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Research Article

Performance Evaluation of Sesame under Regulated Deficit Irrigation Application in the Low Land of Western Gondar, Ethiopia

Sisay Ambachew Mekonnen and Assefa Sintayehu

University of Gondar, Department of Plant Sciences, P.O.Box 196, Gondar, Ethiopia

Correspondence should be addressed to Sisay Ambachew Mekonnen; sisayambachew@yahoo.com

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Sesame (*Sesamum indicum* L.) is the leading oil seed crop produced in Ethiopia. It is the second most important agricultural commodity for export market in the country. It is well suited as an alternative crop production system, and it has low crop water requirement with moderate resistance to soil moisture deficit. The low land of North Western Ethiopia is the major sesame producer in the country, and the entire production is from rainfed. The rainfall distribution in North Western Ethiopia is significantly varied. This significant rainfall variability hampers the productivity of sesame. Irrigation agriculture has the potential to stabilize crop production and mitigate the negative impacts of variable rainfall. This study was proposed to identify critical growth stages during which sesame is most vulnerable to soil moisture deficit and to evaluate the crop water productivity of sesame under deficit irrigation. The performance of sesame to stage-wise and uniform deficit irrigation scheduling technique was tested at Gondar Agricultural Research Center (Metema Station), Northern Western Ethiopia. Eight treatments, four stage-wise deficit, two uniform deficit, one above optimal, and one optimal irrigation applications, were evaluated during the 2017 irrigation season. The experiment was designed as a randomized complete block design with three replications. Plant phenological variables, grain yield and crop water productivity, were used for performance evaluation. The result showed that deficit irrigation can be applied both throughout and at selected growth stages except the midseason stage. Imposing deficit during the midseason gave the lowest yield indicating the severe effect of water deficit during flowering and capsule initiation stages. When deficit irrigation is induced throughout, a 25% uniform deficit irrigation can give the highest crop water productivity with no or little yield reduction as compared with optimal irrigation. Implementing deficit irrigation scheduling technique will be beneficial for sesame production. Imposing 75% deficit at the initial, development, late season growth stages or 25% deficit irrigation throughout whole seasons will improve sesame crop water productivity.

1. Introduction

In recent years, the world has become more complex due to an alarming growing world population and its demand for more food, water, and energy. Because of limited arable land for expanding food production, there is an increase in pressure on natural resources and ecosystem services [1–3]. The essential factors in food production that is per capital of cultivated land and fresh water are declining continuously as the world population increases. The natural resources over the world are limited, and excess manipulation and utilization will exaggerate resource exhaustion [4].

Fresh water and soil nutrient availability remains globally the most limiting crop growth factors [5]. Increase in threats of fresh water shortage, reduction in arable land, decline in soil fertility, and more frequent and severe drought due to climate variability/change have stimulated research into water saving strategies aiming at producing more "crop per drop" [5, 6]. Crop production is the largest global consumer of fresh water, and water is a key resource in agricultural production [7]. In worldwide, agriculture accounts for 80–90% of all fresh water used by humans, and most of the water is used for the cultivation of crop [6]. Realizing the combination of high crop water productivity and improved crop yield is an important element of sustainable development.

The main limitation for irrigation development in most parts of Ethiopia is the availability of water [8]. Whenever the available fresh water supply is a limiting factor for agricultural production, deficit irrigation practices have paramount importance in improving crop water productivity [9–11]. Deficit irrigation application is a simple agronomic practice without extra cost and can be easily implemented as farm water saving strategy for every farming communities.

Crops recommended for deficit irrigation applications are those that are relatively drought resistant and early maturing varieties [12]. Sesame (*Sesamum indicum* L.) belongs to the order Tubiflorae and family Pedaliaceae and is one of the most ancient and early maturing oil crops in the world [13, 14]. Sesame is commonly known as the king of oil crop because of high level oil content of the grain seed (50%–60%) [15]. It is well suited as an alternative crop production system under irrigation because it has low-level crop water requirement [16]. Ethiopia is ranked 6th in level of sesame production with estimated 327,741 tons of production in 2013 cropping season [17]. Sesame seed is a leading crop in the country oil seed export where more than 90% of production is directed to export market [14, 18]. Sesame is the second most important agricultural commodity in Ethiopia next to coffee by foreign exchange earnings in which agricultural commodities are the mainstay of Ethiopian economy [17].

