International Journal of Agriculture and Environmental Research

ISSN: 2455-6939

Volume:04, Issue:03 "May-June 2018"

CROPPING TWO SORGHUM VARIETIES UNDER IRRIGATION, AN INTENSIFICATION STRATEGY TO MITIGATE CLIMATE CHANGE INDUCED EFFECT IN BURKINA FASO, WEST AFRICA

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ABSTRACT

This study was conducted in the Central region of Burkina Faso in 2014 and 2015, to test the options of sorghum adaptation strategies, which are able to enhance sorghum productivity, contributing to food security. Two experiments using a randomized split-plot design were set up under two dry sowings during hot (March) and cold (October) seasons respectively. These experiments were subjected to two water regimes (50% and 100% potential evapotranspiration, two nitrogen levels (0 and 60N) and two sorghum varieties (local improved, *Kapelga* and high yielding, *Sariaso* 14). The treatments were assessed for the varietal performance under irrigated sorghum production. By these experiments, under the cold dry experiment sorghum reproductive cycle was shortened and grain yield and harvest index improved. The study underscored the outperformance of the variety *Sariaso* 14 over that of the *Kapelga* variety regardless of the management options and growing conditions. *Sariaso* 14 was 74% more improved than *Kapelga*. In addition, it was found that under irrigation stress condition and optimum irrigation, nitrogen application did not significantly improve the yield of *Kapelga* .This study would therefore help farmers to decide how to manage *Kapelga* in irrigated systems in case where the high yielding *Sariaso* 14 is not accessible.

Keywords: Adaptive strategies, Burkina Faso, Irrigation, Sorghum productivity.

1. INTRODUCTION

Agricultural intensification appears nowadays as the major way to secure food production as world population is increasing [1]. In the current context, with the events of climate change or climate variability, this intensification system led in rain-fed condition could be damageable for the environment [2]. Then, there is a need to look for an intensification system in West Africa especially in Burkina Faso able to improve yields with lower impacts on the environment. The agricultural intensification system suggested in this study included the use of irrigation, the use of different varieties of sorghum and the intensification of land.

According to Cunha [3], irrigation is an adaptive strategy to climate change as it supplies water to plants, preventing them to be subjected to water stress. Soil water stress is known as one of the major factors reducing plant productivity [4]. Irrigation therefore, is very determinant to yield improvement [5] and to the world agriculture [6]. According to Morison et al. [7], world irrigated agriculture area is about 270 million hectares. Only 18% of this area is cultivated but from this small area comes 45% of the world total agricultural production [8]. These data highlight the importance of irrigated agriculture which could be one way to fulfill the growing population food demands.

In Sub-Saharan Africa, the suitable area for irrigation being estimated to 42.5 million ha [9]. And yet, only 4% of this suitable area for irrigation is exploited [10]. Compared to Asia and to Latin America where the irrigated areas are respectively 37% and 14% of the irrigable areas, Sub-Saharan Africa is far from achieving its irrigation potential even though irrigation is most likely key to enhance food security and thereby improve the livelihood of local populations [9].

In Burkina Faso, only 0.6% of irrigable area is exploited for agricultural production [11]. This study revealed that the productivity in cultivated area is about three times greater than that of rain-fed land. Therefore, investing in irrigation seems the most relevant options to fight against erratic rainfall and stabilize agricultural output, boosting and diversifying agricultural products.

To achieve sustainable food production, water management resource through irrigation must be recommended according appropriate conditions. Optimal conditions of farming are very important for agricultural production [12] as they contributes markedly to increase the productivity of sorghum [13]. Some growth conditions such as cropping in cooler periods and cropping under temperature between 20-30 °C are recommended by respectively Hatfield and Prueger [14] and Plessis [15] in hot tropical area. Expanding irrigated area would be also one way to improve crop yields [16]. This expansion could be environmental friendly as irrigated systems are generally less prone to erosion than rain-fed systems [17]. The productivity of the irrigation system could be also more efficient when combined with high yielding varieties. These

ISSN: 2455-6939

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are varieties that used more efficiently water in water limited condition to produce high yield [18].

