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Effect of deficit and optimum irrigation at various growth stages on growth and yield of *summer* sesame

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Abstract
A field experiment was conducted at Agricultural College, PJTSAU, Polasa, Jagtial during *summer* 2021 to study the "Effect of deficit and optimum irrigation at various growth stages on growth, yield, quality and water requirement of *summer* sesame". The study was aimed at identifying optimum soil moisture stress for *summer* sesame and thereby determining appropriate irrigation schedule under both optimum and limited water resources. The experiment was laid out in a randomized complete block design with eight treatments (T_1 to T_8) and replicated thrice. Treatments comprised of 2 irrigations each at vegetative and flowering stages (T_1), 2 irrigations each at vegetative and capsule filling stages (T_2), 2 irrigations each at flowering and capsule filling stages (T_3), 3 irrigations each at vegetative, flowering and capsule filling stages (T_4), 3 irrigations each at vegetative, prebloom and capsule filling stages (T_5), 4 irrigations each at vegetative, prebloom, flowering and capsule filling stages (T_6), 4 irrigations each at vegetative, flowering, capsule initiation and capsule filling stages (T_7) and 5 irrigations each at vegetative, prebloom, flowering, capsule initiation and capsule filling stages (T_8). Irrigation scheduled at five stages *i.e.*, vegetative, prebloom, flowering, capsule initiation and capsule filling stages resulted in significantly higher plant height (113.3 cm) and dry matter accumulation (203.9 g m^{-2}). First capsule was formed at a height of 23 cm in T_8. Yield attributes like number of capsules $plant^{-1}$ (45), capsule weight (0.32 g) and number of filled seeds $capsule^{-1}$ (55) were higher in treatment provided with 5 irrigations each at vegetative, prebloom, flowering, capsule initiation and capsule filling stages (T_8). Higher seed yield (1150 kg ha^{-1}) was also recorded in T_8.

Keywords: Sesame, deficit irrigation and optimum irrigation, capsules, seed yield

Introduction
Sesame (*Sesamum indicum* L.) (2n=26) belonging to the family Pedaliaceae is one of the earliest domesticated plants of India. It is cultivated in warm regions of the tropic and subtropics. Sesame is renowned for its high oil content (52-54%), hence it is known as 'the queen of oilseeds'. Sesame seed oil contains 83-90% unsaturated fatty acids and 20% proteins. Sesame seeds contain two unique compounds *viz.*, sesamin and sesamolin, which prevent high blood pressure and increase vitamin E supply (Pathak *et al*., 2017) [17]. Sesame seed has a long history for its use as oil as well as for other food products such as bread and bakery items. Approximately, 70% of worldwide sesame seed produced is processed into oil and meal. The Sesame seeds or its powder or oil are used in various Indian dishes as flavoring agent (http://myfasal.com 2018) [16].

Sesame is grown as a *summer* crop, *kharif* crop and as late-*rabi* crop. Sesame is presumed to be tolerant to drought and hence it is generally grown during *summer* season on residual soil moisture. The productivity of *summer* sesame is low in Northern Telangana Zone due to deficit water supply. The Irrigation water supply is often the most critical factor limiting crop growth and yield in crops grown during *summer* season. Scheduling of limited water resources for higher productivity of crops is the need of the hour. Allocation of deficit and optimized irrigations at various growth stages of sesame affect growth, yield and oil content of sesame plants and in turn help to design efficient irrigation scheduling.

Application of irrigation at branching, flowering and seed development stages increased yield attributing characters and yield of *summer* sesame (Dutta *et al.*, 2000) [3]. Sesame is considered as profitable crop during *summer* season in Northern Telangana Zone and with release of high yielding sesame varieties, there is a need to develop optimum irrigation schedule to increase the productivity of *summer* sesame. Hence, the present study was carried out to know the performance of *summer* sesame with deficit and optimum irrigation at various growth stages.

Materials and Methods

The present investigation was carried out at College Farm, Agricultural College, Polasa, Jagtial, Professor Jayashankar Telangana State Agricultural University. The farm is geographically situated at an altitude of 311 m above mean sea level (MSL) on 18º50'22" N latitude and 78º56'59" E longitude and it is categorized under Northern Zone of Telangana State. The cultivar used for the study was JCS 1020 (Jagtial Til-1). The fertilizer dose recommended for the cultivar under study is 60-20-40 kg N, P_2O_5 and K_2O ha^{-1}. The experimental soil texture was sandy clay loam. weekly mean maximum temperature varied from 30.8 ^{0}C to 39.7 ^{0}C with an average of 35.7 ^{0}C and weekly mean minimum temperature ranged from 13.5 ^{0}C to 27.1 ^{0}C with an average of 20.1 ^{0}C. The weekly mean relative humidity (8.30 hrs.) ranged from 68.0 to 91.0% with an average of 80.5% and weekly mean relative humidity (17.30 hrs.) ranged from 30.3 to 53.7% with an average of 40.3%. The total evaporation during the growing season of sesame was 273.5 mm during crop growing season with a range of 1.8 and 6.3 mm (Table 1). It was low at early stage (February, 2021), increased afterwards and reached a peak at capsule filling stage (May, 2021).

Plant height was recorded at the end of each growth stage and was taken from base to tip of the plant using a scale and expressed in cm. Destructive samples were taken from gross plot and shade dried for one day followed by oven drying at 60 ^{0}C for 48 hours. Weight of these dried samples was recorded after discarding the roots and expressed in kg ha^{-1}. Height of the first capsule formed was recorded from five tagged plants in each net plot at capsule initiation stage from base of the plant to the first capsule formed and is expressed in cm.

The arbitrarily chosen plants utilized for recording the plant height were additionally utilized for checking the number of capsules $plant^{-1}$ and average capsules $plant^{-1}$ at harvest was worked out. Representative ten capsules from five tagged plants in each net plot were (8.8 m X 5.5 m) weighed together, averaged and expressed the weight of each capsule in g. The number of filled seeds $capsule^{-1}$ in ten randomly choosed capsules from five tagged plants were counted and the mean number of seeds $capsule^{-1}$ for every treatment was worked out. Plants from the net plot (8.8 m X 5.5 m) were harvested, threshed, sun dried and winnowed separately. The yield acquired from each net plot were weighed in grams and later converted to kg ha^{-1}. Seeds from the tagged plants were also included.