The low land of North Western Ethiopia is the major sesame producing area in the country, and the entire production is from rainfed. The rainfall distribution in north western part of Ethiopia for the last 30 years was significantly varied [19]. This significant rainfall variability hampers the productivity of sesame. Therefore, irrigation agriculture has immense potential to stabilize crop production and mitigate the undesirable impacts of variable or insufficient rainfall for cultivated crops [20]. Irrigation development in Ethiopian context could increase farm production, income, asset endowment, and employment opportunity; reduce the incidence of poverty at the household level; and reduce vulnerability to climate variability in the country [21, 22]. Plant nutrient availability and soil moisture-related issues are the major factors causing frequent crop failure and/or hamper productivity of sesame in Ethiopian context [17]. Abasena is one of the widely cultivated sesame variety in most sesame producing areas of Ethiopia, and the productivity is improved when the production is under irrigation [17].

Recent studies in Ethiopian context support that lands under irrigation system are more stable and profitable than rainfed production. Expanding irrigation development, as supported by the Ethiopian government, is a feasible development strategy with the potential for solving food security problem in the country [23]. With high market demand, promising environmental condition, and fair favorable price for farmers, sesame has been introduced and promoted in the North Western low land of Ethiopian agricultural production system [24]. Sesame is drought tolerant and has short life cycle of 80–120 days to maturity with a good potential for crop intensification in given plot of land [25]. Given the early maturing and low-crop water requirement nature of sesame, assessing the critical growth stages where sesame is most sensitive to water stress could help in improving crop water productivity and water-related managements [25, 26]. The specific objectives of the study were to identify critical growth stage/s during which sesame is most sensitive to water deficit and to evaluate the crop water productivity of sesame with induced deficit irrigation scheduling at different growth stage/s in the low land of North Western Ethiopia.

2. Materials and Methods

2.1. Description of the Study Site. The experiment was conducted at Gondar Agricultural Research Center (Metema Station) in North Western low land of Ethiopia from February 17 to June 7, 2017. Metema is located about 900 km northwest of Addis Ababa and 188 km West of Gondar Town (Figure 1). The site is located at 12°57′01.35″N latitude, 36°15′27.97″E longitude, and 760 meter above sea level. February to May is generally dry, and there was little rain during the experiment period (Figure 2).

The minimum and the maximum annual long-term average daily temperature ranges from 16°C to 24°C and 30°C to 40°C, respectively (Figure 2). Average daily temperature becomes very high during the months of March to May, where it may get to as high as 43°C. The low land of North Western Ethiopia has a monomodal rainfall. The rainy months extend from June until the end of September. The soil had dark brown clay loam texture, low salinity, neutral pH, medium CEC, very low organic carbon, low total nitrogen, and low available phosphorous (Table 1).

2.2. Soil Sampling, Preparation, and Analysis. Composite soil sample was collected using auger at soil depth 0–30 cm from the experimental field to determine selected soil physicochemical properties. However, for determination of bulk density (BD), moisture content at field capacity (FC), and permanent wilting point (PWP), undisturbed soil samples were collected using core samples from the experimental field before planting. The soil samples were analyzed following the standard laboratory procedure described by [27].

The soil moisture content at FC and PWP was measured at -1/3 and -15 bars, respectively, using the pressure plate apparatus. The available water holding capacity of the soil can be obtained by subtracting the water content at PWP from that at FC. The soil bulk density was calculated as the ratio of mass of oven-dried soil to bulk volume of soil in the core.

2.3. Experimental Design and Treatments. The field experiment was designed as randomized complete block design with eight treatments and three replications (Table 2). Each