In Burkina Faso, maize is successfully produced under irrigation in dry season. However, there is little knowledge on production of sorghum under irrigated conditions which is considered as the staple and an adaptive crop [19]. Therefore, the study is testing the effect of irrigation strategy and application of N fertilizer on two contrasting sorghum varieties (local versus high yielding) under two growing conditions (cold dry season and hot dry season). It is hypothesized that (1) the application of N and (2) the optimal application of irrigation water are resulting in higher grain yields for both varieties and (3) the high yielding variety *Sariaso* 14 is outperforming the local *Kapelga* variety regardless of the management options and growing conditions.

2. METHODOLOGY

2.1 Study Area

The experiments were conducted in 2014 and 2015 in two fields close to another in the Central region of Burkina Faso, at the experimental station of Saria (Fig. 1). The site is located at 82 km in the South West of Ouagadougou, in an agro climatic zone with annual rainfall between 700 and 900 mm. According to rainfall data collected in the last 35 years, the average annual rainfall is 811.4 mm with mean number of rainy days of 63. The potential evapotranspiration (PET) is about 6-7 mm day^{-1} from March to June and 3-4 mm day^{-1} from October to February according to the meteorological reports at the site. The average monthly minimum temperatures for the last 35 years are 20 °C and 21 °C respectively in rainy and dry season and the average maximum temperature are 31.5 °C and 36.8 °C respectively in rainy and dry season. The soils are mainly Luvisol with granite rock as parent material. These soils have upper horizons of sandy loam to loamy sand texture and have generally massive structure with low level of fertility [20].

2.2 Experiments Description

The two experiments were set up under two different growth conditions: (i) the first was established on March 17th, 2014 (under temperature > 35° C and the potential evapotranspiration of 7 mm day^{-1} and irrigated permanently) during the dry season experiment was referred to hot dry experiment; (ii) the second dry season experiment called cold dry experiment was set up on October 20th, 2014 (under temperature < 35° C and potential evapotranspiration of 3 mm day^{-1} m^{-2} and irrigated permanently). Each experiment was led out in split-plot design in four repetitions with 3 factors (Fig. 2) which are described as follow:

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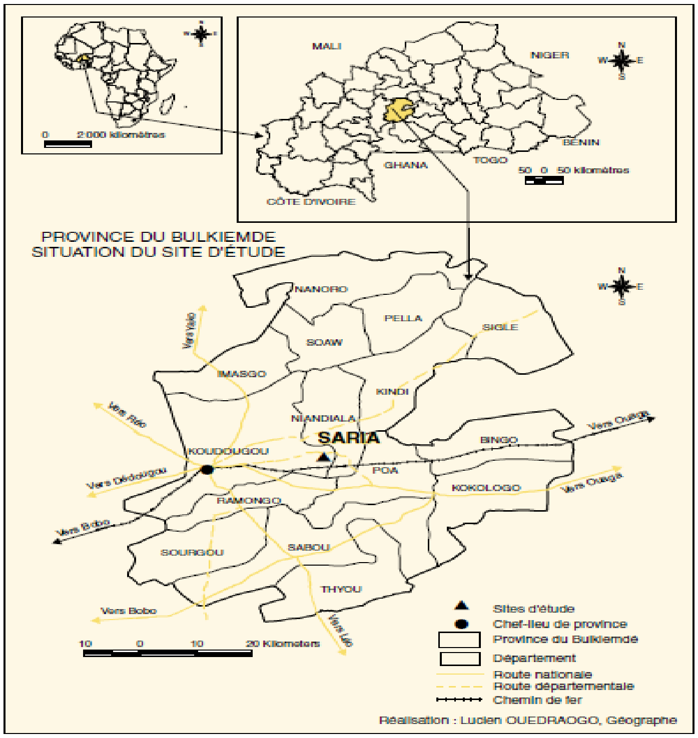

Fig. 1: Location of the study site (Saria)