Table 1: Plant height (cm) of *summer* sesame as influenced by deficit and optimum irrigation at various growth stages

	Treatments	Plant height (cm)				
		Vegetative (10-35 DAS)	Prebloom (36-50 DAS)	Flowering (51-65 DAS)	Capsule initiation (66-80 DAS)	Capsule filling (81-95 DAS)
T_1	2 irrigations each at vegetative and flowering stage	20.3	47.0	61.4	65.4	68.2
T_2	2 irrigations each at vegetative and capsule filling stage	21.1	47.6	51.9	56.2	70.5
T_3	2 irrigations each at flowering and capsule filling stage	17.5	40.2	50.3	60.3	75.1
T_4	3 irrigations each at vegetative, flowering and capsule filling stage	20.6	47.3	63.8	68.6	87.0
T_5	3 irrigations each at vegetative, prebloom and capsule filling stage	21.5	53.2	59.9	66.1	75.1
T_6	4 irrigations each at vegetative, prebloom, flowering and capsule filling stage	21.7	53.6	76.3	79.7	98.5
T_7	4 irrigations each at vegetative, flowering, capsule initiation and capsule filling stage	20.3	46.6	64.1	81.7	101.1
T_8	5 irrigations each at vegetative, prebloom, flowering, capsule initiation and capsule filling stage	21.9	53.6	77.1	91.3	113.3
SEm±		0.7	1.8	2.5	2.9	3.8
CD @ 5%		2.2	5.4	7.7	8.8	11.6
CV		6.2	6.3	7.0	7.0	7.7

Results and Discussions

Growth parameters

Plant height (cm)

Irrigation levels remarkably influenced the plant height of sesame at all the growth stages *i.e.*, vegetative, prebloom, flowering, capsule initiation and capsule filling stages. Plant height increased at a faster rate up to flowering stage and afterwards at a slower pace up to capsule filling stage.

Plant height assumes a significant part in the capture of light and sun-oriented radiation. The increment in plant stature with expansion in water systems could be credited to the reality that water is utilized for the chemical and biochemical interactions supporting plant assimilation and shortfall water restrict the cell division and cell development. Availability of adequate moisture advances the metabolic interaction in plant cells and expands the efficacy of the mineral supplements.

Unvarying irrigation schedule was imposed up to 9 DAS to get appropriate germination and finer establishment. Treatments were imposed from 10 DAS. All the treatments were irrigated at vegetative stage except treatment where 2 irrigations were scheduled each at flowering and capsule filling stages (T_3).

Scheduling of irrigations adequately at 5 growth stages *i.e.*, vegetative, prebloom, flowering, capsule initiation and capsule filling stages resulted in higher plant height at all the growth stages *i.e.*, vegetative (21.9 cm), prebloom (53.6 cm), flowering (77.1 cm), capsule initiation (91.3 cm) and capsule filling stages (113.3 cm). At vegetative stage, plant height noticed in various treatments varied from 17.5 cm to 21.9 cm. Significantly lower plant height (17.5 cm) was observed in treatment with 2 irrigations scheduled at flowering and capsule filling stages (T_3).

Significantly higher plant height at prebloom stage was noticed in treatment provided with 5 irrigations each at vegetative, prebloom, flowering, capsule initiation and capsule filling stages (53.6 cm) and it was on par (53.6 cm) with treatment in which 4 irrigations were scheduled each at vegetative, prebloom, flowering and capsule filling stages (T_6) and treatment with 3 irrigations each at vegetative, prebloom and capsule filling stages (T_5) (53.2 cm). Favorable increase in plant height in sesame with irrigation is in conformity with findings of Sarkar *et al*., (2010) [22]. Lowest plant height at prebloom stage was observed in treatment provided with 2 irrigations each at flowering and capsule filling stages (T_3) as it was devoid of irrigation at both vegetative and prebloom stages. Plant height in treatments provided with 2 irrigations each at vegetative and flowering stages (T_1), 3 irrigations each at vegetative, flowering and capsule filling stages (T_4) and 4 irrigations each at vegetative, flowering, capsule initiation and capsule filling stages (T_7) were 47.0, 47.3 and 46.6 cm, respectively and they were statistically at par as these treatments were provided with irrigation at vegetative stage and lacked irrigation at prebloom stage.

Elevated plant height (77.1 cm) at flowering stage was noticed in treatment provided with 5 irrigations each at vegetative, prebloom, flowering, capsule initiation and capsule filling stages (T_8) and it was on par where (76.3 cm) 4 irrigations were scheduled each at vegetative, prebloom, flowering and capsule filling stages (T_6) as both mentioned treatments received irrigations continuously till flowering stage. It might be due to positive response for application of irrigation in critical growth stages as reported by Garai and Datta (2002) [7]. Lowest plant height was observed in treatment with 2 irrigations scheduled each at flowering and capsule filling stages (T_3) (50.3 cm) and it was on par with treatment provided with 2 irrigations each at vegetative and capsule filling stages (T_2) (51.9 cm).

Higher plant height (91.3 cm) at capsule initiation stage was observed in treatment where irrigation was given continuously at all the stages *i.e.,* vegetative, prebloom, flowering and capsule initiation stages (T_8). Increase in the irrigation regime led to significant increase in plant height (Kassab *et al*., 2005) [10]. Lower plant height was noticed in treatment optimized with 2 irrigations each at vegetative and capsule filling stages (T_2) (56.2 cm) and it was on par with that treatment provided with 2 irrigations each at flowering and capsule filling stage (60.3 cm).

Plant height at capsule filling stage was significantly higher in treatment provided with 5 irrigations each at vegetative, prebloom, flowering, capsule initiation and capsule filling stages. Followed to this, treatments provided with 4 irrigations each at vegetative, prebloom, flowering and capsule filling stages (T_6) and 4 irrigations each at vegetative, flowering, capsule initiation and capsule filling stages (T_7) showed plant height of 98.5 and 101.1 cm, respectively and were statistically at par.

