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Effect of Irrigation Scheduling on Growth, Yield and Irrigation Water use Efficiency of Linseed (*Linum usitatissimum* L.)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A field experiment was conducted to study the effect of irrigation scheduling on growth, yield and water use efficiency of linseed (*Linum usitatissimum* L.) at Main Agricultural Research Station (MARS), Raichur, during the *rabi* season of 2023-24. The experiment was laid out in a randomized complete block design with five treatments, replicated four times. There were five treatments *viz*., T_1: Pre sowing irrigation only, T_2: Pre sowing irrigation *fb* one irrigation at vegetative stage (30-35 DAS), T_3: Pre sowing irrigation *fb* two irrigations at vegetative stage (30-35 DAS) and flowering stage (40-45 DAS), T_4: Pre sowing irrigation *fb* three irrigations at vegetative stage (30-35 DAS), flowering stage (40-45 DAS) and capsule development stage (60-65 DAS) and T_5: Rainfed condition. The results revealed that significantly higher plant height (60.94 cm), number of branches plant^{-1} (6.18), leaf area (36.94 cm^2 plant^{-1}), total dry matter production (16.41 g plant^{-1}), number of capsules plant^{-1} (44.27), number of seeds (8.18 capsule^{-1}), seed weight (2.98 g palnt^{-1}), seed yield (1106 kg ha^{-1}) and straw yield (2344 kg ha^{-1}) was registered with pre-sowing irrigation *fb* three irrigations at vegetative stage (30-35 DAS), flowering stage (40-45 DAS) and capsule development stage (60-65 DAS) which was found to be on par with pre-sowing irrigation *fb* two irrigations at vegetative stage (30-35 DAS) and flowering stage (40-45 DAS). Further, (T_4) recorded significantly lower water use efficiency (5.26 kg ha-mm^{-1}). Whereas the treatment under rainfed conditions (T_5) recorded significantly higher water use efficiency (13.59 kg ha-mm^{-1}) than all other treatments.

Keywords: Growth, Irrigation use efficiency; linseed; yield.

1. INTRODUCTION

Linseed (*Linum usitatissimum* L.) is a self-pollinated crop widely adapted to the temperate climates of the world. It is also known as Agase in Kannada, Javas or Alashi in Marathi, Alsi in Hindi and Ousahalu in Telugu. It is an annual plant belongs to the genus *linum* of the family *Linaceae*. The name *Linum* originated from the Celtic word ‘lin’ or ‘thread’, and the name usitatissimum is a Latin word meaning "most useful". It is believed that linseed, also called flax, originated in the Middle East or Indian regions, one of the oldest crop plants cultivated in around 47 countries for the dual purpose of seed oil and fibre.

“Linseed occupies an area of 32.23 lakh ha, yielding 30.68 lakh tonnes with an average productivity of 952 kg ha^{-1} in the world. In India, it occupies an area of 2.39 lakh ha with a production and productivity of about 1.67 lakh tonnes and 698 kg ha^{-1}, respectively. India is fifth in the area and ranks sixth in production” (Anonymous, 2022). “Though there has been a slight improvement in average productivity over the previous years, it is still far below the potential yield (2000-2200 kg ha^{-1}) of improved linseed varieties in the major linseed growing nations such as Canada (1432 kg ha^{-1}), China (1308 kg ha^{-1}), USA (1258 kg ha^{-1}) and Kazakhistan (809 kg ha^{-1}) underlying the need for upscaling the production and productivity of this crop. The present status of linseed production could be increased to 2-3 folds by adopting improved varieties coupled with recommended production and protection technologies. In Karnataka, it is grown over an area of 26 thousand ha with a production of 25.27 thousand tonnes and productivity” of 972 kg ha^{-1} (Anonymous, 2022a). In Karnataka, it is mainly grown in northern districts *viz.,* Raichur, Vijayapura, Kalaburagi, Bidar, Koppal, Yadagiri and Bellary from October to November under conserved soil moisture and limited nutrient conditions with poor management practices.