Source: from Lucien Ouedraogo, geographer

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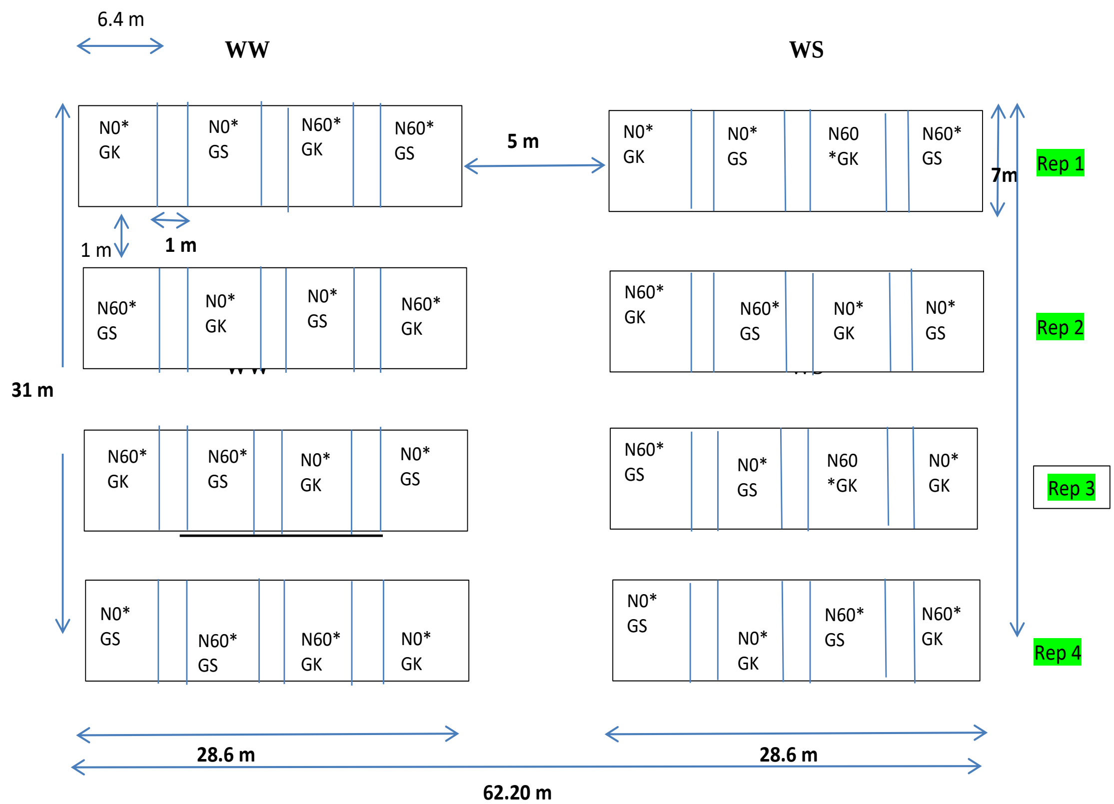

Fig. 1: Experimental design

WW : well-irrigated (100% potential evapotranspiration); WS: irrigated stress (50% potential evapotranspiration) ; N0: no nitrogen (control); N60: 60 kg ha^{-1} of nitrogen; GK: *Kapelga* variety; GS: *Sariaso* 14 variety; Rep: repetitions

Factor 1: Two irrigation regimes: Irrigation stress condition using 50% of the rate of the potential evapotranspiration (PET) during the entire period of production and well-irrigated condition using irrigation amount calculated from the rate of the potential evapotranspiration. The irrigation applied in this well-irrigated condition depended on the growth stages of sorghum plants: (i) 50% of the rate of the potential evapotranspiration (PET) was applied during the first four weeks; (ii) 100% of the rate of the PET was applied from the fifth week to the grain filling period; (iii) 50% of the rate of the PET was then applied from the grain filling period to the physiological maturity period. Daily PET was calculated using the rate of the PET multiply by the area to be irrigated. The irrigation of the two dry experiments was done twice per day (6 a.m. and 4 p.m.) in equal amounts.

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Factor 2: Two nitrogen levels (0 and 60N) were applied to assess their effect on the two irrigated dry experiments. Urea was the source of nitrogen and was applied in two equal half doses to the fertilized plants: the first dose was applied at 15 days after emergence and the second at 45 days after emergence.

Factor 3: Two Sorghum varieties: *Kapelga* (100-105 days) is a local improved variety, while *Sariaso* 14 (110–115 days) is a high yielding variety of sorghum developed in Saria.

