



Research Article

Growth and Yield Response of *Masakwa* Sorghum (*Sorghum bicolor* (L.) Moench) Cultivars to Supplementary Irrigation in a Nigeria Sahel Savanna Vertisols

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ARTICLE INFO:

Keywords:

Masakwa sorghum,
Cultivars,
Supplementary irrigation,
Vertisols,
Economic returns

ABSTRACT

Masakwa sorghum, a post-rainy season crop is commonly grown using residual moisture without supplementary irrigation on heavy clay soils or Vertisols during cool harmattan period. Field experiments were conducted to determine response of *masakwa* sorghum cultivars to supplementary irrigation during 2020/2021 and 2021/2022 dry seasons in sahel savanna vertisols in Monguno Local Government Area of Borno State NE Nigeria. Four irrigation treatments applied at 0.3, 0.6, 0.9 and 1.2 liters/stand constituted the irrigation treatments, while *Adja'ama* and *Tumbuna* constituted the cultivars. The treatments were replicated three times in a Randomized Complete Block Design. Plant heights were significantly higher for 0.3, 0.6 or 0.9 liters ($P < 0.01$) than 1.2 liters at 4 WAT, 0.6 and 0.9 liters ($P < 0.05$) than 0.3 or 1.2 liters at 8 WAT, and 0.3 liter ($P < 0.01$) than 0.6 or 1.2 liters at 10 WAT. Panicle length was significantly ($P < 0.01$) greater for 0.6 and 0.9 liters, while grain yield per plant was significantly ($P < 0.01$) greater for 0.3 liter than the other irrigation levels. Grain yield per hectare was significantly ($P < 0.01$) greater when irrigation was applied at flower inception (0.9 liter), while the cultivar *Tumbuna* significantly ($P < 0.01$) produced superior grain yield than *Adja'ama*. Straw yield per plant was significantly ($P < 0.01$) greater for 1.2 liters, but harvest index was significantly ($P < 0.01$) greater for 0.3 liter than the other treatments. The economic returns from the irrigation levels were negative as the marginal rate of returns: - ₦2.64, - ₦0.82 and - ₦0.23 for 1.2, 0.9 and 0.6 liters per stand, respectively, however, the farmer practice (0.3 liters at transplanting only) realized net benefit of ₦42,960.00 per hectare. It is apparent therefore that the flower inception is the most critical stage for moisture stress in *masakwa* sorghum; however, there is no economic benefit of supplementary irrigation of the sorghum cultivars after transplanting as observed from the current study.

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INTRODUCTION

Masakwa sorghum is a post-rainy season crop grown on heavy clay soils or Vertisols during cool harmattan period using residual soil moisture stored from the previous seasons' rainfall (Ogunlela and Obilana, 1983; Gworgwor, 1989; Dugje and Odo, 2011; Dugje *et al.* 2014). There are about four million hectares of Vertisols or 'Firgi' heavy clay soils that occur mainly between latitudes 8°30', 12°30' and longitudes 10°, 14°E in Nigeria (Klink Enberg and Higgins, 1968). Out of the 420,000 hectares of Vertisols in Borno State, about 41,609 hectares sown to *Masakwa* sorghum (MANR, 1990). The cool dry season offers opportunity for growing the *Masakwa* cultivars at a time when it is practically impossible to grow other grain crops without irrigation. The crop contributes immensely to the local economy of the major *Masakwa* sorghum producing areas in Borno State, Nigeria that include Dikwa, Bama, Ngala, Gwoza, Mafa, Kala Balge, Monguno and Marte Local Government Areas (Olabanji *et al.*, 1996; Gworgwor, 2001; Dugje *et al.*, 2014). It provides supplementary supply of grains and forage during the dry season for both human and livestock consumption.

