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Effect of Supplementary Irrigation on the Yield of Sorghum (*Sorghum bicolor* L. Moench) in the Context of Climate Change in the Dry Savannahs of Togo

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Abstract

Under the current context of climate change, supplementary irrigation may be needed for crop production resilience. We determined the effects of supplementary irrigation on sorghum grain yield in the dry Savannah region of Togo. A two-year trial was conducted in a controlled environment at AREJ, an agro-ecological center in Cinkassé. The plant material was sorghum variety Sorvato 28. The experimental design was a Completely Randomized Block with three replications and three treatments as follows: T_0 control plot (rainfed conditions); T_1 (supplementary irrigation from flowering to grain filling stage) and T_2 (supplementary irrigation from planting to grain filling stage). Two irrigation techniques (furrow and Californian system) were used under each watering treatment. The results showed that irrigation technique significantly affected panicle length with no effect on 1000 grains mass. Panicle length and grain yields varied from 15.59 to 25.71 cm and 0.0 to 2.06 $t \cdot h^{-1}$, respectively, with the highest values (25.66 cm and 2.06 $t \cdot h^{-1}$, respectively) under the T_2 treatment with the California system-based supplementary irrigation. The comparison of results obtained on treatment T_0 and T_2, shows that supplementary irrigation increased the yields by at least 68.62%. Supplementary irrigation during sowing and growing season (T_2) improved sorghum yields in the dry savannahs of Togo, with a better performance of the California irrigation system.

Keywords

Climate Change, Supplementary Irrigation, Sorghum Grain Yield, Dry Savannah,

Togo

1. Introduction

In Togo, cereals represent the leading staple crop and constitute the driving force of households' incomes. Between 2005 and 2022, the areas grown to cereals increased from 210,718 ha to 316,034 ha and more than 53% of the areas are in the dry savannah zone (African Union, 2022; DSID, 2019). Among the cereals produced in Togo, sorghum ranks second after maize and represents 26% of the annual cultivated areas (African Union, 2022). Over the past seventeen years, grain yield of sorghum (with a high nutritional value and source of income especially for women) has never exceeded 1.5 t/ha in the real world (Togo, 2019). Despite the efforts to improve this low productivity, sorghum production is unable to meet the ever-increasing needs of the population (Hatfield et al., 2011; Rao et al., 2015). Instead, we are witnessing the abandonment of its production despite the introduction of new short-cycling varieties such as Sorvato 28.

One of the major constraints to the production of sorghum remains the erratic nature of the rains due to climate change which makes annual production uncertain. One of the effects of this climate change is the appearance of dry spells during sowing and plant development periods (Adewi et al., 2010; Adjoussi, 2000; Atiglo-Gbenou & Azouma, 2023), a phenomenon which considerably affects the crop yield which decreases from year to year. It is therefore urgent to find a solution to improve sorghum production in an area severely threatened by food insecurity where households are reduced to consuming typically one meal a day (Gnon & Azouma, 2018).

To overcome this problem, taking into account the phenomenon of drought, the scarcity and irregularity of rainfall during the sowing and crop growth period, supplementary irrigation is presented as an alternative towards mitigating the effects of water deficit (Diarra et al., 2015; Fadina & Barjolle, 2018). Studies on supplementary irrigation have shown the importance of this practice in correcting the water deficit of crops in order to improve yields. This practice will make it possible to guarantee minimum production whatever the climatic conditions by maintaining a satisfactory water reserve in the soil (Berry et al., 2017; Fadina & Barjolle, 2018). The objective of this study was to determine the effect of supplementary irrigation on the related parameters such as panicle length and yield of sorghum crops in the Dry Savannah region of Togo.

2. Materials and Methods

2.1. Study Area

The study area is the Dry Savannah region of Togo, located between the parallels 9˚25 and 11˚ North latitude and the meridian 0˚ and 1˚ East longitude. It is bordered to the North by Burkina-Faso, to the West by Ghana, to the East by

Benin and to the South by the humid savannah (Figure 1). With an area of 20,321 km^2, rainfall is 1000 to 1300 mm/year (REEM, 2022) with a Sudano-Guinean climate in the south and tropical in the north. The average annual rainfall recorded at the experimental site (Figure 2), for the period March to October 2022,