2.3 Plot Management and Data Collection

The main plot size was 28.6 m x 7 m and the sub-plot size was 6.4 m x 7 m (8 lines). The sowing density was 0.8 m between lines and 0.4 m between seed hills (16 seed hills). Measurements were done on 4 lines in the middle and concerned 12 seed hills. The outer 2 lines and 2 seed hills, each side, were excluded from sampling, resulting in 4 lines with 12 seed hills. Two plants were left per seed hill. The experimental area was ploughed with tractor and harrowed manually before planting. Basal applications of P at 23 Kg ha^{-1} and K at 14 Kg ha^{-1} were applied using triple super phosphate (TSP) and muriate of potash (KCl) respectively. Field data collection consisted of the following operations:

Reproductive cycle: daily field observations of sorghum were made within the area of measurement from flower buds appearance period until maturity to estimate sorghum reproductive cycle. The observations consisted of noting the number of flower buds and the number of panicle per day. The period of 50% flowering and maximum maturity was noted. We also counted the total number of panicles at the maturity stage.

Yield and yield components: to estimate yield, the total numbers of hills with mature panicles have been first counted in the area of measurement. Afterwards, the straw (including panicles) was cut down and weighed. All panicles were harvested and weighed; the empty and full panicles were separated and also counted and weighed. Then, the full panicles were sun-dried, threshed, winnowed and the grains weighed. Straw yield and grains yield were estimated in kilogram per hectare by dividing their weight by the harvested area. Similarly, the harvest index (HI) was calculated by dividing grain yield by the straw yield (including panicle yield). HI = grain yield/ (sum of grain yield +straw yield).

3. STATISTICAL ANALYSIS

To compare variable among treatments, the associated data were subjected to analysis of variance (ANOVA) using GenStat software 9th Edition. The general analysis of variance in randomized split-plot design was used to compare the means of the main and the interaction

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effects of the studied factors using the least significance differences of mean (L.S.D.) at 0.05 of probability level.

4. RESULTS AND DISCUSSION

The summaries of ANOVA are presented in Tables 1, 2 and 3

Table 1: ANOVA table for straw yield

Treatments		Dry hot experiment	Dry cold experiment
Irrigation	50% PET	11483.8	2740.6
	100% PET	15493.4	3797.9
	p.	0.02*	<.001**
	L.S.D	2789.18	232.5
Fertilization	0N	10493.2	2947.0
	60N	16484.0	3591.5
	p.	<.001**	0.021*
	L.S.D	1825.02	508.0
Variety	*Kapelga*	12155.1	3805.9
	Sariaso 14	14822.1	2732.6
	p.	0.03*	<.001**
	L.S.D.	2376.80	368.6
Irrigation x Fertilization		NS	NS
Irrigation x Variety		NS	NS
Fertilization x Variety		NS	NS
Irrigation x Fertilization x Variety		NS	NS
Irrigation x Fertilization x Variety x Growth condition		NS	

PET : potential evapotranspiration; p.: probability level (5%); L.S.D.: Least significant differences of means (5% level); 0N: no nitrogen; 60N: 60 kg ha^{-1} of nitrogen; NS: no significant difference. * and** are significant at P< 0.05 and P< 0.01 levels of probability, respectively.

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Table 2: ANOVA table for grain yield.

Treatments		Dry hot experiment	Dry cold experiment
Irrigation	50% PET	2004.1	882.3
	100% PET	2821.0	1676.5
	p.	NS	<.001**
	L.S.D	NS	129.8
Fertilization	0N	1954.5	1100.7
	60N	2870.7	1458.2
	p.	<.001**	0.003**
	L.S.D	356.1	187.7
Variety	*Kapelga*	1271.6	770.2
	Sariaso 14	3553.5	1788.6
	p.	<.001**	<.001**
	L.S.D.	540.50	105.9
Irrigation x Fertilization		NS	NS
Irrigation x Variety		NS	NS
Fertilization x Variety		NS	NS
Irrigation x Fertilization x Variety		NS	0.002x
Irrigation x Fertilization x Variety x Growth condition		NS	

PET : potential evapotranspiration; p.: probability level (5%); L.S.D.: Least significant differences of means (5% level); 0N: no nitrogen; 60N: 60 kg ha^{-1} of nitrogen; NS: no significant difference. * and** are significant at P< 0.05 and P< 0.01 levels of probability, respectively.

