International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 09 Issue 08 August 2026
DOI: 10.47191/ijcsrr/V9-i8-13, Impact Factor: 8.048
IJCSRR @ 2026
www.ijcsrr.org

Effects of Irrigation Intervals on the Growth and Yield of Flax under Kabul Climate Conditions

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ABSTRACT: Flax (Linum usitatissimum L.) is an important oilseed and fiber crop with significant economic value. Efficient irrigation management is essential for improving crop productivity under the semi-arid conditions of Kabul, where water resources are limited. However, information on the optimum irrigation interval for flax production in this region is scarce.

This field experiment was conducted at the Agricultural Research Farm of the Faculty of Agriculture, Kabul University, during the spring season of 2025.The objective of this study was to evaluate the effect of different irrigation intervals (4, 8, 12, 16, and 20 days) on the growth and yield of flax, Badakhshee variety. The experiment was arranged in a Randomized Complete Block Design (RCBD) with five treatments and three replications across two sites.

Data were recorded on plant height, number of branches per plant, number of pods per plant, number of grains per pod, 1000-grain weight (g) and total yield per hectare. The results showed that irrigation intervals significantly ($P \leq 0.05$) affected all measured parameters. The highest plant height (68.67 cm), number of pods per plant (189), and grain yield (1856.67Kg ha^{-1}) were obtained under the 12-day irrigation interval, which increased yield by approximately (27.87%) compared to the 20-day interval. In contrast, the lowest values for most traits were recorded under the 20-day irrigation interval.

These findings indicate that irrigation every 12 days provides optimal moisture conditions for flax growth under Kabul agro-climatic conditions. Therefore, this interval is recommended for maximizing yield while ensuring efficient water use.

KEYWORDS: Flax, Irrigation intervals, Growth, Yield, Kabul, Climatic conditions.

INTRODUCTION

Flax or linseed is among the oldest crop plants cultivated for oil and fiber production. It belongs to the genus Linum and family Linaceae. It is an annual herbaceous plant with a shallow root system. The common names flax and linseed are used in North America and Asia, respectively, for L. usitatissimum. Oilseed and fiber types represent specialized forms of this species. The cultivars grown primarily for seed/oil production are relatively short in height and possess more secondary branches and seed bolls (seed capsule). The cultivars grown for fiber purpose are tall growing with straight culms and have fewer secondary branches (Jhala & Hall, 2010).

It is widely cultivated in countries such as China, Russia, and Canada. Flax has a cultivation history of over 5,000 years in China and India and about 10,000 years in Egypt and Samaria, and was later introduced into European countries such as Switzerland, Scotland, and Poland (Saleem et al., 2020). The world's linseed production was approximately 3 million tonnes in 2024, and the linseed market is reported to be expanding rapidly (Orhan & Erdogdu, 2026).

Drought stress is one of the most significant factors limiting crop productivity globally. It adversely affects plant physiology, morphology, and biochemical processes, often leading to substantial yield losses. Irrigation, while essential for mitigating water deficits, relies heavily on limited freshwater resources. The agricultural sector consumes nearly 70% of global freshwater supplies to irrigate only 25% of arable land (Ritchie and Roser, 2018; Lakhiar et al., 2024). Increasing water scarcity, driven by population growth, economic development, and climate change, further intensifies pressure on agricultural production systems (Goshime et al., 2021; Yang et al., 2021). Therefore, optimizing irrigation management is crucial for enhancing water-use efficiency, particularly in arid and semi-arid regions like Afghanistan (Orhan & Erdogdu, 2026).

Several studies have highlighted the significant role of irrigation in improving the growth, yield, and fiber quality of flax. A field trial conducted at El-Gemmeiza Research Station, Egypt, during the 2015/2016 and 2016/2017 seasons investigated the effect of irrigation intervals (21, 28, and 35 days). The experiment followed a split-plot design with three replications. The results indicated significant differences among irrigation intervals for all studied traits. Irrigation every 21 days produced the highest values for plant height, straw yield, fiber yield, number of capsules per plant, number of seeds per capsule, seed yield, and oil yield. In contrast, irrigation every 35 days resulted in the lowest values for most traits, while irrigation at 28-day intervals showed intermediate performance without significant difference from the 21-day interval (EL-Shimy et al., 2017).

Another study conducted at Ismailia Agricultural Research Station, Egypt, during the 2004/2005 and 2005/2006 seasons evaluated the effect of sprinkler irrigation intervals (1, 2, and 3 days), row spacing (15 and 20 cm), and Agar Agar as a soil conditioner on flax yield and its components. A split-split plot design with three replications was used. The results showed that irrigation intervals had a significant effect on plant height, Stem length, straw yield, number of capsules per plant, seed yield, and fiber yield. The highest values for most traits were obtained with irrigation every three days (Azzouni et al., 2005).