Treatment provided with 3 irrigations each at vegetative, prebloom and capsule filling stages (T_5) showed significantly lower plant height (75.1 cm) than that provided with same number of irrigations each at vegetative, flowering and capsule filling stages (T_4) as flowering stage was most sensitive to moisture stress and impacted plant growth showing drastic reduction in plant height. Lower plant height was noticed in treatments with optimized irrigation at two stages (T_1, T_2, and T_3). Lower plant height (68.2 cm) was observed in treatment provided with 2 irrigations each at vegetative and flowering stages (T_1) as it was subjected to prolonged moisture stress at late growth stages.

These outcomes show that scheduling of 5 irrigation all through the developing season altogether expanded plant tallness. While, deficit water system levels diminished the moisture accessibility at different plant development stages which was reflected in lessened stature of the plants. There was prominent difference between deficit and optimum irrigated treatments in plant height as reported by Mekonnen and Sintayehu, (2020) [14] in sesame and Rathore *et al*., (2020) [21] in mustard.

Dry matter production (g m^{-2})

Deficit and optimum irrigation levels remarkably influenced dry matter production of *summer* sesame at various growth stages. Increase in dry matter production of sesame with increase in irrigation levels was clearly noticed. Irrespective of treatments, rapid increase in the dry matter production was observed from vegetative to flowering stage followed by a slower pace between flowering to harvest and showed a sigmoid pattern of crop growth.

Dry matter accumulation in sesame at vegetative stage as influenced by deficit and optimum irrigation varied from 32.1 to 38.6 g m^{-2}. Higher dry matter production (38.6 g m^{-2}) was noticed with scheduling 3 irrigations (T_5) at vegetative, prebloom and capsule filling stages and was significantly at par with all other adequate (T_8) and deficit irrigation treatments (T_7, T_6, T_4, T_2 and T_1) except T_3. Lower dry matter production (32.13 g m^{-2}) was noticed in treatment provided with 2 irrigations each at flowering and capsule filling stages (T_3) which was devoid of irrigation at vegetative stage.

At prebloom stage, dry matter production was greater in treatments provided with 4 irrigations each at vegetative, prebloom, flowering and capsule filling stages (T_6), 3 irrigations each at vegetative, prebloom and capsule filling stages (T_5) and 5 irrigations each at vegetative, prebloom, flowering, capsule initiation and capsule filling stages (T_8) (97.8, 96.3 and 96.6 g m^{-2}, respectively). It was mainly due to scheduling irrigation at prebloom stage in these treatments. It was in accordance with Sarkar *et al*., (2010) [22] and Dutta *et al*., (2000) [3]. Lower dry matter of 55.6 g m^{-2} was observed in treatment provided with 2 irrigations each at flowering and capsule filling stages (T_3) as it was subjected to continuous moisture stress at vegetative and prebloom stages.

Higher dry matter production at flowering stage (124.1 g m^{-2}) was noticed when provided with 5 irrigations each at vegetative, prebloom, flowering, capsule initiation and capsule filling stages (T_8) and was at par with scheduling 4 irrigations each at vegetative, prebloom, flowering and capsule filling stages (T_6) (123.6 g m^{-2}). Treatments provided with 2 irrigations each at flowering and capsule filling stages (T_3) and each at vegetative and capsule filling stages (T_2) accumulated remarkably lower dry matter (83.17 and 90.43 g m^{-2}, respectively) at flowering stage as irrigation was given only at a single stage after establishment period. Differential irrigation levels altogether influenced the dry matter production as reported by Puste *et al*., (2015) [19] in sesame.

Dry matter produced at capsule initiation stage was greater (168.43 g m^{-2}) in treatment supplied with 5 irrigations each at vegetative, prebloom, flowering, capsule initiation and capsule filling stages (T_8) where irrigation was scheduled in optimum stages without imposing stress. It was significantly higher than all other deficit irrigation treatments. Lower dry matter accumulation (106.83 g m^{-2}) was observed when irrigation was scheduled twice each at vegetative and flowering stages (T_2) which is subjected to moisture stress for a long period and it was at par with treatments supplied with 2 irrigations each at flowering and capsule filling stages (T_3), 3 irrigations each at vegetative, prebloom and capsule filling stages (T_5) and 2 irrigations each at vegetative and flowering stages.

At capsule filling stage, dry matter production was significantly greater (203.93 g m^{-2}) in treatment with optimum irrigation schedule (T_8). The expansion in development increased yield parameters (number of capsules $plant^{-1}$, capsule weight) and yield of sesame at optimum irrigation schedules could be credited to sufficient water to plants that resulted in increment in photosynthesis which eventually prompts expanded dry matter accumulation (Kirkham, 2005) [12]. Higher dry matter in ideal irrigated treatments could be ascribed to increment in plant stature combined with higher leaf area bringing about upgraded sugar amalgamation which at last prompted higher dry matter production. It was in accordance with findings of Mallick (2018) [13]. Dry matter accumulation in treatments supplied with 4 irrigations (T_6 and T_7) at capsule filling stage as influenced by deficit and optimum irrigation were 178.70 and 180.40 g m^{-2}, respectively. Dry matter produced in treatment irrigated thrice each at vegetative, prebloom and capsule filling stages (T_5) was 142.97 g m^{-2} and it was significantly at par with that provided with same number of irrigations but at various growth stages *i.e.*, vegetative, flowering and capsule filling stages (T_4). Treatment with 2 irrigations each at vegetative and capsule filling stages (T_2) showed lower (121.83 g m^{-2}) dry matter accumulation and it was on par with other treatments provided with 2 irrigations at various growth stages (T_1 and T_3) as they were supplied with deficit irrigation.

The decrease in dry matter amassing of crop at deficit irrigation was expected to limit water availability which was fundamental to do some essential metabolic activities of plants. The outcomes were additionally in conformity with Thakuria *et al.*, (2004) [23] who presumed that dry matter collection at different stages in sunflower was improved with more water accessibility.