“Linseed yield which is a rich source of both non-edible and edible oil. Industrial oil is an important ingredient in manufacturing paint, varnish and linoleum” (Matheson, 1976). “Edible linseed oil is used for human consumption and contains a-linolenic acid (ALA), a polyunsaturated fatty acid with nutritional and health benefits (Wood, 1997). Linseed oil is found to be containing 5 major fatty acids, *viz*., palmitic (about 7 %), stearic (3.4-4.6 %), oleic (18.5-22 %), linoleic (14.2-17 %) and linolenic acid (51.9-55.2 %)” (Vaisey-Genser and Morris, 2016). Linseed is one of the richest sources of lignin (800 times more than any other plant seed except sesame seeds 47 times more), which provides protection against certain forms of cancer due to estrogenic and anti-estrogenic activity in the body. The oil cake is a good feed for milch cattle and poultries and hence is priced 50% higher than rapeseed-mustard cake. It tastes good and contains 36% protein, of which 85% is digestible. It is also used as organic manure. It contains about 5% N, 1.4% P_2O_5 and 1.8% K_2O. Linseed is globally cultivated for its fibres and is called flax. The stem yields good quality fibre having high strength and durability.

"Among all, water is one of the most important critical inputs for agriculture which consumes more than 70 per cent of the water resources of the country. The availability of adequate quantity and water quality is a key factor for achieving higher productivity levels. Investments in the conservation of water, improved techniques to ensure its timely supply and improved its efficient use are some of the imperatives which the country needs to enhance. Poor irrigation efficiency of conventional irrigation systems has not only reduced the anticipated outcome of investments made towards water resource development but has also resulted in environmental problems like water logging and soil salinity, thereby affecting crop yields. Thus, it calls for massive investments in the adoption of improved methods of irrigation, such as drip and sprinkler, including fertigation" (Anonymous, 2017).

."There are several reports of marked response of linseed to irrigation. Significant yield increases from irrigation between early November and January when total rainfall and distribution was poor. The significant positive effect of irrigation on seed yield was attributed to a higher capsule number and more seeds/capsules under irrigation" (Lisson and Mendham, 2000). "The main effect of water stress on linseed yield attributes is on the number of capsules and seeds/plant or unit area" (Hocking and Pinkerton, 1991). "Severe water stress can reduce mean seed weight and lower yield (Hocking, 1995). Water deficit lowers seed yield mainly by reducing PAR interception by shortening growth duration and affecting the canopy development" (Wilson, 1987). Water stress accelerated leaf, stem and pod senescence in linseed and thus reduced capsule and seed growth. Usually, it is cultivated in rainfed areas. If winter rains fail, it creates soil moisture stress. To overcome this, supplemental irrigation is required. Hence, scheduling irrigation at different growth stages helps to increase the growth and yield by reducing moisture stress. Efficient water management is important in getting higher yields with good quality produce, higher water use efficiency, increased soil productivity, higher fertilizer use efficiency and lesser irrigation cost, which can be achieved by following an optimum irrigation schedule.