Hireholi et al. (2024) reported that three irrigations (vegetative, flowering, capsule development stages) produced the highest seed yield (1106 kg ha^{-1}) and straw yield (2344 kg ha^{-1}). However, water-use efficiency was lowest under this regime (5.26 kg ha^{-1} mm^{-1}), while rainfed conditions had the highest efficiency (13.59 kg ha^{-1} mm^{-1}). Thus, two irrigations offered a better balance between yield and efficiency (Hireholi et al., 2024).

In Afghanistan, particularly under the semi-arid conditions of Kabul, flax cultivation faces several challenges, including irregular rainfall, limited irrigation water, and declining soil fertility. Farmers often depend on traditional irrigation practices without scientifically validated recommendations, which may result in inefficient water use and reduced crop productivity. Although the effects of irrigation on flax have been investigated in different regions, limited information is available regarding the optimum irrigation interval for flax production under Kabul agro-climatic conditions. Therefore, systematic research is needed to identify an appropriate irrigation schedule that can maximize yield while improving water-use efficiency. This study is important for improving water-use efficiency and promoting sustainable flax production under water-limited conditions. The objective of this study was to evaluate the effects of different irrigation intervals on the growth, yield, and yield components of flax (Linum usitatissimum L.) and to determine the most suitable irrigation interval for Kabul conditions.

MATERIALS AND METHODS

local flax (Linum usitatissimum L.) genotype (Badakhshee), obtained from the Badam Bagh Research Farm, Kabul, Afghanistan, was used as the planting material.

The field experiment was conducted during the 2025 growing season at the Experimental Farm, Kabul, Afghanistan (34.3104° N, 69.0823° E; 1,809 m above sea level). The experimental field had relatively uniform fertility, even topography, and homogeneous soil texture. It was connected to the main irrigation canal and a tube well, ensuring a reliable water supply throughout the experimental period. The area is characterized by a semi-arid climate, with an average annual precipitation of approximately 300 mm and an annual evapotranspiration of about 1,600 mm. Rainfall occurs mainly during winter and spring, whereas summers are generally dry (Hamidi et al., 2023; Hashimi et al., 2025). The soils of the study area are predominantly alluvial loam with slightly alkaline pH (7.0–8.0) and relatively low organic matter content, which is typical of agricultural soils in Kabul Province (Rasouli & Vaseashta, 2023; FAO, 2023; ICARDA, 2022). No soil chemical analysis was conducted prior to the experiment; however, the field was considered uniform based on previous cultivation history.

The experiment was arranged in a Randomized Complete Block Design (RCBD) consisting of five irrigation intervals (4, 8, 12, 16, and 20 days) with three replications, resulting in 15 experimental plots. The RCBD design was selected to minimize the effect of field variability and improve the precision of treatment comparisons.

Each plot measured 2 m × 2 m (4 m^2), giving a total experimental area of 60 m^2. Treatments were randomly allocated within each replication to minimize field variability and improve the precision of treatment comparisons. Buffer spaces and irrigation channels were maintained between plots to prevent lateral water movement and treatment interference.

The land was deeply ploughed three weeks before sowing, followed by repeated cultivation and leveling to obtain a fine seedbed. Crop residues and weeds were removed before plot layout and irrigation channels were prepared.

Seeds were treated with Vitavax-Thiram wettable powder fungicide (RRD, India) and sown on 2 April 2025 at a depth of 3 cm under approximately 60% field capacity soil moisture. Row spacing and plant spacing were maintained at 20 cm and 10 cm, respectively. Organic manure was applied at 1.5 t ha^{-1}, while urea was applied at 150 kg ha^{-1}. All organic manure and half of the urea were incorporated into the soil before sowing, whereas the remaining urea was top-dressed 40 days after sowing. Irrigation was

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applied manually using the check basin irrigation method according to the designated treatment intervals. Irrigation was started after germination and then continued at specified intervals throughout the growing season. Weed control was carried out manually without the use of herbicides throughout the growing season. The crop was harvested on 21 July 2025 at physiological maturity.

Data were collected from ten randomly selected plants in each plot, excluding border rows. The same sampling procedure was followed for all treatments to ensure consistency and minimize sampling bias. Growth parameters included plant height and number of branches per plant. Yield-related traits included number of capsules (pods) per plant, number of seeds per capsule, 1,000-seed weight, grain yield (g m^{-2}), and grain yield (kg ha^{-1}). These data were recorded from the central rows to avoid border effects. Plant height was recorded at physiological maturity by measuring from the soil surface to the tip of the main stem of each selected plant. The number of branches, capsules, and seeds was determined by manual counting. Thousand-seed weight and grain yield were measured using a precision electronic balance. Grain yield was determined after harvesting, threshing, and cleaning the seeds from the net plot area before conversion to hectare yield.

