings in early July. These trends reinforce those of Traoré (2016) who found higher sorghum yields when sowing was done in the 2nd decade of June to the 2nd decade of July.

The variability in optimal sowing periods between southern and northern Mali is due to the different climate types characterizing the two zones. This improvement in yield observed with the favorable sowing periods for sorghum in these zones can be explained by the fact that the sowing was carried out at a period favorable to the development of the seedlings, which experienced good growth. In addition, of these factors, a probable high level of CO_2 used by the plant for the production of a greater amount of dry matter may be the basis of this yield improvement. This is characterized by increased photosynthesis per unit leaf area and increased water use efficiency and increased photorespiration rates (Attri and Rathore, 2003). We did not collect physiological data in this study, as they would likely have induced observed yield improvements. Indeed, increased atmospheric CO_2 can promote photosynthesis and in this case increase biomass production and thus productivity (Meza *et al.,* 2008; Kolawolé and Samson, 2009; Balogoun *et al.,* 2013) of the crop.

During the two years of experimentation at the two study areas, the third sowing date gave the lowest yield, this result confirms that found by Traoré *et al*. (2013) who showed that late sowing of maize, sorghum and cotton systematically induced low yields in Mali. This same finding was made by Balogoun *et al. (*2013) in Benin who showed that late planting resulted in low grain yields of maize and favored attack by granivorous birds. In addition, late planting subjects plants to high water stress risks, which affects growth and nutrient uptake by plants (Asadi and Clemente, 2003; Soler *et al.*,2007; Balogoun *et al*., 2013). Our results showed that early planting combined with early sorghum varieties are effective crop adaptation strategies to climate change. The results of the present study should be made available to smallholder farmers in the Sudanian and Sahelian zones of Mali for sustainable sorghum production and food security.

5. CONCLUSION

Soil fertility levels prior to the installation of crops were relatively low. This indicates soil degradation. The amount of rainfall recorded in the two zones was over 800 mm in Koulikoro and 600 mm in San during the two years of experimentation, which allowed for a reasonable level of yield depending on the soil fertility of the sites. The climatic parameters recorded during the two growing seasons were relatively favorable for good growth of a crop such as sorghum, resulting in good soil moisture during the growing period for the first sowings. The average values of water use efficiency induced a reasonable level of yield when sowing is done in the first decade of July. The average values of harvest indices were significantly affected by sowing dates and variety sown. The best harvest indices were recorded with the first sowing dates. From this, improved yield levels are inferred with the sorghum variety Fambè for sowing in early July. This result could be proposed as an adaptation strategy to climate change for improving sorghum productivity and ensuring food security in the study area.

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