Height of first capsule

Height at which first capsule was formed effected the number of capsules that could be formed on the main axis. As the cultivar chosen for the study (JCS 1020) was non branched variety, height of the first capsule formation showed positive correlation with number of capsules formed. There was significant difference in height of first capsule formation in optimum and deficit irrigated treatments. Height of the first capsule formed near to the ground in optimum irrigated treatments and it increased with increasing water stress as shown in T_8 treatment where five irrigations were scheduled each at all growth stages *i.e.*, vegetative, prebloom, flowering, capsule initiation and capsule filling stages. First capsule was formed at a height of 23.03 cm from base of the plant and it was statistically on par with treatments provided with 4 irrigations each at vegetative, flowering, capsule initiation and capsule filling stages (T_7), 4 irrigations each at vegetative, prebloom, flowering and capsule filling stages (T_6), 3 irrigations at vegetative, flowering and capsule filling stages (T_4) and 2 irrigations each at vegetative and flowering stages (T_1).

Height of first capsule formed in treatment supplied with 4 irrigations each at vegetative, prebloom, flowering and capsule filling stages *i.e.*, T_6 (24.1 cm) was very close to that provided with 5 irrigations (T_8) as both the treatments were irrigated continuously till flowering stage. Scheduling of 2 irrigations each at vegetative and flowering stages (T_1), 3 irrigations each at vegetative, flowering and capsule filling stages (T_4) and 4 irrigations each at vegetative, flowering, capsule initiation and capsule filling stages (T_7) showed first capsule formation at a height of 25.2, 25.3 and 25.5 cm, respectively. These values were slightly greater than ideal irrigated one as moisture stress was imposed at prebloom stage. First capsule formed was at a greater height (29.6 cm) in treatment provided with 2 irrigations each at vegetative and capsule formation stages (T_2) as it was subjected to moisture stress at flowering and it was on par with treatments provided with 2 irrigations each at flowering and capsule filling stages (T_3) and 3 irrigations each at vegetative, prebloom and capsule filling stages (T_5) (27.7 and 28.4 cm, respectively).

First capsule was formed at higher height (27.7 cm) in stressed treatment with 2 irrigations each at flowering and capsule filling stages (T_3) due to incessant moisture stress till flowering stage. In treatment supplied with 3 irrigations each at vegetative, prebloom and capsule filling stages (T_5), capsules formed at a greater height (28.4 cm) as it was put through water stress at flowering stage. It appears that as frequent irrigations were provided, the competition for resources especially water began to reduce and more ideal conditions were provided for growth and building of assimilates. Consequently, branch-bearing was sped up and the primary capsule distance from ground reduced as well (Jouyban and Moosavi, 2011) [9].

Yield Attributes and Yield

Number of capsules $plant^{-1}$

Number of capsules $plant^{-1}$ at harvest is an indispensable determinant of seed yield in sesame crop. The number of capsules $plant^{-1}$ was prominently influenced by deficit and optimum irrigation in summer sesame at various growth stages. Yield is a composite of number of capsules $plant^{-1}$, seeds $capsule^{-1}$ and seed weight and almost 85% of sesame yield variations were achieved by capsules $plant^{-1}$ or capsules unit $area^{-1}$ (Rao *et al*., 1991) [20]. Increasing the number of irrigations increased the number of capsules $plant^{-1}$ and thus maximum number of capsules $plant^{-1}$ (45.0) were recorded when 5 irrigations were scheduled each at various growth stages i.e., vegetative, prebloom, flowering, capsule initiation and capsule filling stages. Followed to this, number of capsules in treatments provided with 4 irrigations each at vegetative, flowering, capsule initiation and capsule filling stages (T_7) and with same number of irrigations each at vegetative, prebloom, flowering and capsule filling stages (T_6) were 35.1 and 33.6 capsules $plant^{-1}$, respectively and statistically at par and both the treatments were higher than other treatments. Lower number of capsules $plant^{-1}$ in later treatment might be attributed to poor capsule development as it was devoid of irrigation at capsule initiation stage. Scheduling of 3 irrigations each at vegetative, flowering and capsule filling stages (T_4) produced higher number of capsules $plant^{-1}$ (25.7) over T_5 where 3 irrigations scheduled at vegetative, prebloom and capsule filling stages (18.7) It may be due to the reason that later treatment was subjected to moisture stress at flowering stage which directly influences flower formation and in turn number of capsules $plant^{-1}$. Lowest number of capsules $plant^{-1}$ (10.4) were recorded in treatment provided with 2 irrigations each at vegetative and capsule filling stages (T_2). This might be due to prolonged moisture stress during the crop growing period especially at flowering. However, it was on par with same number of irrigations scheduled each at vegetative and flowering stages (T_1) (13.0) and 2 irrigations scheduled each at flowering and capsule filling stages (T_3) (13.3). Water stress at reproductive stage brought about an irreversible impact which could not be revoked during subsequent good soil moisture levels when the crucial processes of capsule development are still underway. The results obtained in the current investigation were supported by Sarkar *et al*. (2010) [22], Puste *et al*. (2015) [19] and Mekonnen and Sintayehu, (2020) [14].

Capsule weight (g)

Capsule weight of sesame was remarkably greater (0.32 g) when provided with adequate irrigations (5) each at vegetative, prebloom, flowering, capsule initiation and capsule filling stages (T_8) and was higher than all other deficit irrigated treatments. Lowest capsule weight (0.21 g) was noticed in treatment provided with 2 irrigations each at vegetative and capsule filling stages (T_2) and it was statistically on par with treatment provided with 2 irrigations each at vegetative and flowering stages (T_1) (0.23 g), 2 irrigations each at flowering and capsule filling stages (T_3) (0.22 g) and treatment with 3 irrigations scheduled at vegetative, prebloom and capsule filling stages (T_5) (0.24 g). This was supported by Mila *et al*., (2017) [15] and Eltarabily *et al*., (2020) [5] in sunflower.

Least capsule weight in treatment provided with 2 irrigations each at vegetative and capsule filling stages (T_2) was due to prolonged moisture stress during the crop growth period especially at flowering. Lower capsule weight in the treatments provided with 2 irrigations each at vegetative and flowering stages (T_1) and 2 irrigations each at flowering and capsule filling stages (T_3) can be attributed to deficit irrigation schedule with 2 irrigations which led to retarded growth, consequently reduced number of capsules with less weight. Scheduling of 3 irrigations each at vegetative, prebloom and capsule filling stages (T_5) resulted in less capsule weight as it was subjected to moisture stress at flowering stage which led to deformed capsules with lower weight.