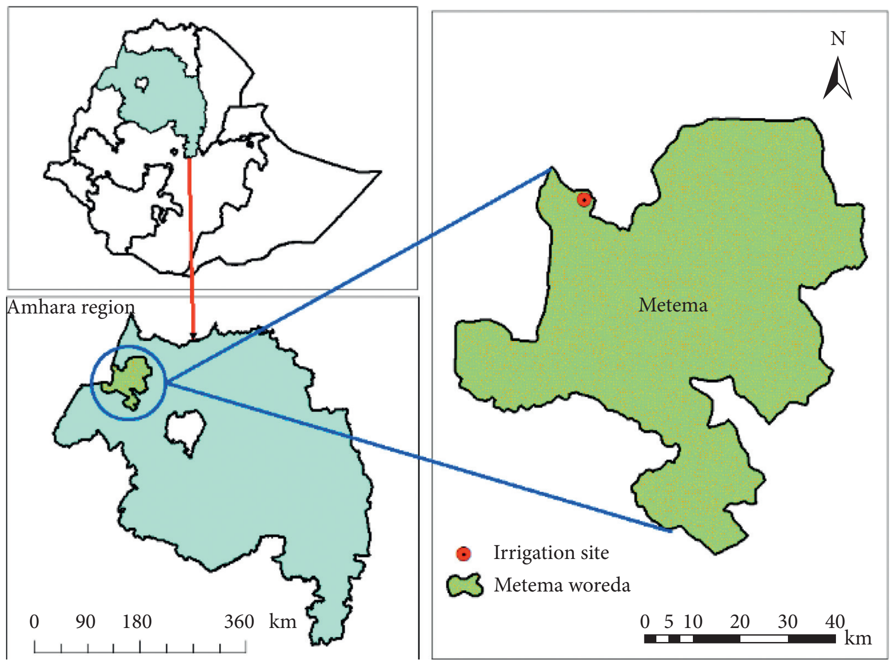

Figure 1: The geographic map of Metema Experiential Site, North Western low land of Ethiopia.

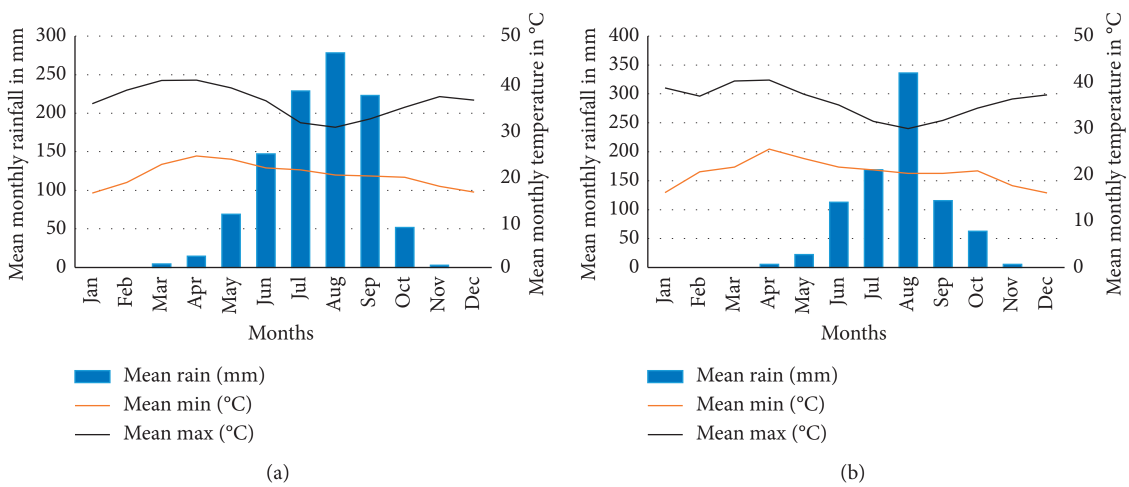

Figure 2: Long-term monthly average rainfall and daily mean minimum and maximum temperatures (a) and mean daily temperature and annual rainfall of 2017 calendar year (b).

experimental unit had six rows. The two outer rows of each sides were used as the buffer row, while the four central rows were used for agronomic data collection. Sesame (variety Abasena) was planted 10 cm between crops and 40 cm between rows on a $2.4 \times 5\,m^2$ plot per treatment. Two seeds were planted per hills and thinned to one plant after emergence. Frequent weeding was done manually in all experimental units when there was an invasion of weeds.

Furrows were 5 m long, closed end, and with 1% average slope of the experimental field. Nationally blanket recommended P_2O_5 fertilizer at a rate of 46 kg ha^{-1} P_2O_5 was applied at the time of planting. The source of N was urea fertilizer (46% N), and DAP (18% N) at the rate 64N kg·ha^{-1} was applied for all treatments uniformly with split application: half at time of planting and half 45 days after planting.