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Table 3: ANOVA table for harvest index.

Treatments		Dry hot experiment	Dry cold experiment
Irrigation	50% PET	0.14	0.37
	100% PET	0.21	0.48
	p.	0.04*	<.001**
	L.S.D	0.06	0.02
Fertilization	0N	0.15	0.40
	60N	0.20	0.45
	p.	<.001**	0.03*
	L.S.D	0.02	0.04
Variety	*Kapelga*	0.11	0.19
	Sariaso 14	0.25	0.66
	p.	<.001**	<.001**
	L.S.D.	0.05	0.03
Irrigation x Fertilization		NS	NS
Irrigation x Variety		NS	<.001**
Fertilization x Variety		NS	NS
Irrigation x Fertilization x Variety		NS	0.04
Irrigation x Fertilization x Variety x Growth condition		NS	

PET : potential evapotranspiration; p.: probability level (5%); L.S.D.: Least significant differences of means (5% level); 0N: no nitrogen; 60N: 60 kg ha^{-1} of nitrogen; NS: no significant difference. * and** are significant at P< 0.05 and P< 0.01 levels of probability, respectively.

4.1 Effect of growth conditions on sorghum reproductive cycle, on grain and straw yields and harvest index

Table 4 revealed that compared to the production fact sheet, sorghum reproductive cycle was significantly longer (p. < 0.05) in the irrigated hot dry experiment. In this experiment, *Kapelga* variety presented longer flowering days than *Sariaso*14 variety. Flowering and maturity dates were about 50 days longer in *Kapelga* than in *Sariaso*14. For *Sariaso*14, the delay in flowering and maturity days was just about 5 days (Table 4).

Under the irrigated hot dry experiment, the length of the reproductive cycle may be due to the sensitivity of the local variety to photoperiod. The length of this hot dry experiment contributed

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to increase sorghum plant growth and therefore the increase in the straw yield (Fig. 3). During this experiment, *Sariaso* 14 flowered when the temperature was about 38 °C. No significant length was found in this *Sariaso* 14 variety reproductive cycle. However the panicles that flowered were not filled of grain leading to many empty panicles. The panicles may not be able to form grains and this situation may be linked to the rising temperature occurred at the flowering period. It should be noted that the experiment took place in an ambient environment where air humidity was overall low since it was hot and dry. This result corroborated with those of Hatfield and Prueger [14], Singh et al. [21] and Song et al. [22] who reported that high temperature (> 38 ºC) can prevent fertility in sorghum and can also increase risk to sorghum productivity by reducing grain yield. Despite the heat stress effect that prevented panicle fertility, at the end of this irrigated hot dry experiment, grain yield assessment was found higher than that of the cold dry experiment. This was due to the grains formed by the secondary panicles (tillers) developed when the rainy season started. The result agreed with Alam et al. [23] study where they showed that tillers can increase grain yield by increasing the number of panicles. Despite the high grain yield, adopting this practice will be difficult given the length of the reproductive cycle (especially for *Kapelga* variety that reproductive cycle was more lengthened).

Table 4: Sorghum reproductive cycle as affected by growth conditions (in days).

Growth conditions	Beginning flowering		50% flowering		Maturity	
	Kapelga	*Sariaso* 14	*Kapelga*	*Sariaso* 14	*Kapelga*	*Sariaso* 14
Production fact sheet	69	76	76	82	105-110	110-115
Hot dry Experiment	120	80	133	95	160	125
Cold dry Experiment	58	57	82	72	101	85
p.	< 0.05*	< 0.05*	< 0.05*	< 0.05*	< 0.05*	< 0.05*
L.S.D (0.05)	9.74	4.61	9.03	6.33	9.15	9

p.: probability level (5%); L.S.D.: Least significant differences of means (5% level). * is significant at $P < 0.05$ level of probability.