Number of filled seeds capsule^{-1}

Significantly higher number of filled seeds capsule^{-1} (55.0) was noticed in treatments provided with 5 irrigations each at vegetative, prebloom, flowering, capsule initiation and capsule filling stages (T_8). Maximum number of seeds capsule^{-1} were produced when sesame received irrigations at all the critical stages (Sarkar *et al*., 2010 and Mekonnen and Sintayehu, 2020) [22, 14]. Followed to this, scheduling of 4 irrigations each at vegetative, flowering, capsule initiation and capsule filling stages (T_7) produced higher number of filled seeds capsule^{-1} (48.9) and was at par with treatment where 4 irrigations were given at vegetative, prebloom, flowering and capsule filling stages (T_6) (47.5) and with treatment (T_4) where 3 irrigations were scheduled each at vegetative, flowering and capsule filling stages. Significantly lower number of filled seeds capsule^{-1} (29.5) were recorded in treatment with 2 irrigations provided each at vegetative and capsule filling stages (T_2) and it was on par with treatments optimized with 2 irrigations scheduled at vegetative and flowering stages and flowering and capsule filling stages (30.8 and 31.4 in T_1 and T_3, respectively). The results obtained in the current investigation were supported by Chauhan *et al*. (2016) [2], Mallick (2018) [13] and Mekonnen and Sintayehu, (2020) [22] in sesame and by Lovelli *et al*. (2007) in safflower, Istanbulluoglu *et al*. (2010) in rapeseed, Langerhoodi *et al*. (2014) and Eltarabily *et al*. (2020) [5] in sunflower and Rathore *et al*. (2020) [21] in mustard.

Table 2: Dry matter accumulation (g m^{-2}) of *summer* sesame as influenced by deficit and optimum irrigation at various growth stages

	Treatments	Dry matter accumulation (g m^{-2})				
		Vegetative (10-35 DAS)	Prebloom (36-50 DAS)	Flowering (51-65 DAS)	Capsule initiation (66-80 DAS)	Capsule filling (81-95 DAS)
T_1	2 irrigations each at vegetative and flowering stage	38.2	85.0	105.9	123.0	135.5
T_2	2 irrigations each at vegetative and capsule filling stage	37.8	83.3	90.4	106.8	121.8
T_3	2 irrigations each at flowering and capsule filling stage	32.1	55.6	83.2	117.9	137.6
T_4	3 irrigations each at vegetative, flowering and capsule filling stage	37.1	84.9	106.3	134.8	158.5
T_5	3 irrigations each at vegetative, prebloom and capsule filling stage	38.6	96.3	101.4	120.9	143.0
T_6	4 irrigations each at vegetative, prebloom, flowering and capsule filling stage	37.9	97.8	123.6	140.5	178.7
T_7	4 irrigations each at vegetative, flowering, capsule initiation and capsule filling stage	38.1	85.2	104.5	137.5	180.4
T_8	5 irrigations each at vegetative, prebloom, flowering, capsule initiation and capsule filling stage	37.3	96.6	124.1	168.4	203.9
SEm±		1.6	3.6	4.3	5.3	6.3
CD @ 5%		4.8	10.9	13.1	16.2	19.2
CV		7.4	7.3	7.1	7.0	7.0

Seed yield

Seed yield of *summer* sesame as influenced by deficit and optimum irrigation at various growth stages was indicated in Table 4.9 and illustrated in Fig. 4.9. The results of analysis of variance showed that there was significant influence of deficit and optimum irrigation on seed yield of *summer* sesame. A few researchers recognized the critical stages for water application since this crop was predominantly cultivated in post rainy or summer season with restricted water accessibility and yield decrease was essentially because of water deficiency particularly at moisture sensitive stages showing the significance of irrigation on plant growth and development (Chauhan *et al*., 2016) [2]. Water assumes a fundamental part in the sugar digestion, protein and oil synthesis, cell division and elongation.

The highest seed yield with an average amount of 1150 kg ha^{-1} was obtained by scheduling five irrigations each at vegetative, prebloom, flowering, capsule initiation and capsule filling stages. Higher seed yield of sesame with optimum irrigation schedule was supported by Khadse *et al*., (2017) [11], Pereira *et al*., (2017) [18], Hailu *et al*., (2018) [8], Mallick *et al*., (2018) [13], Abdelraouf and Anter (2020) [1].

Increase in the seed yield under fully irrigated conditions as in treatment provided with 5 irrigations each at vegetative, prebloom, flowering, capsule initiation and capsule filling stages was due to enhanced performance of all growth and yield contributing characters of sesame because of uninterrupted soil moisture availability during entire crop period. Irrigation at early vegetative or branching stage perhaps had bought about the lively development of the crop while irrigation provided at flowering may have helped in maintaining size, duration and photosynthetic movement of the green plant parts subsequent to flowering and furthermore in movement of photosynthates to the sink. Moreover, this is the period in which likely capsules and seed number is resolved.

Grain yield decreased with diminishing water availability (Eskandari *et al*., 2009) [6]. There was reduction in seed yield (976 kg ha^{-1}) when provided with 4 irrigations each at vegetative, flowering, capsule initiation and capsule filling stages (T_7). However, it was statistically at par (931 kg ha^{-1}) when 4 irrigations were scheduled each at vegetative, prebloom, flowering and capsule filling stages (T_6). Reduced seed yield in the later treatment in comparison to prior one might be due to stress imposed at capsule initiation stage which led to aversion in capsule formation and seed development.

Seed yield obtained with scheduling 3 irrigations each at vegetative, prebloom and capsule filling stages (T_5) was 616 kg ha^{-1}. With same number of irrigations each at vegetative, flowering and capsule filling stages (T_4) seed yield was noticed to be 818 kg ha^{-1}. The variance between the yield of both treatments could be attributed to termination of flowers and capsule formation due to stress imposed at flowering. Remarkable effect of the deficit application at the midseason stage on sesame grain yield was in accordance with different discoveries which show that water deficiency that happens at the reproductive stage exceptionally during flowering and capsule formation stage showed drastic reduction in grain yield (Ekom *et al*., 2019) [4].