A 25 mm preplant irrigation water was applied to experimental field 5 days before planting date to break clods, to loosen the soil for better planting and to ensure that the crop germinates well and for desired crop stand establishment. Subsequent irrigations throughout the experimental period were applied as per the treatments depth. The CROPWAT 8.0 computer program which was based on the FAO Penman–Monteith method [28] was used for calculating reference crop evapotranspiration (ETo) with long-term monthly average climatic parameters. Crop water requirement (ETc) and irrigation requirement were estimated on daily basis. The crop parameters adopted to calculate crop

Table 1: Study site soil characteristics.

Soil characteristics	Mean values
Total nitrogen (%)	0.11
Organic matter (%)	2.25
Available phosphorus (mg/kg)	12.7
Cation exchange capacity (cmol (+) kg^{-1} soil)	48.3
pH	6.93
Electric conductivity (ds/m)	0.041
Sand (%)	15.5
Clay (%)	58.0
Silt (%)	26.5
Textural class	Clay
Field capacity (v/v)	0.340
Permanent wilting point (v/v)	0.228
Bulk density (g cm^{-3})	1.3
Total available water (v/v)	0.112

water requirement at daily step are presented in Table 3. These parameters include the crop coefficient (Kc), rooting depth taken here as the sowing depth, manageable soil moisture depletion level (*P*), and the number of days at each growth stages. Irrigation water was applied as variable depth on fixed seven-day interval for each treatment throughout the experimentation periods.

The experimental field was arranged to create favorable condition for crop growth and furrow irrigation application as per the recommendation of the agronomic requirement of sesame. The irrigation water source was from the nearby water channel. The water was then brought to the experimental field by water pump and collected in a pond for ease of controlled irrigation water application. And then the water was applied carefully to every experimental unit through narrow delivery pump to ensure application at desired level of water for each treatment and to avoid over flow of water during irrigation water application.

2.4. Data Collection and Analysis. The following agronomic data were collected from the middle four rows of each experimental units, that is, the gross size of $2.4 \times 5\,m^2$. And the net (harvestable) plot was $1.6 \times 5\,m^2$. Plant phenological stages such as days to flowering and maturity were recorded in the plot base. Parameters such as number of capsule per plant and number of seed per capsule were recorded on plant bases. Thousand seed weight (g), grain yield (kg/ha), and crop water productivity (kg $ha^{-1}\,mm^{-1}$) were recorded in plot base. Days to flowering 50%: number of days from planting until 50% of the plant in the plot initiates flowering. Days to physiological maturity: days to physiological maturity were recorded number of days from planting until 75% of the plants in the plot bear matured capsules.

Crop water productivity (kg mm^{-1}) was calculated with the following empirical formulas:

$$\mathrm{WP} = \frac{\mathrm{Ya}}{\sum \mathrm{ETa}}, \quad (1)$$

where WP stands for crop water productivity (kg mm^{-1}). Ya is the marketable crop yield (kg/kg ha^{-1}), and ETa refers to the actual volume of water lost through evaporation and/crop transpiration during the crop cycle (m^3/mm) [9]. Since there is no easy way of distinguishing between transpiration by plants and evaporation from field, they are generalized under the terms of evapotranspiration [29].

The yield response factors for deficit irrigation treatments which is the ratio of relative yield reduction to relative evapotranspiration were calculated using the following equation [28, 30]:

$$\left(1 - \frac{\mathrm{Ya}}{\mathrm{Ym}}\right) = \mathrm{Ky}\left(1 - \frac{\mathrm{ETa}}{\mathrm{ETm}}\right), \quad (2)$$

where K_y refers to the yield response factor, Ya stands for the actual crop yield ($kg{\cdot}ha^{-1}$), Ym stands for the maximum crop yield ($kg{\cdot}ha^{-1}$), ETa refers to actual evapotranspiration (mm), and ETm also stands for maximum evapotranspiration (ETc) in mm.

The data analysis for the collected crop data was done using analysis of variance (ANOVA) following general linear model procedure of Statistical Analysis Software (SAS). Means were separated using the least significance difference (LSD) test at the 95% level of probability when there was a statistically significant difference between treatments.