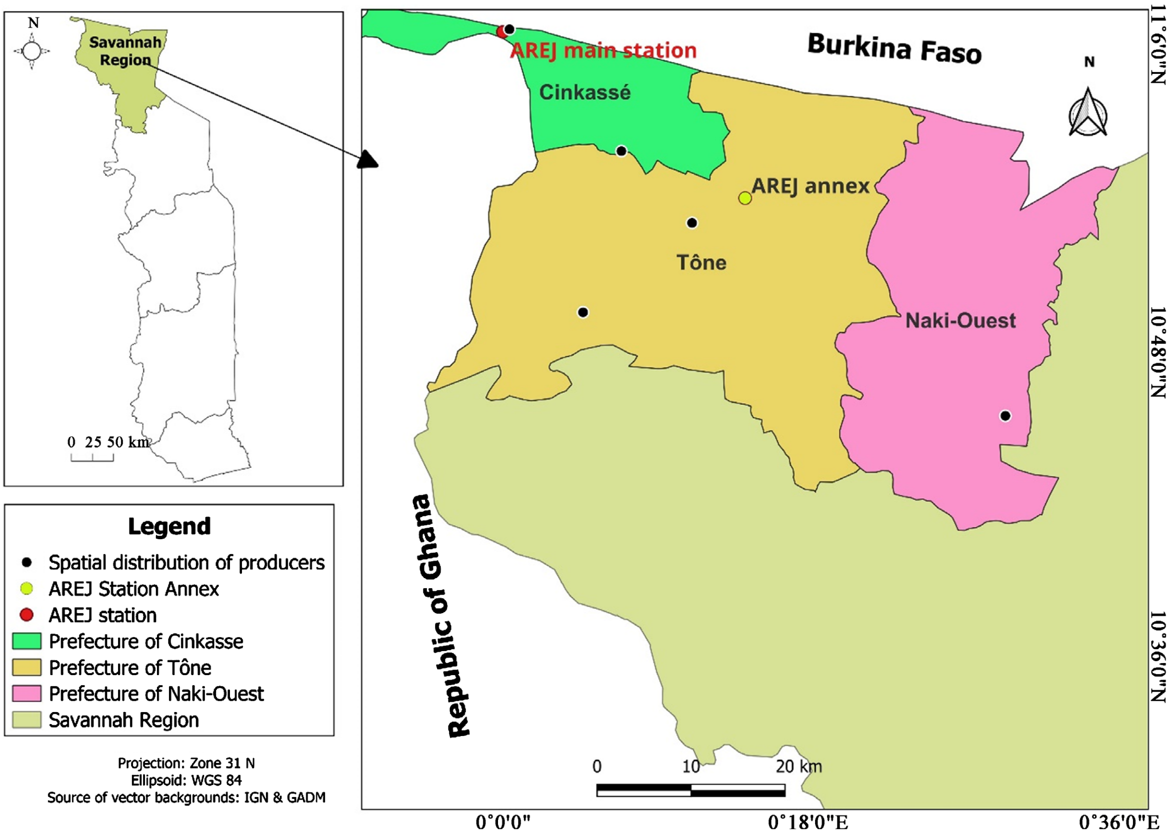

Figure 1. Map of the study area.

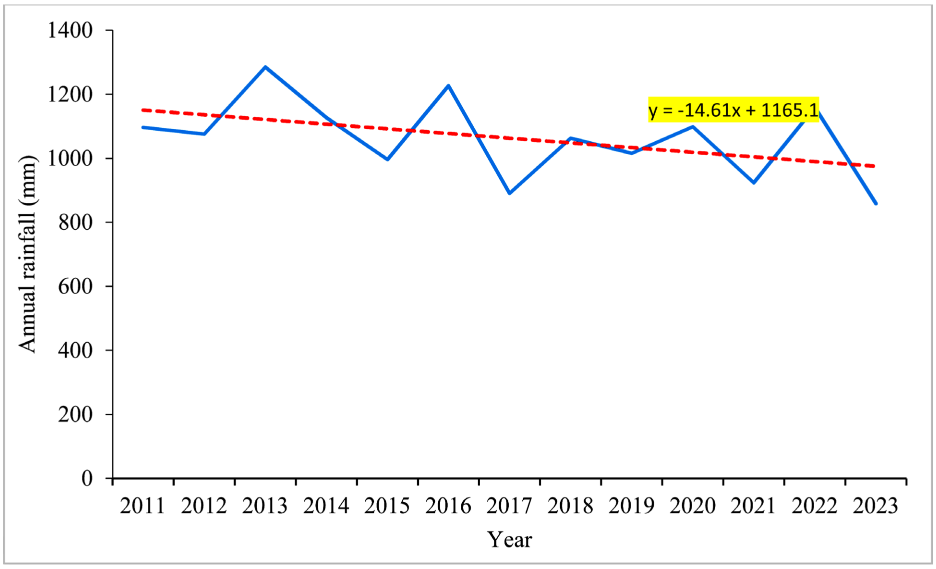

Figure 2. Annual rainfall at the experimental site (Sources: meteorological data from the Savannah region of Togo, 1980-2023).