The effects of water stress on crop growth and grain yield depends on the timing and magnitude of water stress as well as crop type, since different crops have different levels of tolerance to water stress (Irmak and Rudnick, 2014). For many field crops, the most critical period of water stress is during the transition from vegetative to reproductive growth or from flowering to fruit setting stages of growth (Doorenbos and Pruitt, 1977). Plants respond and adapt to and survive under drought stress by the induction of various morphological, biochemical and physiological responses. Due to their ability to grow only under residual moisture soil, *masakwa* sorghum has a high resistance to drought. Drought tolerance is

defined as the ability to grow, flower and display economic yield under suboptimal water supply. Drought stress affects the water relations of plants at cellular, tissue and organ levels, causing specific as well as unspecific reactions, damage and adaptation reactions (Beck *et al.*, 2007). To cope with the drought, tolerant plants initiate defense mechanisms against water deficit (Chaves and Oliveira, 2004), which need to be investigated in further detail. Relative water content, leaf water potential, stomatal resistance, rate of transpiration, leaf temperature and canopy temperature are important characteristics that influence plant water relations.

Four principal cultivars of *Masakwa* sorghum are most consistent across the Chad Basin Area and described in Kanuri/Shuwa Arab loanwords include: *Adjagama* (*Adja'ama*) – cream seeded; *Bulwalana* (*Bul,walana, Wala, Walagana*) – white seeded; *Buruku* (*Burgu, Buruku-Kime, Buruwu*) – brown seeded; and *Tumbuna* – dirty white seeded (Dugje *et al.*, 2014). Preliminary investigations conducted in the major *Masakwa* growing areas of Borno State indicate that average grain yield of *Masakwa* is much less than that of the rain fed sorghum (Olabanji *et al.*, 1996). A survey of ethno-agronomic practices and constraints to *Masakwa* sorghum production in parts of northeast Nigeria identified the major production constraints as low yield potential of existing cultivars, moisture stress, persistent weeds, pests and disease infestations, low plant density, hardening of the soils and dearth of research information on the crop (Dugje *et al.*, 2014). Under arid and semi-arid conditions, which prevail in Borno State, satisfactory grain yields are dependent upon the crop cultivar's ability to tolerate water stress (Mubeen *et al.*, 2013). Under field conditions, water shortage often occurs concurrently with high air temperature in the low to mid-latitudes and are therefore important threat limitations to plant growth (Farooq *et al.*, 2012) and sustainable agriculture (Ahuja *et al.*, 2010) worldwide.

Three main mechanisms reduce crop yield by soil water deficit: (i) reduced canopy absorption of photosynthetically active radiation, (ii) decreased radiation-use efficiency and (iii) reduced harvest index (Earl and Davis, 2003).

Masakwa is becoming a crop of interest in the dry environments of Borno State frequently exposed to water stress due to the promise that it may be a lower water use crop compared to other cereals grown in this environment. Investigations revealed that sorghum yield potential might greatly reduce depending on the timing of drought stress relative to the growth stage with the critical period being about one week prior to booting through two weeks past flowering (Kelley and Lawson 2013). There is however, limited research that aims to identify growth and yield response of *Masakwa* to varying irrigation regimes applied at different stages of its growth. The aim of the study is to evaluate the growth and yield responses of *Masakwa* sorghum to supplementary irrigation imposed at different stages of growth.

MATERIALS AND METHODS

Experimental site

A two-year field experiment was conducted at Mainari (12.41° N, 13.36° E) in Sahel Savanna, Monguno Local Government Area of Borno State Nigeria during the October 2020 to February 2021 and October 2021 to February 2022 cool harmattan dry seasons. The site lies in Sahel savanna agro-ecological zone with an average annual rainfall and temperature of 500 mm and 33 – 35°C, respectively. The soil texture is very fine heavy clay, low in organic matter, and among the major *Masakwa* sorghum producing areas in Borno state.

Nursery management

A non-waterlogged area was selected for the nursery site at Monguno. Two seedbeds measuring 3 m x 3 m were prepared to raise the seedlings for the study. One-kilogram seed of each cultivar treated with Apron Star 42 WS at the rate of 10 g of seed to control pre and post

emergence pests and diseases. The seeds were evenly broadcast in the seedbed and properly incorporated into the soil with hand hoe. Weeds removed by hand pulling and the seedlings allowed growing for 5 weeks in the nursery.