The experimental data were analyzed using STAR (Statistical Tool for Agricultural Research) software. Analysis of variance (ANOVA) appropriate for the Randomized Complete Block Design was performed to determine the effects of irrigation intervals on growth, yield, and yield-related traits of flax. Treatment means were compared using the Least Significant Difference (LSD) test at the 5% probability level ($P \leq 0.05$). The coefficient of variation (CV), F-values, and significance levels were calculated to assess treatment effects. Normality and homogeneity of variance were checked prior to ANOVA to ensure validity of statistical assumptions.

RESULTS

Irrigation interval significantly influenced most of the measured growth and yield traits of flax, except the number of grains per pod and thousand-seed weight, which were not significantly affected (Table 1).

Plant height was significantly affected by irrigation intervals ($P < 0.01$). The highest plant height (68 cm) was obtained under the 12-day irrigation interval, whereas the lowest value (36 cm) was recorded under the 20-day irrigation interval. Mean comparison showed that the 4-day (56 cm) and 8-day (54 cm) intervals were statistically similar, while all other treatments differed significantly from each other. Analysis of variance indicated a highly significant treatment effect ($F = 59.68$), with a coefficient of variation of 5.30% (Table 1).

The number of branches per plant increased significantly with irrigation intervals ($P < 0.01$). The highest value (9 branches) was recorded under the 12-day interval, while the lowest (5 branches) occurred under the 20-day interval. The 4-day and 8-day intervals were statistically similar to each other and showed no significant difference, while the 16-day interval was intermediate, showing overlap with both higher and lower groups. ANOVA indicated a significant treatment effect ($F = 8.54$), with a coefficient of variation of 11.27% (Table 1).

The number of pods per plant was significantly influenced by irrigation intervals ($P < 0.01$). The highest number (189 pods) was recorded under the 12-day interval, while the lowest value (152 pods) was observed under the 20-day interval. The 4-day (180) and 8-day (183) intervals were statistically similar to each other, while the 16-day interval (172) was intermediate, differing from the 12-day and 20-day treatments but not from the lower overlapping group. Analysis of variance revealed a highly significant treatment effect ($F = 17.50$), with a coefficient of variation of 3.49% (Table 1).

Irrigation interval had no significant effect on the number of grains per pod ($P > 0.05$). Although some numerical variation was observed among treatments, these differences were not statistically significant. The highest value (8 grains per pod) was recorded under the 12-day irrigation interval, while the lowest (6.7 grains per pod) was observed under the 20-day interval. This indicates that grain setting per pod remained relatively stable across different irrigation schedules, suggesting a lower sensitivity of this trait to irrigation frequency under the experimental conditions (Table 1).

Thousand-seed weight was not significantly influenced by irrigation intervals ($P > 0.05$). However, slight numerical differences were recorded among treatments. The maximum thousand-seed weight (4 g) was obtained under the 12-day irrigation interval, whereas the minimum value (3.5 g) was recorded under both the 4-day and 20-day irrigation intervals. The relatively small variation suggests that seed weight was less responsive to changes in irrigation frequency compared to other yield components (Table 1).

Grain yield per square meter responded significantly to irrigation interval ($P < 0.01$), indicating a strong influence of water management on final yield formation. The maximum yield (186 g m^{-2}) was recorded under the 12-day irrigation interval, whereas

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the lowest yield (145.2 g m^{-2}) was observed under the 20-day interval. ANOVA confirmed a highly significant treatment effect (F = 91.41), with a low coefficient of variation (1.91%), indicating good experimental precision (Table 1).

Grain yield per hectare was significantly influenced by irrigation intervals ($P < 0.01$). The highest yield (1857 kg ha^{-1}) was obtained under the 12-day interval, while the lowest yield (1452 kg ha^{-1}) was recorded under the 20-day interval. The 8-day (1527 kg ha^{-1}) and 16-day (1579 kg ha^{-1}) intervals were statistically similar, whereas the 4-day (1457 kg ha^{-1}) and 20-day (1452 kg ha^{-1}) intervals also showed no significant difference. Analysis of variance indicated a highly significant treatment effect (F = 88.39), with a coefficient of variation of 1.95% (Table 1), confirming the reliability of the experimental results

Irrigation interval significantly affected most of the growth and yield traits of flax, except the number of grains per pod and 1000-seed weight, which were not significantly influenced. The analysis of variance (ANOVA), F-values, coefficients of variation (CV), and least significant difference (LSD) values are presented in Table 2.