was 1159.5 mm (CARTO, 2022). Temperatures vary from 39˚ to 17˚ in the dry season and from 34˚ to 22˚ (**Figure 3**) in the rainy season (REEM, 2022). The soil of the study area is the tropical ferruginous type with concretions made up of granite and gneiss, highly degraded with a very marked agricultural influence (ITRA, 2005).

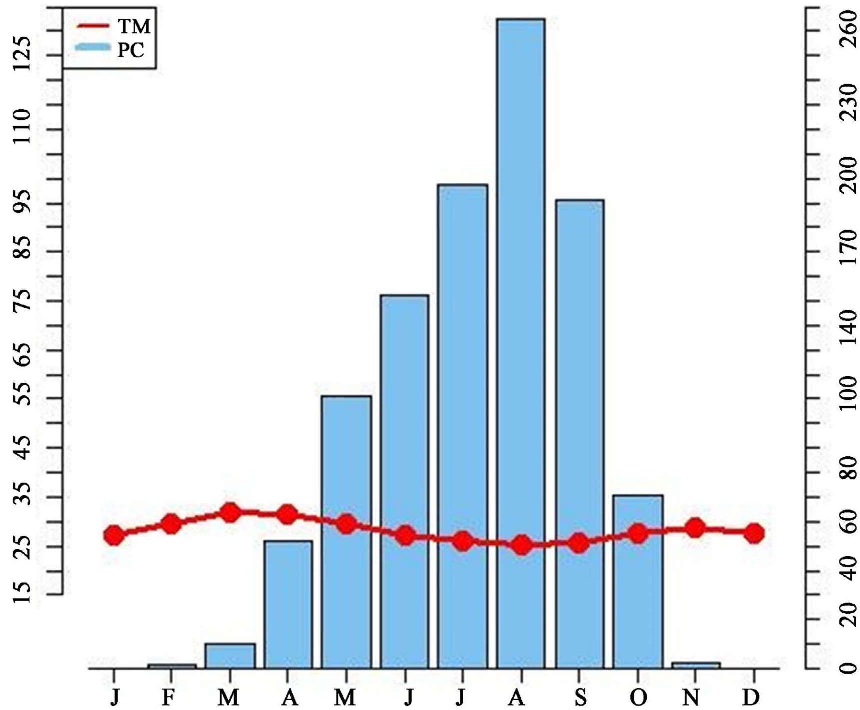

Figure 3. Umbro-thermal curve of the study area (Sources: meteorological data from the Savannah region of Togo, 1980-2023).

2.2. Plant Material

The plant material used consisted of the variety of sorghum (Sorghum bicolor) grown in the Dry Savannahs zone (**Table 1**). Among the varieties grown in the study area, the earliest-maturity available for extension was tested in response to climate change phenomena, in order to evaluate the yield of the crop. The particularity of this variety, unlike those cultivated in the area by producers, lies in its cycle which is 110 days, shorter than that of the local variety, whose cycle reaches 140 days.

Table 1. Characteristics of sorghum (Sorghum bicolor) variety tested.

Varieties	Days to maturity	Plant height (cm)	Panicle type	Seed color	Mass of 1000 grains (g)	Grain texture	Potential yield (t/ha)
Sorvato 28	100 - 110	210 - 220	Semi-compact	Red	23	Horned - toothed	3 - 4

Source: (FAO, 2008).

2.3. Setting up the Trial on Station

The test was carried out during the long rainy season from June to October 2022 for the first implementation and from July to November for the repetition at the AREJ center in Cinkassé, located at latitude 11˚6'34.4898" North latitude and 0˚0'6.13512" west longitude. The soil of the study area is the tropical ferruginous type with concretions made up of granite and gneiss, highly degraded due to agricultural influence (ITRA, 2005). The experimental design adopted is Completely Random Block with three repetitions with three treatments. Sorvato 28, sorghum variety performance was tested under two irrigation techniques, furrow and the Californian system. Individual plots area of was 38.4 m^2 (8 m × 4.8 m) each. Sowing was carried out on June 23th 2022 for the first trials and July 1st for the repetition on blocks arranged perpendicular to the slope to achieve successful irrigation. Sorghum variety Sorvato 28 is sown according to the cropping pattern recommended by extension agricultural service in the study area. Sowing spacing was 0.80 m distance between lines and 0.40 m between two consecutive pockets on a line giving a density of 62,500 plants·ha^{-1}.