The irrigated cold dry experiment caused early flowering and maturity of the two sorghum varieties. Flowering and maturity in the *Kapelga* variety were respectively 11 and 9 days earlier than indicated in the production fact sheet. For *Sariaso*14 variety, the cycle was 19 and 30 days earlier in the flowering and maturity periods respectively (Table 4). Under this irrigated cold dry experiment, although water use is less [24] in this experiment grain yield and harvest index were much improved (Fig. 3). The result could be linked to the low temperature during this experiment that could prevent high evaporative demand; water and nitrogen which were supplied

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did not evaporate and were profitable to sorghum plants. The result was in accordance with the conclusions of Blum [25] and Fixen et al. [26] according to which sorghum production was linked to the capacity to use efficiently water and nitrogen. The high grain yield and harvest index under this irrigated cold dry experiment may also be due to the earlier maturation (Table 4) allowing the cold dry experiment to be more productive. This result contrasted that of Ouma and Akuja [27] who found that earlier flowering and maturity decreased sorghum grain yield. The positive results induced on yield and yield components by the irrigated cold dry experiment underscored the positive effect of growing sorghum under irrigation in cold dry season.

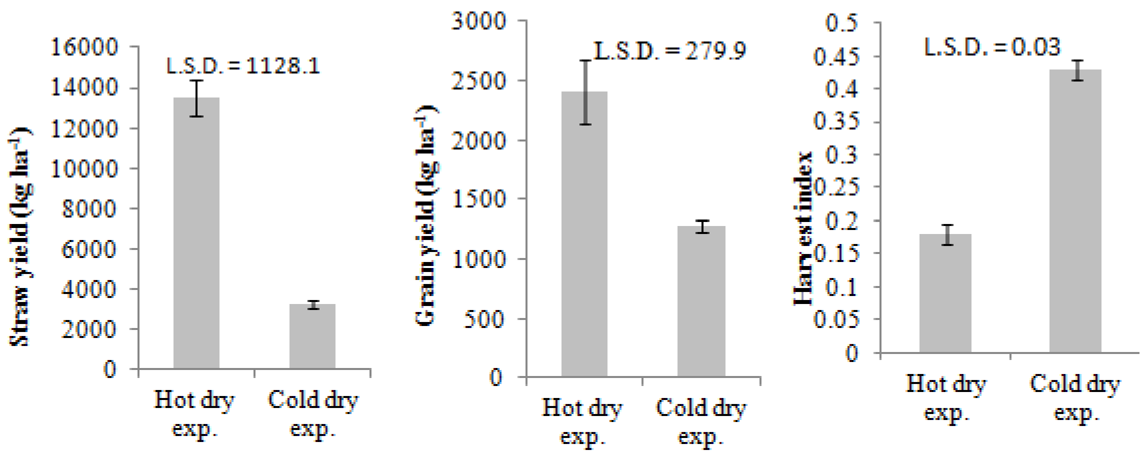

Fig. 2: Sorghum straw, grain yields and harvest index as affected by growth conditions

Hot dry exp.: hot dry experiment sown on March 17th, 2014 (under temperature > 35 °C and the potential evapotranspiration of 7 mm day^{-1} and irrigated permanently); Cold dry exp.: cold dry experiment sown on October 20th, 2014 (under temperature < 35 °C and potential evapotranspiration of 3 mm day^{-1} and irrigated permanently); The numbers on the figure represent the L.S.D.: Least significant differences of means (5% level). The bars represent the standard errors.

4.2 Evaluation of the effect of irrigation regimes on sorghum production

In the two irrigated dry experiments (dry hot and dry cold), the well-irrigated condition (using 100% of PET) presented the highest straw and grain yields and harvest index (Fig. 4). Compared to irrigation or water stress condition, sorghum straw yield was improved by 26% and 28% in the irrigated hot and cold dry experiments respectively under well-irrigated or well-watered condition (Fig. 4). Under the same well-irrigated condition, grain yield was also improved by 29% and 47% in the irrigated hot and cold dry experiments respectively. The well-irrigated condition contributed to improve sorghum harvest index by 33% and 23% in the irrigated hot and cold dry experiment respectively compared to that under irrigation stress condition. This

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underscored the importance of available water for sorghum production. Similar results were noted by Boyer [28] who argued that yield reduction due to water deficit was greater than yield reduction due to other any environmental stresses. To reduce the effect of drought stress on sorghum yield, irrigation would be therefore necessary as it was also noted by Wasige [29].