3. Result and Discussion

3.1. Crop Water and Irrigation Requirement. The values of the reference crop evapotranspiration (ET_o) of the experimental site were calculated using the FAO Penman–Monteith method during the cropping season on daily step, and the value varied between 4.05 mm/day in February and 6.59 mm/day in April (Table 4). The calculated ET_o value of the experimental site varies from 4.05 to 6.59 mm/day, and the evapotranspiration demand ranges from moderate to high [28]. The crop coefficient (K_c) values adopted from [28] varied from 0.60 at the time of sowing to high of 1.1 during midseason (Table 3). Accordingly, the optimum irrigation amount required under no stress condition (100% ET_c) was about 548 mm (Table 3), while the minimum amount was 287 mm (50% ETc) and the maximum amount 679 mm (120% ETc).

3.2. Phenological Variability and Plant Height. Deficit irrigation water application showed significant difference ($p < 0.05$) on plant height in sesame crop which was recorded at the time of physiological maturity (Table 5). The maximum plant height (182 cm) was observed under optimum irrigation water application throughout the growth season (UO), and the lowest plant height was also recorded (158 cm) on experimental plots which received 50% deficit irrigation throughout the growth season. Similar research findings on sesame have been reported in [31, 32]. Water is important to build plant tissue and carries out biochemical and physiological activities within the plant body to express the development.

Crop phenological data collected from the field study showed that days to 50% flowering were significantly affected ($p < 0.01$) by different levels of irrigation treatments and stage-wise deficit irrigation water application (Table 5).

Table 2: Description of irrigation treatments.

No.	Treatments	Growth stages				Remark
		*P*1	*P*2	*P*3	*P*4	
1	T1	1	1	1	1	100% ETc, normal irrigation throughout
2	T2	0	1	1	1	Deficit at P1 only and the rest normal
3	T3	1	0	1	1	Deficit at P2 only and the rest normal
4	T4	1	1	0	1	Deficit at P3 only and the rest normal
5	T5	1	1	1	0	Deficit at P4 only and the rest normal
6	T6	50%	50%	50%	50%	50%, water requirement will be applied
7	T7	75%	75%	75%	75%	75%, water requirement will be applied
8	T8	120%	120%	120%	120%	120%, water requirement will be applied

Note. 1, normal watering—100% of ETc irrigation water application; 0, 75% deficit, indicates only 25% of ETc irrigation water application. 50% = 50% deficit, indicates only 50% of ETc irrigation water application; 75% = 25% deficit, indicates only 75% of ETc irrigation water application; 120% = application of 120% of ETc irrigation water application. *P*1: initial (planting to juvenile); *P*2: development (first buds to flower initiation); *P*3: midseason (flower initiation to late bloom stage); *P*4: late season (ripening to physiological maturity) growth stages.

Table 3: Sesame crop parameters used for crop water estimation.

	Growth stage				
	Initial	Developed	Mid	Late	Total
Depletion fraction (*P*)	0.45	0.45	0.45	0.45	
Crop coefficient (K_c)	0.6	0.85	1.1	0.25	
Growth stage (days)	20	30	40	20	110

Source: Allen et al. (1998).

The 50% deficit application throughout the growing season ($0.5 \times$ ETc) and deficit irrigation water application during the midseason stage (DM) took the shortest number of days (52) to bear flowers, while experimental plots provided with uniform optimal irrigation (UO) through the whole growth season took the longest number of days (61) from planting to 50% plants in a plot to bear flowers. Deficit irrigation water application during the midseason stage could reduce number of days from planting to 50% flowering.

Statically significant ($p < 0.05$) variability in the days to maturity was observed (Table 5) among irrigation treatments. Meanwhile, experimental plots which received 50% deficit throughout the whole growth season also mature 10 days in advance compared with maturity date of optimally treated experimental units. For both days to 50% flowering and days to maturity, the variability among the stage-wise deficit irrigation application treatments was not statistically significant ($p < 0.05$). However, significant variability in days to 50% flowering for stage-wise deficit irrigation has been observed when deficit has been induced at the development stage. This may be explained by the fact that the crop was able to recover from the stress (deficit irrigation induced at early crop growth stages) when optimum irrigation amount was applied during the rest of growth stages.