The trials were conducted according to the following technical itinerary: clearing, adding enriched compost (5 t·ha^{-1}) (**Table 2**), ploughing, sowing, weeding at the 15th, 30th and 45th day after sowing. The applying of mineral fertilization, specifically NKP 15-15-15 (150 kg·ha^{-1}) and Urea 46% (50 kg·ha^{-1}) at the 15th and 30th after planting for NKP 15-15-15 and 45th day from sowing for urea as recommended. Additionally, crop protection against armyworm was implemented by spraying hemacot on plant using sprayer followed by harvesting at november for the first year and no harvesting for the second implementation. *Zea mays* and vegetables are the crops usually grown on the experimental plot.

The treatments were as follow:

- Treatment (T_0): control plot under rainfed conditions;
- Treatment (T_1): supplementary irrigation from flowering to grain filling stage;
- Treatment (T_2): supplementary irrigation from planting to grain filling stage (**Figure 4**);
- Two experimental set-ups were used for each irrigation technique, on the experimental site.

Table 2. Rates of nutrients applied in the form of enriched compost.

Parameters	Total nitrogen (N)	Assimilable Phosphate (P_2O_5)	Soluble potassium (K_2O)	Organic carbon	pH (1: 20)
Corresponding quantitity of nutrient (kg ha^{-1})	105	65.5	45.5	397	8.5

Source: Togolese Institute of Agronomic Research (ITRA)/Laboratory Department/Analysis report.

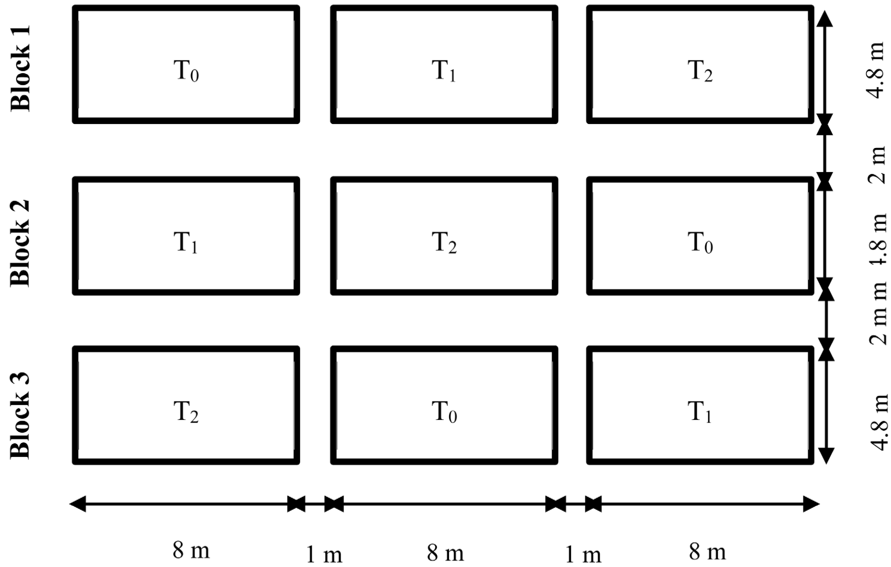

Figure 4. Experimental set-up of the controlled environment trials.

2.4. Irrigations Techniques

Furrow irrigation consisted of creating and supplying water through a pipe to small parallel trenches in the ground to transport water to the feet of the plants. In this practice, the plants were generally installed on the ridges (FAO, 1990). This technique required prior site planning to take account of the topography, and waste water.

The Californian irrigation system consisted of bringing irrigation water to the crops through rigid PVC pressure pipes with a diameter of 40 - 50 mm buried at a depth of 0.5 m in order to protect them from UV rays and agricultural works. Intakes were connected to these rigid pipes at regular intervals of 18 - 36 m. A watering hose was connected to the intakes for crop irrigation (WOCAT, 2018). Furrow and Californian system was tested on a different experimental set-up.