Transplanting

The experimental site was cleared of grasses when the floodwater had receded in October each year. Each year, 5-week-old seedlings uprooted from nursery and two seedlings transplanted per stand at equidistant spacing of 1.0 m x 1.0 m (20,000 plants/ha) as recommended (Dugje and Odo, 2011) in October 2020 and 2021 each year. Transplanting holes 15 – 20 cm deep were dug manually with a digger locally referred to as *gafkal* or *tuman*. Seedlings of similar size were selected and placed inside the hole, seedling roots were pushed into the mud at the bottom of the hole, and 0.3 liters of water was poured into each hole. No fertilizer was applied as this is the farmer practice in the area.

Treatments and experimental design

The treatments comprised two cultivars and four irrigation levels. The two cultivars include: i) *Adja;ama* and ii) *Tumbuna*. The four irrigation levels were: i) Irrigation with 0.30 liters per stand at the time of transplanting (Control); ii) Irrigation with 0.60 liters per stand at end of vegetative growth only; iii) Irrigation with 0.90 liters per stand at inception of flowering only; iv) Irrigation with 1.20 liters per stand at grain filling stage only. The treatments replicated three times in a randomized block design in 2 x 4 factorial arrangements. Each of the 24 experimental plots measured 5 m x 6 m separated by 0.5 m alleys. Each plot bordered on all sides by an earthen ridge to prevent run-on and run-off to adjacent plots.

Irrigation management

All treatments were applied 0.3 liters of water per stand of two plants at transplanting using graduated watering can. Additional irrigation applied once with 0.6, 0.9 and 1.2 liters per

stand at vegetative, flower inception and grain filling stage, respectively,

Data collection and analysis

Crop growth characteristics measured at vegetative, flowering, and physiological maturity stages of growth each year include plant establishment count, plant height (cm), stem diameter (cm), number of leaves per plant, leaf area per plant (cm²), panicle length (cm), grain yield per plot (kg), straw yield (kg) and harvest index (%). Data collected were subjected to analysis of variance (ANOVA) and means separated by LSD ($p < 0.05$) test where appropriate. Partial budgeting and marginal analysis were applied to determine the profitability of the irrigation levels.

RESULTS AND DISCUSSION

Plant height

The response of *masakwa* sorghum to supplementary irrigation revealed that plant heights at 4 weeks after transplanting (WAT) were significantly ($P < 0.01$) lower for 1.2 liters than for either 0.3, 0.6 and 0.9 liters in 2021, and 2022 (Table 1). Application of 1.2 liters per stand significantly ($P < 0.01$) reduced plant height by 56% compared to the other irrigation levels. Plant height at six WAT did not significantly differ among the treatments across years and the combined mean. The 0.3 liters had slightly taller plants than the other treatments, while the 1.2 liters recorded relatively shorter plants than the other irrigation levels. At eight WAT, application of 0.6 or 0.9 liters of water per stand significantly ($P < 0.05$) produced taller plants than 0.3 or 1.2 liters in 2021, 2022 and the combined mean. There was no significant difference between 0.3 and 1.2 liters on one hand, and 0.6- and 0.9-liter irrigation levels on the other. Plant height at 10 WAT was significantly ($P < 0.05$) greater for 0.3 liters than the other irrigation levels in 2021, 2022 and the combined mean. These treatments did not significantly differ from 0.6 liters in 2021 and 0.9 liters in 2022. In addition, there were no

significant differences in plant height between 0.6 and 1.2 liters in 2021, 0.9 and 1.2 liters in 2022 and between 0.6, 0.9, 1.2 liters for the combined mean at 10 WAT (Table 1).