2. MATERIALS AND METHODS

A field experiment was conducted during *rabi* season of 2023-24 at Main Agricultural Research Station (MARS), Raichur, Karnataka. The field where the experiment was conducted is located at a Latitude 16.15° N and Longitude 77.20° E with an altitude of 407 meters above the Mean Sea Level (MSL). The soil of the experimental field was sandy loam in texture with alkaline pH (8.39), bulk density (1.61 g cm^{-3}), organic carbon content (0.66 %), available nitrogen (206.58 kg ha^{-1}), phosphorus (23.25 kg ha^{-1}) and potassium (236.98 kg ha^{-1}) contents. The experiment was laid out in a randomized complete block design (CRBD) with five treatments and replicated four times. There were five treatments *viz*., T_1: Pre sowing irrigation only, T_2: Pre sowing irrigation *fb* one irrigation at vegetative stage (30-35 DAS), T_3: Pre sowing irrigation *fb* two irrigations at vegetative stage (30-35 DAS) and flowering stage (40-45 DAS), T_4: Pre sowing irrigation *fb* three irrigations at vegetative stage (30-35 DAS), flowering stage (40-45 DAS) and capsule development stage (60-65 DAS) and T_5: Rainfed condition. The linseed variety NL-115, lasting 110-115 days, was sown with a spacing of 30 x 5 cm with a seed rate of 25 kg ha^{-1}. The recommended dose of fertilizer being 40:20:20 kg NPK ha^{-1}), the entire quantity of P_2O_5, K_2O and 50 per cent of nitrogen were applied as basal dose at the time of sowing in the form of Urea, DAP and Muriate of Potash, respectively. The remaining 50 per cent of nitrogen was top dressed after first irrigation (30 DAS) in all the treatments and in rainfed with the available soil moisture using urea as band application. Suitable plant protection measures were taken during the cropping season. The irrigation treatments were imposed as per the schedule. Five plants were randomly selected for taking observations on growth and yield attributing parameters as per the schedule. The crop in each net plot was harvested separately as per treatment and the values were converted into hectare basis and expressed in kilograms per hectare. The Irrigation Use Efficiency of each treatment was computed using the following formula (Thanki et al., 2014).

$$\text{IWUE} = \frac{\text{Y}}{\text{WR}}$$

Where, IWUE = Irrigation water use efficiency (kg ha-mm^{-1})

Y = Crop yield (kg ha^{-1})
WR = Total water applied in the field (mm)

The experimental data obtained were subjected to statistical analysis adopting Fisher's method of analysis of variance as outlined by Gomez and Gomez (1984). The level of significance used in "F" test was given at 5 per cent. Critical difference (CD) values are given in the table at 5 per cent level of significance, wherever the "F" test was found significant.

3. RESULTS AND DISCUSSION

3.1 Effect on Crop Growth Parameters

The results of the experiment revealed that, among the treatments, at harvest, significantly higher plant height, number of branches per plant, leaf area and total dry matter production (60.94 cm, 6.18, 36.94 cm^2 plant^{-1} and 16.41 g plant^{-1}, respectively) were recorded with pre-sowing irrigation *fb* three irrigations at vegetative stage (30-35 DAS), flowering stage (40-45 DAS) and capsule development stage (60-65 DAS) which was at par with pre-sowing irrigation *fb* two irrigations at vegetative stage (30-35 DAS) and flowering stage (40-45 DAS) which recorded on par growth parameters (plant height, number of branches per plant, leaf area and total dry matter production (58.39 cm, 5.93, 34.71 cm^2 plant^{-1} and 15.11 g plant^{-1}, respectively). Whereas rainfed condition recorded significantly lower plant height (41.52 cm), number of branches (4.28), leaf area (24.30 cm^2 plant^{-1}) and total dry matter production (10.90 g plant^{-1}) (Table 1). This is mainly due to the plants under ambient and sufficient moisture conditions utilising other growth resources and accelerating the enzymatic activity, photosynthesis, carbohydrate metabolism, protein synthesis and cell division, which in turn enhances the growth and development of plants owing to the right amount of water at the right time. Similar results were also obtained by many workers (Khemmouli et al., 2023; Ebied and Badawi, 2023; Ebied and Badawi, 2023; Ibrahim et al., 2023; Marbate et al., 2020).