2.5. Determination of the Crop's Water Needs

In order to know the quantity of water to bring to each plot, the water needs of the crop were evaluated by the Cropwat 8.0 software. Supplementary irrigation using a borehole was carried out as soon as the rains stopped for at least two days after sowing or following a short and light rainfall that could not satisfy the crop's daily needs during this period. The required irrigation per decade is shown in Table 3. Determination of the flow rate of the sprinklers allowed respect of the watering time that could satisfy the daily needs of the sorghum crop.

2.6. Agronomic Parameters

The agronomic parameters studied were: length of panicle, mass of 1000 grains (to provide information on how yields are achieved and any problems the plant may have encountered during its development) and yield.

Sorghum yield was determined by formula (1):

Table 3. Evaluation of the decadal water requirements of sorghum on the experimental plot.

Month	Decade	Stage	Coefficient Cultural (Kc)	ETc (mm/decade)	Effective rainfall (mm/decade)	Irrigation required (mm/decade)
June	3rd	Initial	0.7	13.9	0.0	13.9
July	1st	Initial	0.7	26.1	0.0	26.1
July	2nd	Growth	0.71	24.8	0.0	24.8
July	3rd	Growth	0.79	29	0.0	29
August	1st	Growth	0.87	28.1	0.0	28.1
August	2nd	Mid-season	0.95	29.6	0.0	29.6
August	3rd	Mid-season	1.02	35.2	0.0	35.2
September	1st	Mid-season	1.02	32.7	0.0	32.7
September	2nd	Mid-season	1.02	33.3	0.0	33.3

Sources: meteorological data from the Savannah region of Togo, 1980-2020 and cropwat 8.0; Etc: crop evapo-transpiration.

$$R = \frac{P \cdot 10000}{S} \quad (1)$$

R = yield (in t/ha);

S = plot area (m^2);

P = mass of grain harvested on the elementary plot (t).

The statistical analysis of the collected data was carried out using Xlstat and SPSS software. The Student-Newman-Keuls test at the 5% threshold was performed to determine the different statistics.

3. Results and Discussion

3.1. Effect of Supplementary Irrigation on Panicle Length

Table 4 summarizes the results obtained on the average panicle length of sorghum 28. The highest value of panicle length, 24.42 cm, was recorded under the T_2 irrigation treatment in Californian system, followed by the T_1 treatment, 21.20 cm. On the plots under the furrow irrigation, this average panicle length measured under the T_1 treatment was 23.53 cm, followed by the T_2 treatment at 21.62 cm. Not depending of the irrigation technique, the average panicle length of the T_0 treatments did not exceed 16 cm. The analysis of variance shows that there was a significant difference at the 5% level between irrigations techniques. These results show that irrigation technique has an effect on panicle length. Although the test conditions are not geographically the same, the results confirm the work of Abera et al. (2020), Yemane and Habtamu (2019) who showed through their study that the highest sorghum panicle lengths are obtained under crops that have obtained the full water requirement through irrigation. The

Table 4. Average panicle length, of Sorvato 28 under Californian and furrow irrigation obtained in controlled conditions.

Treatment		Average panicle length (Mean ± SD)
California irrigation system	T_0	15.54 ± 0.55^b
	T_1	21.20 ± 0.67^a
	T_2	24.42 ± 2.33^a
Furrow irrigation	T_0	15.24 ± 0.42^b
	T_1	23.53 ± 1.45^a
	T_2	21.62 ± 0.88^a
F		0.557
p		0.003

T_0: control plot under rainfed conditions; T_1: supplementary irrigation from flowering to grain filling stage; T_2: supplementary irrigation from planting to grain filling stage.

availability of water from planting to grain filling stage (T_2 treatment) and from the flowering to grain filling stage (T_1 treatment) resulted in the longest panicle length. Supplementary irrigation contributed to the improvement of the panicle length of sorghum (Carsky et al., 2002; Derese et al., 2018; Sun et al., 2018).

3.2. Effect of Supplementary Irrigation on 1000 Grains Mass and Grain Yield

The result of the analysis of the mass of 1000 grains is for the first year of implementation. In fact, during the repetition trial, panicle formation coincided with the period of heavy rain, causing abortion. **Table 5** shows identical average values whatever the treatment. These results show that the irrigation technique has no effect on the 1000 grains mass obtained. Statistical analysis did not reveal any significant difference at the 5% level. Similar results are obtained by Bruns (2015) who stated through their study that supplementary irrigation seems not to bring effects on 1000-grain mass.