The shrink -swell properties of vertisols, may explain the decrease in plant height of *masakwa* sorghum with increase in irrigation levels. The swell property is at its peak at the time of flooding until the floodwater recede to a level when soil air and water are close to equilibrium. Addition of water immediately after this level of equilibrium at 4 WAT probably restored saturation to some extent thus reducing soil aeration and inhibiting growth. Application of higher irrigation levels during the season continued to reflect superior plant heights for lower irrigation levels probably because *masakwa* sorghum a deep-rooted crop may respond sparingly to further irrigation after transplanting due to the very low percolation and low soil aeration characteristics of the soil. FAO (1998) referred to vertisols as soils having a vertic horizon within the 100 cm from the soil surface. The heavy clayey (30 - 95%) soils become very hard and develop deep and wide cracks during the dry season. During the first few rains, water moves downward the soil profile without being absorbed into the soil matrix. Infiltration occurs in the subsoil matrix via the bottom of the cracks and along the crack faces, a process named 'internal catchment'.

The results for the *masakwa* cultivars showed significant differences in plant height in 2021 and 2022 at 4 WAT (Table 1). The cultivar *Adja'ama* significantly ($P < 0.01$) produced taller plants than *Tumbuna* at these dates. However, there was no significant difference in plant height of the two cultivars as growth progressed until almost similar heights (198.6 m) attained for the combined mean at 10 WAT. There is probably little or no genetic variability between the cultivars in the expression of plant height under similar environmental conditions of the sahel savanna vertisols.

Panicle length

Panicle length was significantly higher for 0.6 and 0.9 liters than 0.3 and 1.2 liters in 2021 ($P < 0.05$), 2022 ($P < 0.01$) and combined mean ($P < 0.01$) (Table 2). There was no significant difference between 0.6 and 0.9 liters on one hand and 0.3 and 1.2 liters on the other across the years. Moderate supplementary irrigation at flower inception therefore increased panicle length compared to low or high irrigation levels. There was no significant difference between the cultivars in panicle length.

Grain yield per plant

There was no significant difference in grain yield per plant in 2021, 2022 and the combined mean (Table 2). Grain yield per plant increased in the order: 0.3 > 1.2 > 0.6 > 0.9 liters, indicating mixed response as the lowest level of irrigation recorded greater yield per plant than the highest level. The response of the cultivars to the supplementary irrigation showed no significant difference in grain yield per plant.

Grain yield per hectare (kg)

Grain yield per hectare was significantly ($P < 0.01$) higher for 0.6 liters in 2021 and 0.9 liters in 2022 than other treatments (Table 2). There was no significant difference for the combined mean. Irrigation at flower inception and grain filling therefore increased grain yield per hectare as the timing of the application probably suppressed water stress. Irmak and Rudnick (2014) reported that the effects of water stress on crop growth and grain yield depends on the timing and magnitude of water stress as well as crop type, since different crops have different levels of tolerance to water stress. For many field crops, the most critical period of water stress is during the transition from vegetative to reproductive growth or from flowering to fruit setting stages of growth (Doorenbos and Pruitt, 1977).

Grain yield per hectare was significantly ($P < 0.01$) higher for *Tumbuna* (464 kg/ha) than *Adja'ama* (448 kg/ha) (Table 2). This confirms

similar finding by Olabanji *et al.* (1996) who reported higher grain yield for *Tumbuna* than the other cultivars in selected communities in both sudan and sahel savanna zones of Nigeria. Similarly, Dugje *et al.* (2008) reported significantly higher grain yields for Bougouri-28 Cameroon (951 kg/ha) an improved variety, *Bulwalana-Yeshawa-Gajibo* (776 kg/ha), and *Tumbuna – Bama* (716 kg/ha) than 24 other entries tested at Ngala in sahel savanna. Since the cultivars are grown under moisture deficit, Mubeen *et al.* (2013) reported that satisfactory grain yields are dependent upon the ability of the crop cultivar to tolerate water stress.

Straw yield per plot (kg)

There were no significant differences among irrigation levels on straw yield per plot in 2021, 2022 and combined years (Table 3). However, the 1.2 liters slightly recorded greater straw weight than the other treatments, while 0.3 liters produced the lowest value. The two sorghum cultivars did not significantly differ in straw weight, but the cultivar *Tumbuna* had slightly higher straw weight than *Adja'ama*.