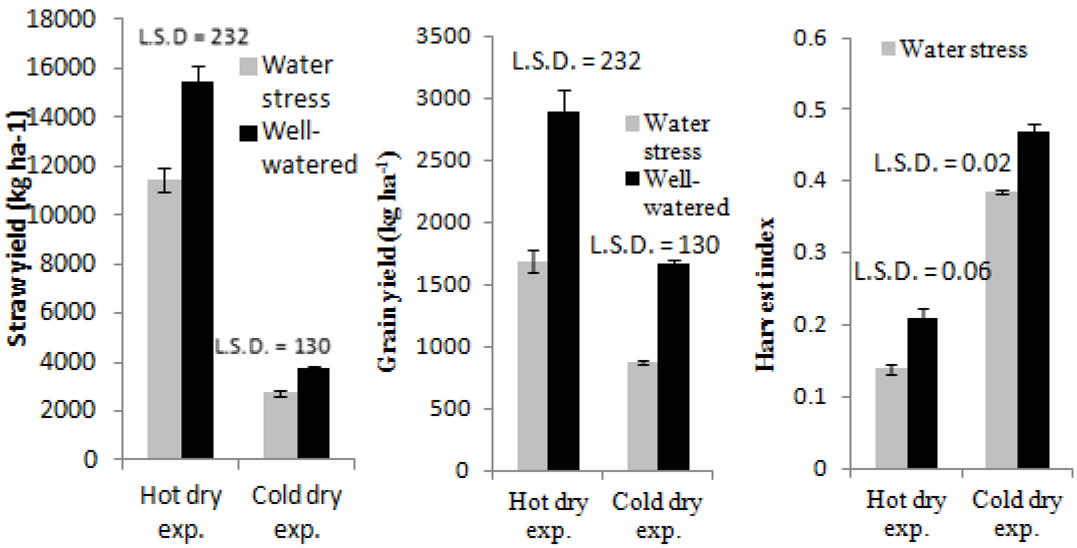

Fig. 3: sorghum straw and grain yields as affected by irrigation regimes

Hot dry exp.: hot dry experiment sown on March 17th, 2014 (under temperature > 35 ^{o}C and the potential evapotranspiration of 7 mm day^{-1} and irrigated permanently); Cold dry exp.: cold dry experiment sown on October 20th, 2014 (under temperature < 35 ^{o}C and potential evapotranspiration of 3 mm day^{-1} and irrigated permanently); The numbers on the figure represent the L.S.D.: Least significant differences of means (5% level). The bars represent the standard errors.

4.3 Evaluation of the effect of irrigation regimes and nitrogen fertilization on the production of two sorghum varieties, *Kapelga* and *Sariaso* 14

With regards to *Kapelga* variety, using the L.S.D. at the probability level of 0.05 to separate the means within the 50% PET x 0N and 50% PET x 60N, we realized that except the straw yield, no significant effect was found on grain yield and harvest index under the two experiments (Table 5, 6 and 7). Within the 100% PET x 0N and 100% PET x 60N, except the harvest index in the hot dry experiment, a significant influence of this interaction between the irrigation and fertilization was noted under the two experiments (Table 5, 6 and 7).

as for the *Sariaso* 14variety, the interaction within 50% PET x 0N and 50% PET x 60N in addition with 100% PET x 0N and 100% PET x 60N under the hot dry experiment, a significant effect of these interactions was expressed on straw yield and grain yield (Table 5 and 6). Under the cold dry experiment, these interactions effect was significant on grain yield and harvest index (Table 6 and 7).

The highest grain yield and harvest index were found in the *Sariaso* 14 variety (Table 6 and 7). Even at 50% PET x 60N, grain yield is 52% higher in *Sariaso* 14 than in *Kapelga* under 100% PET x 60N in the cold dry experiment. Therefore, nitrogen application (60N) and optimal irrigation (100% PET) did not significantly improve the yield of *Kapelga*. The highest grain yield and harvest index obtained in the *Sariaso* 14 variety revealed that *Sariaso* 14 is the high yielding sorghum variety. It may have some genetic characters which allow it to be more performance than the *Kapelga* variety. In addition, these genetic characters of *Sariaso* 14 may allow it to develop more productive secondary tillers. The results are consistent with those of Mutava et al. [30] and Haussmann et al. [31] who reported significant variations among sorghum genotypes contributing to more or less production. This genetic characters could also allow the *Sariaso* 14 variety to shorten its reproductive cycle and to produce more than it was in the *Kapelga* variety during the irrigated cold dry experiment.