Grain yields of sorghum variety obtained on station are recorded in **Table 5**. Low yields were obtained under treatments T_0 and T_1, with respective averages of 0.71 $t \cdot ha^{-1}$ and 1.17 $t \cdot ha^{-1}$ for the Californian irrigation system; 0.00 $t \cdot ha^{-1}$ and 0.43 $t \cdot ha^{-1}$ for the furrow irrigation system. Lower yield is due to plant losses where there is not supplementary irrigation. Some treatment yields are zero, as a result of abortion phenomena occurring during pollination, another consequence of climate change on sorghum production. The best average grain yield was recorded under the T_2 treatment, which is 2.06 $t \cdot ha^{-1}$ under the California irrigation system. In fact, most of the plants that received supplementary irrigation produced panicles early, unlike the rain-fed plants, which experienced delayed growth and were hit by panicle abortion. These results support the hypotheses that supplementary irrigation contributes to yield improvement. The best yield is obtained from some treatment that present a good panicle length average. The

Table 5. Average mass of 1000 grains and grain yield of Sorvato 28 under Californian and furrow irrigation obtained in controlled conditions.

Treatment		Mass of 1000 grains (Mean ± SD)	Grain yield (t/ha) (Mean ± SD)
California irrigation system	T_0	27.87 ± 0.33^a	0.71 ± 0.71^b
	T_1	27.97 ± 1.00^a	1.17 ± 0.58^{ab}
	T_2	27.60 ± 0.88^a	2.06 ± 0.35^a
Furrow irrigation	T_0	38.93 ± 0.58^a	0.43 ± 0.43^b
	T_1	28.37 ± 1.45^a	0.00 ± 0.00^b
	T_2	28.33 ± 0.33^a	0.97 ± 0.57^{ab}
F		2.763	5.810
p		0.069	0.006

T_0: control plot under rainfed conditions; T_1: supplementary irrigation from flowering to grain filling stage; T_2: supplementary irrigation from planting to grain filling stage.

results show the positive effect of panicle length on yield. The longer the panicle is, the more numerous is the grain that defining a good yield.

The grain yields of the sorghum variety obtained are the results of the combined effect of organic, mineral fertilization and supplementary irrigation. These results confirm those of Fox and Rockström (2003) and Andom et al. (2017) who demonstrated through their study that supplementary irrigation and fertilization can increase crop yields. Also the work of Mohammed and Misganaw (2022) carried out on the modelling of sorghum crop showed that the increase in sorghum yields will be conditioned by the application of supplementary irrigation and nitrogen fertilization to sorghum crops in semi-arid zones. Supplementary irrigation increased yields by about 1 $t \cdot ha^{-1}$ (Getachew et al., 2021). The zero yields achieved on some plots in the first year of implementation and during the trial repetition are due to the effect of abiotic factors on the sorghum crop. Indeed, increased rainfall during the fertilisation phase of sorghum in our trials resulted in flower abortion of some plants and thus reduced number of grains per panicle or no seed formation (Jabereldar et al., 2017). Low yields in treatments T_0 and T_1 are the effects of water stress in the early vegetative phase leading to reduction in panicle length, panicle weight and number of grains per panicle (d'Arc Coulibaly et al., 2020; Jabereldar et al., 2017). The comparison of these results with T_2 treatments highlights the effects of supplementary irrigation in improving sorghum crop yields (Chen et al., 2021; Sigua et al., 2020; Wale et al., 2019).

4. Conclusion

This study shows that supplementary irrigation contributes effectively to yield improvement. Indeed, compared to the T_1 treatment in furrow irrigation, the yield increased by 52.91% for the T_2 treatment under Californian irrigation system. Average panicle length is one of the parameters influencing grain yield of sorghum unlike 1000 grain mass which has no significant effect on yield. Supplementary irrigation of sorghum during the sowing and flowering periods is a recommended practice in dry savannah areas with low rainfall at the beginning of the cropping season. The absence of supplementary irrigation for treatment T_1 had a degressive effect on yield due to the loss of young plants. Watering during the days following sowing (Treatment T_2) has a considerable effect on grain yield of sorghum. This study will help producers in the dry Savannahs of Togo to reduce crop losses that can affect yields due to pockets of drought, by implementing supplementary irrigation in the context of climate change. In addition, it would enable agriculture's extension workers to determine a new sowing date conform to sorghum 28, so that to avoid panicle formation falling within the period of heavy rains, which can cause panicle abortion.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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