Straw yield per plant (g)

Straw yield per plant was significantly ($P < 0.01$) higher for 1.2 liters than the other irrigation levels (Table 3). The 1.2 liters was not significantly different from 0.9 liters in 2021, while no significant differences observed among the other treatments in 2021, 2022 and the combined mean. The response of cultivars revealed that straw yield per plant was significantly ($P < 0.05$) higher for *Tumbuna* than *Adja'ama* in 2021.

Harvest index (%)

Harvest indices were significantly greater for 0.3 liters in 2021 ($P < 0.05$), 2022 ($P < 0.05$) and the combined mean ($P < 0.01$) (Table 3). However, these did not significantly differ with 0.9 liters in 2021 and 0.6 liters in 2022. The allocation of assimilates for grain yield was therefore expressed more by the control treatment than the supplementary irrigation levels during both

years and combined. Like grain yield, the cultivar *Tumbuna* expressed greater ($p < 0.05$) harvest index than *Adja'ama*.

Economic returns from irrigation

The marginal rates of returns from additional irrigation versus control or farmer practice were all negative (Table 4). The economic losses increased with increase in irrigation levels. The marginal rates of return were ~~₦~~2.64, ~~₦~~ 0.82 and ~~₦~~ 0.23 for application of 1.2, 0.9 and 0.6 liters per stand, respectively. This implies that for every naira invested in application of 1.2 liters, 0.9 liters and 0.6 liters, ₦ 2.64, ₦ 0.82, and ₦ 0.23 is lost, respectively. However, the farmer practice (0.3 liters at transplanting only) realized net benefit of ₦ 42, 960.00 per hectare. Therefore, there is no economic advantage of additional irrigation of *masakwa* sorghum cultivars after transplanting as the practice result in economic losses as observed from the current study conducted in the sahel savanna vertisols.

CONCLUSIONS

Application of supplementary irrigation to *masakwa* sorghum cultivars in sahel savanna vertisols revealed mixed responses. Plant height decreased with increase in irrigation levels early in the season, but latter stabilized to similar heights towards the end of the seasons. Panicle length and grain yield per plant were greater for control than the higher irrigation levels.

However, grain yield per hectare was greater when irrigation was applied at flower inception, which probably alleviated moisture stress at this critical growth stage. The cultivar *Tumbuna* also expressed superior grain yield than *Adja'ama*. The allocation of assimilates for grain yield or harvest index was also greater for control than the higher irrigation levels. Increasing irrigation levels decreased marginal rate of returns. Hence, there is no economic advantage of supplementary irrigation for *masakwa* sorghum after the initial application done at transplanting in this study,

CONFLICT OF INTEREST

The authors declare no conflict of interest in the execution and publicizing the results of the Institutional Based Research (IBR) approved for University of Maiduguri and funded by Tertiary Education Trust Fund (TETFUND).

ACKNOWLEDGEMENTS

This research work is Institution Based Research (IBR) funded by Tertiary Education Trust Fund (TETFUND) being part of approved research projects for University of Maiduguri, Nigeria. The support of research assistants and farmers during the field work is greatly appreciated. The research team is greatly indebted to the Center for Research and Innovation University of Maiduguri for their patience with delay in the completion of the project due to insecurity.

Table 1: Effect of irrigation levels on plant height of *Masakwa* sorghum cultivars at different growth stages in 2021, 2022 and combined years