Deficit irrigation treatments were those irrigated only twice during the crop period apart from the irrigation given for establishment. Seed yield when provided with 2 irrigations each at vegetative and flowering stages was (T_1) 469 kg ha^{-1} and was at par with irrigation scheduled at vegetative and capsule filling stages (T_2) (410 kg ha^{-1}) and treatment provided with 2 irrigations each at flowering and capsule filling stages (T_3) (485 kg ha^{-1}) of seed yield. All the aforementioned treatments were on par but the contrast in the yields obtained might be due to scheduling irrigation at critical stages like flowering.

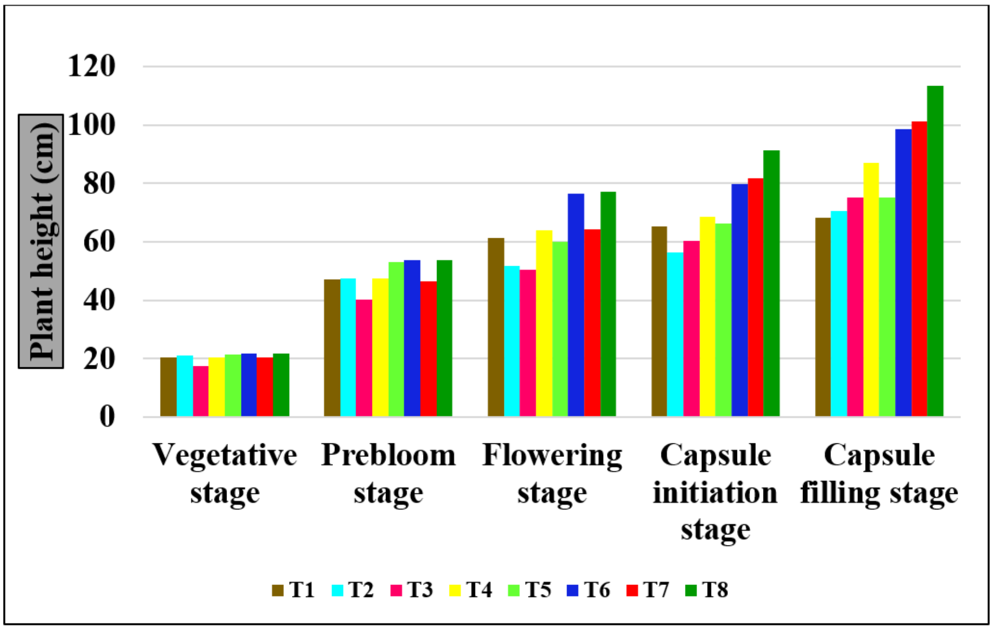
In this way, moisture stress at flowering and capsule development period may have caused flower abortion which in turn showed diminished number of capsules and seeds in deficit irrigated treatments. This load of adverse impacts on growth and yield attributes might have diminished the seed yield. Distinct variation among yields obtained under optimum and deficit irrigation shows that there is clear cut impact of water stress imposed at various stages of sesame crop.

Table 3: Height of first capsule (cm) of *summer* sesame as influenced by deficit and optimum irrigation at various growth stages

	Treatments	Height of first capsule (cm)
T_1	2 irrigations each at vegetative and flowering stage	25.2
T_2	2 irrigations each at vegetative and capsule filling stage	29.6
T_3	2 irrigations each at flowering and capsule filling stage	27.7
T_4	3 irrigations each at vegetative, flowering and capsule filling stage	25.3
T_5	3 irrigations each at vegetative, prebloom and capsule filling stage	28.4
T_6	4 irrigations each at vegetative, prebloom, flowering and capsule filling stage	24.1
T_7	4 irrigations each at vegetative, flowering, capsule initiation and capsule filling stage	25.5
T_8	5 irrigations each at vegetative, prebloom, flowering, capsule initiation and capsule filling stage	23.0
SEm±		0.9
CD @ 5%		2.7
CV (%)		6.1

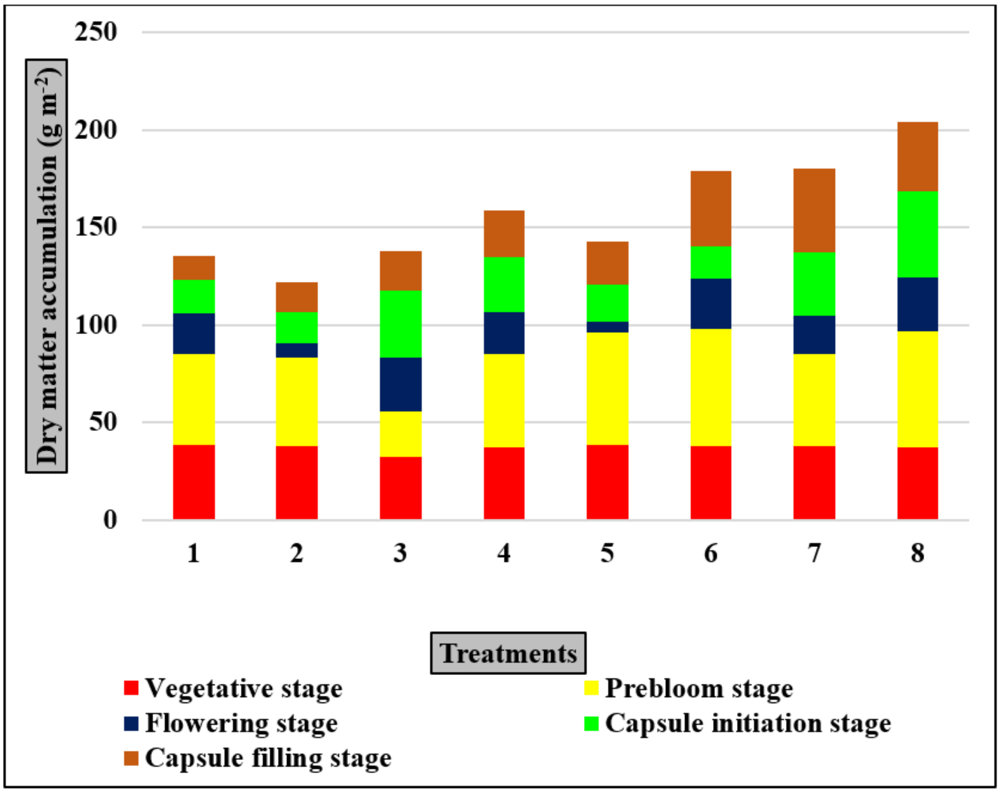
Table 4: Number of capsules plant^{-1}, capsule weight (g), number of filled seeds capsule^{-1} and seed yield (kg ha^{-1}) as influenced by deficit and optimum irrigation at various growth stages in *summer* sesame