3.2 Effect on Yield Parameters and Yield

Among the treatments, significantly higher yield attributes *viz*., number of capsules plant^{-1} (44.27), number of seeds capsule^{-1} (8.18), seed weight plant^{-1} (2.98 g) and 1000 seed weight (8.16 g) were recorded with irrigation scheduled at pre-sowing irrigation *fb* three irrigations at vegetative stage (30-35 DAS), flowering stage (40-45 DAS) and capsule development stage (60-65 DAS) that resulted in higher yield attributing parameters and yield levels as compared to other treatments. Whereas, the number of capsules plant^{-1} (41.53) and seeds capsule^{-1} (7.75), seed weight plant^{-1} (2.71 g) and 1000 seed weight (7.99 g) were on par with irrigation scheduled at pre-sowing irrigation *fb* two irrigations at vegetative stage (30-35 DAS) and flowering stage (40-45 DAS). This might be due to improved growth parameters that, in turn, lead to better translocation of photosynthates from source to sink, which helped in attaining higher yield attributing parameters and yield. However, the 1000 seed weight of linseed was non-significant with irrigation scheduling in linseed. From the result, it was found that, the application of pre-sowing irrigation *fb* three irrigations at the vegetative stage (30-35 DAS), flowering stage (40-45 DAS) and capsule development stage (60-65 DAS) resulted in higher seed yield (1106 kg ha^{-1}) and straw yield (2344 kg ha^{-1}) and this was found to be on par with pre-sowing irrigation *fb* two irrigations at vegetative stage (30-35 DAS) and flowering stage (40-45 DAS) with seed (995 kg ha^{-1}) and straw yield (2188 kg ha^{-1}), respectively. Rainfed conditions registered significantly lower seed yield (477 kg ha^{-1}) and straw yield (1287 kg ha^{-1}) (Table 2).

Table 1. Growth parameters of linseed at harvest as influenced by scheduling of irrigation

Treatment	Plant height (cm)	Number of branches plant^{-1}	Leaf area (cm^2 plant^{-1})	Total dry matter production (g plant^{-1})
T_1	42.39	4.46	25.11	11.50
T_2	45.95	4.69	28.89	12.32
T_3	58.39	5.93	34.71	15.11
T_4	60.94	6.18	36.94	16.41
T_5	41.52	4.28	24.30	10.90
S. Em. ±	2.17	0.47	1.57	0.32
C.D. (P = 0.05)	6.69	1.44	4.83	0.99
CV %	8.71	14.29	9.71	4.91

Table 2. Yield parameters and yield of linseed as influenced by scheduling of irrigation

Treatment	Number of capsules plant^{-1}	Number of Seeds capsule^{-1}	Seed weight (g plant^{-1})	1000 seed weight (g)	Seed yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest index
T_1	27.66	5.85	1.15	7.29	510	1322	0.28
T_2	36.59	6.25	1.82	7.61	755	1720	0.30
T_3	41.53	7.75	2.71	7.99	995	2188	0.31
T_4	44.27	8.18	2.98	8.16	1106	2344	0.32
T_5	25.50	5.25	1.04	7.14	477	1287	0.27
S. Em. ±	1.59	0.43	0.17	0.28	52	94	0.02
C.D. (P = 0.05)	4.90	1.32	0.53	NS	162	289	NS

The higher seed and straw yields are typically the result of a combination of optimal soil and water management, use of high-yielding crop varieties, effective pest and disease control, favourable climatic conditions and good agronomic practices. Implementing these factors collectively can lead to significant improvements in crop yield and overall productivity. Adequate and well-managed soil moisture ensures that plants have enough moisture throughout their growing period, which supports robust growth and high yield. Proper irrigation scheduling can prevent drought/stress and waterlogging, leading to better crop yields (Khemmouli et al., 2023). Soils rich in essential nutrients (nitrogen, phosphorus, potassium, *etc*.) support strong crop growth and development and higher yields. Proper fertilization practices can enhance nutrient availability. Similar observations were recorded by previous workers (Khemmouli et al., 2023; Ebied and Badawi, 2023; Ibrahim et al., 2023; Gurjar et al., 2017; Kashyap et al., 2017).