Treatments Irrigation (L/Stand)	4 WAT			6 WAT			8 WAT			10 WAT		
	2021	2022	Combined	2021	2022	Combined	2021	2022	Combined	2021	2022	Combined
0.30	42.27 ^a	42.37 ^a	42.34 ^a	110.73 ^a	109.73 ^a	110.23 ^a	126.77 ^b	126.77 ^b	126.77 ^b	202.41 ^a	202.41 ^a	202.41 ^a
0.60.	43.08 ^a	42.17 ^a	42.63 ^a	117.73 ^a	108.63 ^a	108.68 ^a	151.15 ^a	149.50 ^a	149.50 ^a	201.53 ^{ab}	192.83 ^c	197.18 ^b
0.90	42.17 ^a	43.08 ^a	42.63 ^a	108.93 ^a	117.43 ^a	117.68 ^a	149.50 ^a	151.15 ^a	151.15 ^a	192.83 ^c	201.53 ^{ab}	197.18 ^b
1.20	18.68 ^b	18.58 ^b	18.63 ^b	101.63 ^a	102.60 ^a	102.63 ^a	130.43 ^b	130.43 ^b	130.43 ^b	197.43 ^b	197.43 ^b	197.43 ^b
SE	2.6475 ^{**}	2.6475 ^{**}	3.3976 ^{**}	4.1884 ^{ns}	4.1884 ^{ns}	4.1884 ^{ns}	6.2816 [*]	6.2816 [*]	6.2816 [*]	1.3893 ^{**}	1.3893 ^{**}	1.3447 ^{**}
LSD (0.05)	8.030	8.030	9.727	NS	NS	NS	19.053	19.053	19.053	4.2140	4.2140	3.8498
Cultivar												
<i>Adja'ama</i>	44.17 ^a	42.83 ^a	36.500 ^a	108.97 ^a	110.50 ^a	110.50 ^a	140.96 ^a	137.97 ^a	137.97 ^a	198.61 ^a	198.50 ^a	198.55 ^a
Tumbuna	28.83 ^b	29.27 ^b	36.500 ^a	110.50 ^a	108.97 ^a	108.97 ^a	137.97 ^a	140.96 ^a	140.96 ^a	198.50 ^a	198.61 ^a	198.55 ^a
SE	1.8721 ^{**}	1.8721 ^{**}	2.4025 ^{ns}	2.9616 ^{ns}	2.9616 ^{ns}	2.9616 ^{ns}	4.4418 ^{ns}	4.4418 ^{ns}	4.4418 ^{ns}	0.9824 ^{ns}	0.9824 ^{ns}	0.9509
LSD (0.05)	5.6783	5.6783	6.8782	8.9832	NS	NS	NS	NS	NS	NS	NS	NS
Interaction												
I x C	**	**	**	*	*	*	NS	NS	NS	NS	NS	NS

WAT = Weeks after Transplanting, *, ** = *F*-test significant at $p < 0.1$ and $p < 0.05$ respectively; NS = *F*-test not significant at $p < 0.05$

Table 2: Effect of irrigation levels on panicle length, and grain yield of *Masakwa* sorghum cultivars in 2021, 2022 and combined years

Treatments Irrigation (L/Stand)	Panicle length (cm)			Grain yield/plant (kg)			Grain yield/ha (kg)		
	2021	2022	Combined	2021	2022	Combined	2021	2022	Combined
0.30	25.00 ^b	25.00 ^b	25.00 ^b	0.01 ^a	0.013 ^a	0.013 ^a	446.77 ^c	446.77 ^c	446.77 ^a
0.60	28.25 ^a	27.77 ^a	28.01 ^a	0.01 ^a	0.012 ^a	0.010 ^a	441.12 ^d	470.60 ^a	455.86 ^a
0.90	27.77 ^a	28.25 ^a	28.01 ^a	0.01 ^a	0.009 ^a	0.010 ^a	470.60 ^a	441.12 ^d	455.86 ^a
1.20	24.38 ^b	24.38 ^b	24.38 ^b	0.01 ^a	0.012 ^a	0.012 ^a	451.83 ^b	451.83 ^b	451.83 ^a
SE	0.791*	0.793**	0.797**	1.85ns	1.848ns	1.327ns	0.698**	0.697**	14.114ns
LSD (0.05)	2.400	2.402	2.289	NS	NS	NS	2.117	2.167	NS
Cultivar									
<i>Adja'ama</i>	24.69 ^b	24.01 ^a	24.35 ^a	0.010 ^a	0.012 ^a	0.011 ^a	442.82 ^b	453.33 ^b	448.08 ^a
Tumbuna	28.01 ^a	28.69 ^b	28.35 ^a	0.012 ^a	0.010 ^a	0.011 ^a	463.83 ^a	464.82 ^a	463.82 ^a
SE	0.559ns	0.555***	0.565ns	1.306ns	1.306ns	9.388ns	0.494**	0.534***	9.902ns
LSD (0.05)	NS	1.692	NS	NS	NS	NS	1.497	1.967	NS
Interaction									
I x C	NS	*	NS	NS	NS	NS	**	**	NS