The effect of different deficit irrigation water applications resulted in a statistically significant ($p < 0.05$) variability in the number of capsules per plant in the sesame field experiment (Table 5). The maximum number of capsules (122) per plant was observed under optimal irrigation water application treatment (UO), and the minimum number of capsules (67 and 71.1) per plant was obtained under deficit 75% during midseason stage (DM) and 50% deficit irrigation application throughout the whole growth season, respectively. These results are in accordance with the findings of Nadeem et al. [33] who reported that number of capsules per plant in sesame plants have been significantly affected by different levels of soil moisture regimes.

The variability among different irrigation water application treatments was statistically significant in the number of seeds per capsule on sesame plants ($p < 0.05$). The maximum number of seeds (74.4) per capsule was obtained under the optimum irrigation water application throughout, while the lowest number of seeds (57.7) per capsule was obtained when 50% water deficit is induced throughout the whole growth season. Among the stage-wise deficit irrigation water application treatments, 75% deficit applied during the midseason (DM) stage resulted in a statistically lower number of (58.3) seeds per capsule. Flower abortion due to stress at the midseason growth stage might be an explanation why the number of capsules per plant for sesame is substantially reduced when deficit irrigation is induced at the midseason growth stage [32].

3.3. Yield and Crop Water Productivity. The different deficit irrigation treatments affected the average grain yield of sesame significantly ($p < 0.01$) (Table 6). For uniform deficit irrigation water application treatments throughout the whole growth season, the lowest yield (670 kg·ha^{-1}) was obtained when 50% deficit irrigation was induced throughout the whole growth season, while the highest yield (1840 kg·ha^{-1}) was obtained under optimum irrigation (UO). The average grain yield sesame reduction was not statistically significant among stage-wise deficit irrigation application treatments at the initial, development, and late season growing stages. But when the stage-wise deficit irrigation was induced at flowering and pod-bearing stage (deficit during the midseason stage), significantly lower yield (58.6%) was recorded compared with the optimal irrigation (UO).

The grain yield reductions of sesame with stage-wise deficit irrigation when compared with uniform optimal irrigation application are as follows: when the deficit was induced at the initial stage, the yield reduction was (4.0%); when the deficit was induced at the development stage, the yield reduction was (13.3%); and when the deficit was induced at the late season stage, the yield reduction was (8.9%).

Table 4: Crop water requirement and depth of irrigation water application (mm) on weekly bases.

Date	DAS	ETo (mm/day)	K_c	CWR (mm)	Net irrigation applied (mm/period)							
					UO	DI	DD	DM	DL	50	75	120
17/02	—	—	—	25	25	25	25	25	25	25	25	25
21/02	4	4.5	0.60	18.9	18.9	4.7	18.9	18.9	18.9	9.5	14.2	22.8
28/02	11	4.5	0.60	18.9	18.9	4.7	18.9	18.9	18.9	9.5	14.2	22.8
7/03	18	5.89	0.60	24.7	24.7	6.2	24.7	24.7	24.7	12.4	18.6	29.6
14/03	25	5.89	0.68	28.8	28.8	22.8	13.8	28.8	28.8	14.0	21.0	34.6
21/03	32	5.89	0.80	33.0	33.0	33.0	8.3	33.0	33.0	16.5	24.7	39.6
28/03	39	5.89	0.91	37.5	37.5	37.5	9.4	37.5	37.5	18.8	28.1	45
4/04	46	6.59	1.03	47.5	47.5	47.5	11.9	47.5	47.5	23.8	35.6	57
11/04	53	6.56	1.10	50.5	50.5	50.5	28.9	34.2	50.5	25.3	37.9	60.6
18/04	60	6.59	1.10	50.7	50.7	50.7	50.7	12.7	50.7	25.4	38.1	60.6
25/04	67	6.59	1.10	50.7	50.7	50.7	50.7	12.7	50.7	25.4	38.1	60.6
2/05	74	6.23	1.10	48.0	48.0	48.0	48.0	12	48.0	24.0	36.0	57.6
9/05	81	6.23	1.10	48.0	48.0	48.0	48.0	16.9	48.0	24.0	36.0	57.6
16/05	89	6.23	0.98	42.7	42.7	42.7	42.7	42.7	10.7	21.4	32.1	51.2
23/05	96	6.23	0.55	24.0	24.0	24.0	24.0	24.0	3.4	12.0	18.0	30.0
30/05	End	6.23	0.25	0	0	0	0	0	0	0	0	0
Total				548	548	496	423	389	496	287	417	654