3.3 Effect on Irrigation Water use Efficiency

The total quantity of irrigation water applied in each irrigation treatment *viz*., T1, T2, T3, T4 and T5 was 50 mm, 100 mm, 150 mm, 200 mm and 25 mm, respectively with a depth of 50 mm each time that is measured by installed cutthroat flume for individual treatment). The effective rainfall received during season was 10.08 mm which was computed by balance sheet method.. Thus the total quantity of water available to different treatments was 60.08 mm, 110.08 mm, 160.08 mm, 210.08 mm and 35.08 mm in different treatments, *viz.*, pre-sowing irrigation only, pre-sowing irrigation fb one irrigation at vegetative stage (30-35 DAS), pre-sowing irrigation *fb* two irrigations at vegetative stage (30-35 DAS) and flowering stage (40-45 DAS), pre-sowing irrigation *fb* three irrigations at vegetative stage (30-35 DAS), flowering stage (40-45 DAS) and capsule development stage (60-65 DAS) and rainfed condition, respectively. Water use efficiency differed significantly due to different irrigation scheduling at different growth stages of linseed. Water use efficiency can be presented regarding yield realized per hectare meter of water used. Among all the treatments pre-sowing irrigation FB, three irrigations at the vegetative stage (30-35 DAS), flowering stage (40-45 DAS), and capsule development stage (60-65 DAS) recorded significantly lower water use efficiency of 5.26 kg ha-mm^{-1}. Water use efficiency shows a decreasing trend with an increase in the amount of water used. The rainfed condition treatment recorded a significantly higher irrigation water use efficiency of 13.59 kg ha-mm^{-1} over all other irrigation treatments (Table 3).

Excessive irrigation may lead to reduced efficiency, potentially due to issues like waterlogging or less effective water management practices. Water management emphasize the need for carefully managing irrigation schedules to avoid overuse and to optimize water use. Effective water management strategies could balance water application with crop needs to maximize yield per unit of water used. While irrigation is necessary for crop growth, excessive water application can diminish efficiency. Linseed appears to be highly efficient under limited water conditions, suggesting that targeted irrigation practices and water conservation can improve water use efficiency. The results conform with the previous findings (Khemmouli et al., 2023; Sharma et al., 2012; Ebied and Badawi, 2023; Ibrahim et al., 2023).

Table 3. Total Water applied and Irrigation Water Use Efficiency of linseed as influenced by scheduling of irrigation

Treatment	Total irrigation water applied (mm)	Irrigation water use efficiency (kg ha-mm^{-1})
T_1: Pre sowing irrigation only	60.08	8.48
T_2: Pre sowing irrigation *fb* one irrigation at vegetative stage (30-35 DAS)	110.08	6.86
T_3: Pre sowing irrigation *fb* two irrigations at vegetative stage (30-35 DAS) and flowering stage (40-45 DAS)	160.08	6.21
T_4: Pre sowing irrigation *fb* three irrigations at vegetative stage (30-35 DAS), flowering stage (40-45 DAS) and capsule development stage (60-65 DAS)	210.08	5.26
T_5: Rainfed condition	35.08	13.59
S. Em. ±	-	0.66
C.D. (P = 0.05)	-	2.04

4. CONCLUSION

From the above study, it can be concluded that the application of irrigation water at optimum quantity is essential to improve crop yields. If an ample amount of irrigation water is available, then scheduling of irrigation at pre-sowing irrigation fb three irrigations at the vegetative stage (30-35 DAS), flowering stage (40-45 DAS), and capsule development stage (60-65 DAS) helps in getting a higher yield. If water is limited, then irrigation scheduling at pre-sowing irrigation fb two irrigations at the vegetative stage (30-35 DAS) and flowering stage (40-45 DAS) are essential for higher yield. Water use efficiency shows a decreasing trend with an increase in the amount of water utilised. Rainfed conditions recorded significantly higher water use efficiency. Whereas, pre-sowing irrigation fb three irrigations at the vegetative stage (30-35 DAS), flowering stage (40-45 DAS) and capsule development stage (60-65 DAS) recorded significantly lower water use efficiency.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

We authors hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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