*, ** = *F*-test significant at $p < 0.1$ and $p < 0.05$ respectively; NS = *F*-test not significant at $p < 0.05$

Table 3: Effect of Irrigation levels on straw yield and harvest index of *Masakwa* sorghum cultivars in 2021, 2022 and combined years

Treatments Irrigation (L/Stand)	Straw yield/plot (kg)			Straw yield /plant (kg)			Harvest index (%)		
	2021	2022	Combined	2021	2022	Combined	2021	2022	Combined
0.30	0.717 ^a	0.72 ^a	0.717 ^a	0.033 ^b	0.033 ^b	0.033 ^b	27.73 ^a	28.22 ^a	27.97 ^a
0.60	0.760 ^a	0.80 ^a	0.780 ^a	0.028 ^b	0.036 ^{ab}	0.032 ^b	22.09 ^b	24.02 ^{ab}	23.06 ^b
0.90	0.800 ^a	0.76 ^a	0.780 ^a	0.036 ^{ab}	0.028 ^b	0.032 ^b	24.02 ^{ab}	22.09 ^b	23.06 ^b
1.20	0.833 ^a	0.83 ^a	0.833 ^a	0.046 ^a	0.046 ^a	0.046 ^a	20.82 ^b	22.66 ^b	21.74 ^b
SE	0.055ns	0.0546ns	0.0375ns	0.012*	0.012*	0.0034*	1.813*	1.625*	1.302**
LSD (0.05)	NS	NS	NS	0.020	0.021	0.009	4.887	4.932	4.728
Cultivar									
<i>Adja'ama</i>	0.734 ^a	0.73 ^a	0.734 ^a	0.034 ^a	0.038 ^a	0.036 ^a	21.43 ^b	24.58 ^a	23.00 ^a
Tumbuna	0.821 ^a	0.82 ^a	0.821 ^a	0.038 ^a	0.034 ^a	0.036 ^a	25.91 ^a	23.92 ^a	24.91 ^a
SE	0.0386ns	0.0386ns	0.0265ns	2.806*	2.806ns	2.465ns	1.2824*	1.1497ns	0.9208*
LSD (0.05)	NS	NS	NS	0.0013	NS	NS	2.567	NS	2.6361
Interaction									
I x C	NS	NS	*	*	*	NS	NS	*	*

* = *F*-test significant at $p < 0.05$; NS = *F*-test not significant at $p < 0.05$

Table 4: Partial budget and marginal analysis of supplementary irrigation levels on *Masakwa* sorghum grain yield, 2021 and 2022 combined years

Partial budget/Irrigation Levels	1.2 liters	0.9 liters	0.6 liters	0.3 liters	
Average grain yield (kg/ha)	452	456	456	447	
Adjusted yield (kg/ha)	406.8	410.4	410.4	402.3	
Gross field benefits (₦/ha)	81360	82080	82080	80460	
Costs that vary/ha					
Water	100,000	75000	50,000	25,000	
Labour for application	50,000	37500	25000	12,500	
Total cost	150,000	112500	75,000	37500	
Net benefit (₦/ha)	-68640	-30420	7080	42960	
Marginal analysis					
Irrigation Levels	Total cost- (₦)	Net benefit (₦)	Marginal Cost (₦)	Marginal net Benefit (₦)	Marginal rate of return
1.2 liters	150000	-68640	37500	-99060	-2.64
0.9 liters	112500	-30420	75000	-61560	-0.82
0.6 liters	75000	7080	112500	-25680	-0.23
0.3 liters (control)	37500	42960	-	-	

Average market price of masakwa sorghum grains in 2021 and 2022 = ₦ 200 per kg

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