This study also indicated that under irrigation stress condition and optimum irrigation (100% PET), nitrogen application (60N) did not significantly improve the yield of *Kapelga*. This situation could result from absorption reduction and increasing nitrogen waste due to water deficit and excess in the soil where *Kapelga* was grown. This study would therefore help farmers to decide how to manage *Kapelga* in irrigated systems in case where the high yielding *Sariaso* 14 variety is not accessible.

Table 5: *Kapelga* and *Sariaso* 14 straw yield as affected by irrigation regimes and nitrogen fertilization

Treatments		*Kapelga*		*Sariaso* 14	
Irrigation regimes	N fertilization	Hot experiment.	Cold experiment.	Hot experiment.	Cold experiment.
50% PET	0N	7125.8	3093.0	9261.3	1891.0
	60N	13962.1	3615.1	15586.1	2363.3
100% PET	0N	10156.2	3847.7	15429.7	2956.3
	60N	17376.2	4668.0	19011.4	3719.8
L.S.D. (0.05)		2716.2	515.4	2716.2	515.4

N: nitrogen; PET: potential evapotranspiration; 0N: no nitrogen (control); 60N: 60 kg ha^{-1} of nitrogen; L.S.D.: Least significant differences of means (5% level).

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Table 6: *Kapelga* and *Sariaso* 14 grain yield as affected by irrigation regimes and nitrogen fertilization

Treatments		*Kapelga*		*Sariaso* 14	
Irrigation regimes	N fertilization	Hot experiment.	Cold experiment.	Hot experiment.	Cold experiment.
50% PET	0N	650.6	350.9	2453.3	1202.8
	60N	723.0	328.2	4189.6	1647.4
100% PET	0N	1263.3	877.1	3450.6	1971.9
	60N	2449.6	1524.8	4120.6	2332.3
L.S.D. (0.05)		970.07	198.23	970.07	198.23

N: nitrogen; PET: potential evapotranspiration; 0N: no nitrogen (control); 60N: 60 kg ha^{-1} of nitrogen; L.S.D.: Least significant differences of means (5% level).

Table 7: *Kapelga* and *Sariaso* 14 harvest index as affected by irrigation regimes and nitrogen fertilization

Treatments		*Kapelga*		*Sariaso* 14	
Irrigation regimes	N fertilization	Hot experiment.	Cold experiment.	Hot experiment.	Cold experiment.
50% PET	0N	0.09	0.12	0.21	0.60
	60N	0.05	0.09	0.23	0.68
100% PET	0N	0.14	0.23	0.28	0.65
	60N	0.15	0.33	0.27	0.72
L.S.D. (0.05)		NS	0.04	NS	0.04

N: nitrogen; PET: potential evapotranspiration; 0N: no nitrogen (control); 60N: 60 kg ha^{-1} of nitrogen; L.S.D.: Least significant differences of means (5% level).

5. CONCLUSION

The experiments conducted in this study showed the possibility to produce sorghum under irrigation in dry season especially in dry cold season where the length of sorghum reproductive cycle is shortened especially that of the high yielding *Sariaso* 14variety. The study underscored the outperformance of the high yielding *Sariaso* 14 variety over the local *Kapelga* variety regardless of the management options and growing conditions. This study also demonstrated that the application of nitrogen fertilizer and the optimal application of irrigation water are key to higher grain yields for the high yielding *Sariaso* 14 variety. However, under the same condition, the yields of the local *Kapelga* variety did not significantly improve. This study had therefore to merit of helping farmers to decide on how to manage the local improved *Kapelga* variety in irrigated systems in case the high yielding *Sariaso* 14 variety was not accessible.

6. ACKNOWLEDGEMENTS

The lead author is grateful to the West African Science Service Center on Climate Change and Adapted Land Use (WASCAL) for the financial support of her PhD study. She is also grateful to the staff of the Institut de l'Environnmentet de recherches Agricoles (INERA)/Kamboinsé especially to her field assistants and to the laboratory assistant who contributed a lot to the success of her study during data collection and their analyses. She would like also to thank the coauthors for their great contributions to the success of this manuscript.

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