DAS, days after sowing; ET_o, reference crop evapotranspiration (mm/period); K_c, crop coefficient; CWR, crop water requirement (mm/period); NI, net irrigation requirement (mm/period); 100, optimum irrigation (ET_a); UO, uniform optimum application (100% ET_c); DI, 75% deficit at the initial stage; DD, 75% deficit at the development stage; DM, 75% deficit at the midseason stage; DL, 75% deficit at the late stage; 50-50%, uniform deficit; 75-75%, uniform deficit; 120-20% (ET_c), over irrigation water application.

Table 5: Plant height, phenological stages, and yield component of sesame as influenced by different levels of irrigation.

Treatments	Plant height (cm)	Days to 50% flowering	Days to maturity	No. of capsules per plant	No. of seeds per capsule	1000 seed weight (g)
UO (1111)	182.7^{a}	61^{ab}	107.3^{ab}	122.0^{a}	74.7^{a}	2.607
DI (0111)	172.4^{ab}	59^{ab}	104.0^{b}	119.6^{a}	71.7^{a}	2.547
DD (1011)	173.6^{ab}	60^{ab}	104.7^{b}	106.6^{a}	73.3^{a}	2.607
DM (1101)	161.2^{b}	52^{c}	106.7^{b}	67.0^{b}	58.3^{b}	2.547
DL (1110)	174.8^{ab}	62^{a}	106.3^{b}	105.1^{a}	73.7^{a}	2.530
50 (50%)	158.5^{b}	52^{c}	104.3^{b}	71.1^{b}	57.7^{b}	2.577
75 (75%)	172.4^{ab}	57^{b}	108.7^{ab}	121.0^{a}	73.3^{a}	2.597
120 (120%)	175.4^{ab}	62^{a}	113.8^{a}	82.3^{b}	64.3^{b}	2.610
G. mean	171.4	58	106	99.3	68.4	2.58
LSD (0.05)	19.4	4.1	6.4	18.5	6.9	NS
CV (%)	4.1	2.5	2.1	6.5	3.5	1.7

G. mean, grand mean; LSD, least significant difference; NS, no significantly different at probability level of 5%; CV, coefficient of variation. Means with same letter in each column are not significantly different at probability level of 5% using the LSD test.

The significant impact of the deficit application at the midseason stage on sesame grain yield was in line with other findings which indicate that water deficit that occurs at the reproductive stage specially during flowering and capsule formation stage affects grain yield more severely [32, 34].

Crop water productivity (CWP) of sesame varied from 2.041 $kg \cdot ha^{-1} mm^{-1}$ under deficit irrigation application at the midseason stage (DM) to 4.281 $kg \cdot ha^{-1} mm^{-1}$ when 75% deficit was applied throughout the growth seasons (Table 6). Deficit irrigation application at the flowering/grain feeling (DM) stage resulted in the lowest crop water productivity among the whole stage-wise deficit irrigation treatments which were even less than the optimal irrigation water application (UO). Hence, inducing deficit irrigation water application during the midseason period (DM) could not be valuable for both yield improvement and for the enhancement of crop water productivity. This result highlights that, in stage-wise deficit irrigation application, inducing deficit irrigation at flowering and capsule bearing stage for sesame crop yield reduction is amplified. It is therefore important to consider the growth stage of the crop when we want to plan stage-wise deficit irrigation. Accordingly, in planning deficit irrigation scheduling practice, deficit should be mild at the midseason growth stage to reduce grain yield reduction for sesame.

The finding in [35] reported that the grain yield of maize is severely affected by soil moisture stress at anthesis/early reproductive stages ultimately affecting crop water productivity. Another finding related to stage-wise deficit irrigation on mung bean by Ambachew et al. [36] also noted that application of adequate water during flowering and pod development was the most significant factor in deficit irrigation scheduling.

3.4. Yield Response Factor to Water Deficit. From our field study, the yield response factor to each growth stage except

Table 6: Effect of irrigation levels on yield and crop water productivity of sesame.