	Treatments	No of capsules plant^{-1}	Capsule weight (g)	Number of filled seeds capsule^{-1}	Seed yield (kg ha^{-1})
T_1	2 irrigations each at vegetative and flowering stage	13.0	0.23	30.8	469
T_2	2 irrigations each at vegetative and capsule filling stage	10.4	0.21	29.5	410
T_3	2 irrigations each at flowering and capsule filling stage	12.3	0.22	31.4	485
T_4	3 irrigations each at vegetative, flowering and capsule filling stage	25.7	0.27	43.9	818
T_5	3 irrigations each at vegetative, prebloom and capsule filling stage	18.7	0.24	38.1	616
T_6	4 irrigations each at vegetative, prebloom, flowering and capsule filling stage	33.6	0.28	47.5	931
T_7	4 irrigations each at vegetative, flowering, capsule initiation and capsule filling stage	35.1	0.28	48.9	976
T_8	5 irrigations each at vegetative, prebloom, flowering, capsule initiation and capsule filling stage	45.0	0.32	55.0	1150
SEm±		1.67	0.01	1.82	33.6
CD @ 5%		5.06	0.03	5.53	101.20
CV (%)		11.93	6.4	7.8	7.9



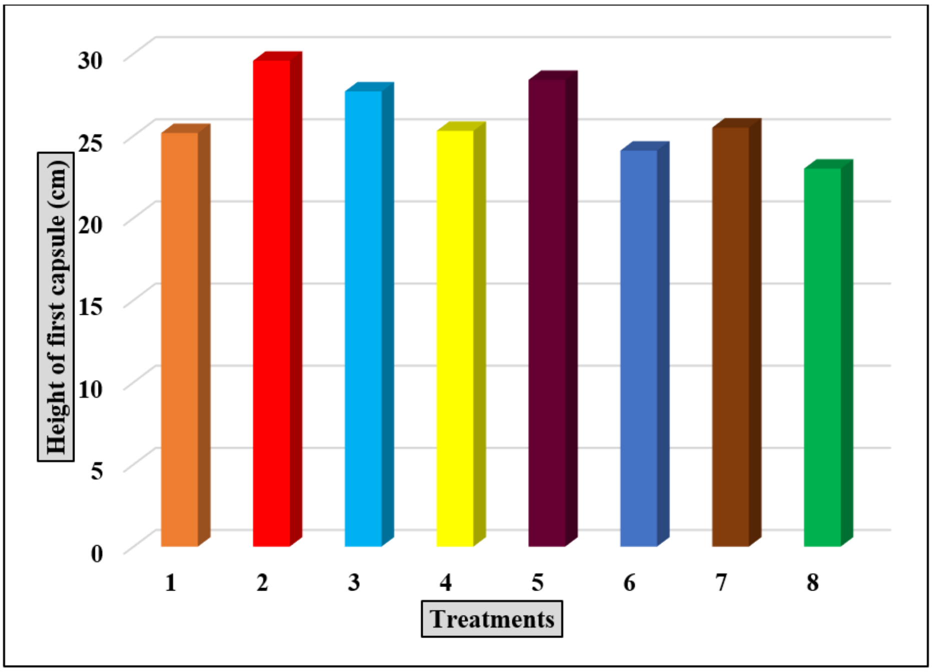
T_1: 2 irrigations each at vegetative and flowering stages
T_2: 2 irrigations each at vegetative and capsule filling stages
T_3: 2 irrigations each at flowering and capsule filling stages
T_4: 3 irrigations each at vegetative, flowering and capsule filling stages
T_5: 3 irrigations each at vegetative, prebloom and capsule filling stages
T_6: 4 irrigations each at vegetative, prebloom, flowering and capsule filling stages
T_7: 4 irrigations each at vegetative, flowering, capsule initiation and capsule filling stages
T_8: 5 irrigations each at vegetative, prebloom, flowering, capsule initiation and capsule filling stages

Fig 1: Plant height (cm) of sesame as influenced by deficit and optimum irrigation at various growth stages



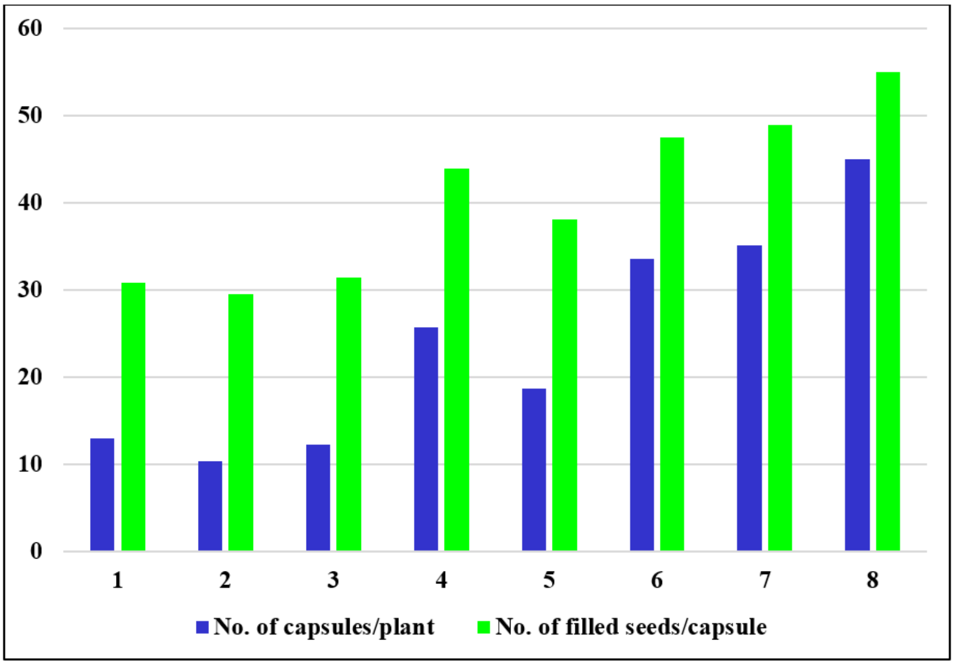
T_1: 2 irrigations each at vegetative and flowering stages
T_2: 2 irrigations each at vegetative and capsule filling stages
T_3: 2 irrigations each at flowering and capsule filling stages
T_4: 3 irrigations each at vegetative, flowering and capsule filling stages
T_5: 3 irrigations each at vegetative, prebloom and capsule filling stages
T_6: 4 irrigations each at vegetative, prebloom, flowering and capsule filling stages
T_7: 4 irrigations each at vegetative, flowering, capsule initiation and capsule filling stages
T_8: 5 irrigations each at vegetative, prebloom, flowering, capsule initiation and capsule filling stages