Treatments	Average seed yield (kg/ha)	CWP ($kg{\cdot}ha^{-1}\,mm^{-1}$)
UO (1111)	1840[a]	3.358[b]
DI (0111)	1766[ab]	3.582[b]
DD (1011)	1596[b]	3.772[b]
DM (1101)	794[c]	2.041[c]
DL (1110)	1677[ab]	3.381[b]
50 (50%)	670[c]	2.337[c]
75 (75%)	1785[ab]	4.281[a]
120 (120%)	1547[b]	2.366[c]
G. mean	1460	3.139
LSD (0.05)	248	0.507
CV (%)	5.7	5.5

G. mean, grand mean; LSD, least significant difference; NS, not significantly different at probability level of 5%; CPW, crop water productivity; CV, coefficient of variation. Means with same letter in each column are not significantly different at probability level of 5% using the LSD test.

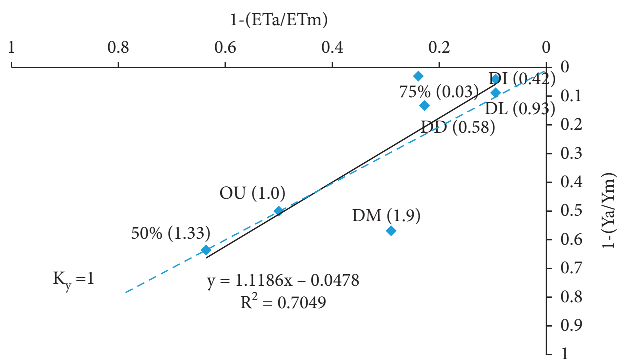

Figure 3: Relative sesame yield response to relative season water deficit.

water deficit at the development stage in stage-wise deficit irrigation scheduling was less than one (Figure 3). Yield response factor (K_y) reflects the complex relationship between production and water use by the crop. This relationship could reflect a remarkable validity and allowable procedure to quantify the effect of water deficit on economical yield. Therefore, relative yield reduction was less than the relative evapotranspiration deficit when deficit irrigation scheduling was induced at initial, development, and late development stages [30]. Among all deficit irrigation scheduling treatments, the highest K_y value (1.9) was obtained when the deficit was induced at the midseason stage. This reflects the sensitivity of the crop to water deficit with proportionally larger yield reduction when deficit was implemented at this stage.

The midseason stage in sesame was found to be very sensitive to water stress, while water deficit induced during the late growth stage has limited impact on yield. Inducing deficit irrigation at early stages (at initial or at development stage) and then the crop could get enough time for recovery, provided that optimal irrigation is applied to the rest of the growth stages. Variability in the yield response factor (K_y) might be observed under different irrigation practices, such as cultivation method, stage of the crop deficit irrigation induced, and extent of deficit irrigation induced [37].

4. Conclusion and Recommendation

Sesame is commonly grown as a rainfed crop in north western part of Ethiopia, but its productivity significantly improved when the crop is cultivated under irrigation. The field experiment revealed that crop phenology, yield component, grain yield, and crop water productivity of sesame significantly affected deficit irrigation treatments at different growth stages and throughout the growth season. Deficit irrigation scheduling can be applied for sesame production. But in stage-wise deficit irrigation, applying deficit at the midseason stage will not be beneficial because substantial yield reduction has been observed with induced deficit irrigation at this growth stage. With 30% irrigation water deficit (with stage-wise deficit irrigation) at the midseason stage, 58.6% grain yield reduction has been recorded. In deficit irrigation scheduling through the whole growth season, mild deficit is more beneficial in sesame production. When deficit irrigation is imposed with 25% uniform deficit throughout, the crop water productivity of sesame will improve significantly with no or reasonable crop yield reduction. The productivity of sesame will enhance by implementing irrigation production practice, and the crop is worthy for deficit irrigation scheduling with due emphasis on the growth stage when the deficit is stage-wise deficit irrigation. Sesame is found to be moderately sensitive to drought and with a potential for deficit irrigation scheduling. This study is one-year single location experiment; furthermore, similar studies are recommended for validating this finding and to go for further possible growth stage combinations under deficit irrigation scheduling to refine crop water productivity of sesame in the district.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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