Fig 2: Dry matter production (g m^{-2}) of sesame as influenced by deficit and optimum irrigation at various growth stages



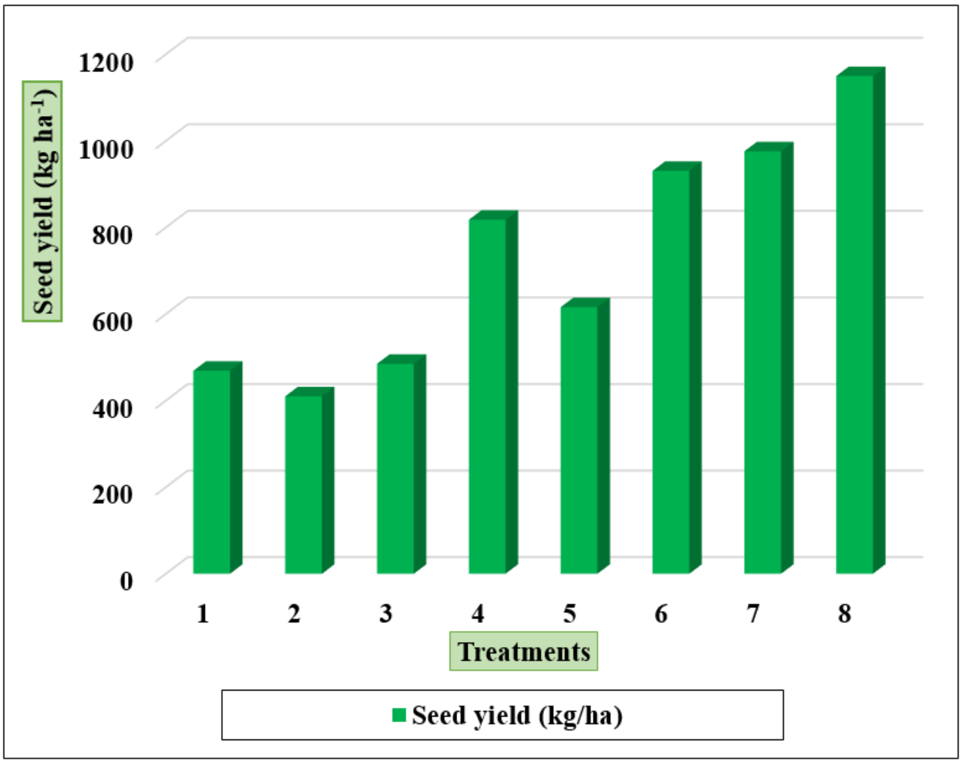
T_1: 2 irrigations each at vegetative and flowering stages
T_2: 2 irrigations each at vegetative and capsule filling stages
T_3: 2 irrigations each at flowering and capsule filling stages
T_4: 3 irrigations each at vegetative, flowering and capsule filling stages
T_5: 3 irrigations each at vegetative, prebloom and capsule filling stages
T_6: 4 irrigations each at vegetative, prebloom, flowering and capsule filling stages
T_7: 4 irrigations each at vegetative, flowering, capsule initiation and capsule filling stages
T_8: 5 irrigations each at vegetative, prebloom, flowering, capsule initiation and capsule filling stages

Fig 3: Height of first capsule formation (cm) in sesame as influenced by deficit and optimum irrigation at various growth stages



T_1: 2 irrigations each at vegetative and flowering stages
T_2: 2 irrigations each at vegetative and capsule filling stages
T_3: 2 irrigations each at flowering and capsule filling stages
T_4: 3 irrigations each at vegetative, flowering and capsule filling stages
T_5: 3 irrigations each at vegetative, prebloom and capsule filling stages
T_6: 4 irrigations each at vegetative, prebloom, flowering and capsule filling stages
T_7: 4 irrigations each at vegetative, flowering, capsule initiation and capsule filling stages
T_8: 5 irrigations each at vegetative, prebloom, flowering, capsule initiation and capsule filling stages

Fig 4: Number of capsules plant^{-1} and filled seeds capsule^{-1} in sesame as influenced by deficit and optimum irrigation at various growth stages



T_1: 2 irrigations each at vegetative and flowering stages
T_2: 2 irrigations each at vegetative and capsule filling stages
T_3: 2 irrigations each at flowering and capsule filling stages
T_4: 3 irrigations each at vegetative, flowering and capsule filling stages
T_5: 3 irrigations each at vegetative, prebloom and capsule filling stages
T_6: 4 irrigations each at vegetative, prebloom, flowering and capsule filling stages
T_7: 4 irrigations each at vegetative, flowering, capsule initiation and capsule filling stages
T_8: 5 irrigations each at vegetative, prebloom, flowering, capsule initiation and capsule filling stages

Fig 5: Seed yield (kg ha^{-1}) in sesame as influenced by deficit and optimum irrigation at various growth stages

Conclusion

The current investigation revealed that deficit and optimum irrigation has a significant effect on growth, yield attributes and yield of *summer* sesame. It can be concluded that providing 5 irrigations at various growth stages can result in higher seed yield. Based on the results obtained, if water resources are meagre, scheduling 4 irrigations each at vegetative, flowering, capsule initiation and capsule filling stages can be recommended and if only 3 irrigations are available, scheduling 3 irrigations each at vegetative, flowering and capsule filling stages can be advised.

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