Table 1. Analysis of variance of the effects of irrigation intervals on growth attributes and grain yield of Flax

Parameters	F-value	P-value	CV (%)	LSD (0.05)	Significance
Plant height (cm)	59.68	<0.001	5.3	5.2	**
Number of branches/plant	8.54	0.0055	11.27	1.56	**
Number of pods/plant	17.5	0.0005	3.49	11.53	**
Number of grains/pod	0.94	0.4886	12	NS	NS
Grain yield (kg/ha)	88.39	<0.001	1.95	57.81	**
1000-seed weight (g)	3.54	0.0605	6.3	NS	NS

Note: ** = Significant at $P \leq 0.01$; NS = Not significant. LSD = Least Significant

Table 2. *Effect of irrigation intervals on growth attributes and grain yield of flax*

Treatment	Plant Height	Number of Branch/Plant	Number of Pods/plant	Number of grain/Pod	Grain Yield gr/m^{-2}	1000 seeds weight	Grain Yield kg ha^{-1}
T1 (4 Days)	56 b	8 ab	180 ab	8	145.7	3.5	1457 c
T2 (8 Days)	54 b	8 ab	183 ab	8	152.7	4	1527 b
T3 (12 Days)	68 a	9a	189 a	8	185.7	4	1857 a
T4 (16 Days)	46 c	6 bc	172 b	7.3	157.9	3.7	1579 b
T5 (20 Days)	36 d	5 c	152 c	6.7	145.2	3.5	1452 c

DISCUSSION

The present study demonstrated that irrigation interval is a key determinant of flax growth and productivity under semi-arid conditions, where limited and irregular rainfall cannot meet crop water requirements. Variations in irrigation scheduling significantly influenced both vegetative development and yield formation, indicating that flax is highly sensitive to soil moisture availability during its growth cycle.

Vegetative growth responses observed in this study can be attributed to differences in soil moisture availability, which directly affects physiological processes such as cell expansion, nutrient uptake, and photosynthetic efficiency. Adequate irrigation promotes stomatal conductance and enhances chlorophyll activity, resulting in improved plant growth, whereas moisture deficit conditions reduce metabolic activity and restrict vegetative development. The superior vegetative performance under moderate irrigation intervals is consistent with findings reported by EL-Shimy et al. (2017), Azzouni et al. (2005), and Dohat et al. (2017), who emphasized that balanced irrigation regimes enhance flax growth under field conditions. Similarly, water stress–induced growth reduction reported by Kwiatkowska et al. (2023) supports the present observations, confirming that flax growth is highly dependent on continuous and adequate moisture supply.

In addition, similar positive responses of vegetative traits to improved irrigation have been widely reported in other studies, where better soil moisture conditions consistently enhanced plant height, biomass accumulation, and overall vigor due to improved physiological activity and efficient nutrient transport within the plant system. These consistent findings across different environments further confirm the strong dependency of flax vegetative growth on adequate water availability.

The observed variation in plant height across irrigation treatments can be explained by the role of water in promoting cell elongation and maintaining turgor pressure. Under moisture deficit conditions, reduced cell expansion and limited nutrient transport likely contributed to suppressed vertical growth, whereas moderate irrigation intervals maintained optimal physiological conditions for stem elongation and canopy development. These findings align with Patel et al. (2017), who reported improved plant height under optimized irrigation scheduling, and Azzouni et al. (2005), who highlighted the sensitivity of flax height to irrigation frequency. However, Keten et al. (2015) reported that the effects of irrigation on vegetative growth components such as plant height and branching may vary depending on environmental conditions, indicating that these responses are not always consistent across different agro-climatic regions.

Branch formation is closely linked to vegetative vigor and assimilate availability. Adequate soil moisture enhances meristematic activity by maintaining optimal cell turgor pressure, which directly promotes lateral bud initiation and shoot development. In addition, sufficient water supply improves nutrient uptake and transport, particularly nitrogen and potassium, which are essential for active vegetative growth and branching. In contrast, water stress reduces axillary bud activation due to restricted carbohydrate production, hormonal imbalance (especially auxin and cytokinin regulation), and decreased photosynthetic efficiency.

The present results agree with Istanbulluoglu et al. (2015) and Patel et al. (2017), who reported increased branching under improved irrigation conditions, indicating that irrigation management directly influences canopy architecture and potential sink capacity in flax. Similar observations have also been reported in other oilseed crops, where adequate irrigation significantly enhanced lateral branching, biomass accumulation, and overall plant vigor. This suggests that branching is not only a genetic trait but is also strongly modulated by environmental factors, particularly soil moisture availability during the vegetative stage. Furthermore, improved branch formation under moderate irrigation intervals contributes to higher assimilate production capacity and ultimately supports greater yield formation by increasing the number of reproductive sites.

Yield formation in flax is highly dependent on water availability during reproductive stages, particularly flowering, capsule initiation, and seed filling. Water stress during these critical stages can disrupt assimilate partitioning and reduce reproductive success. Improved pod formation under moderate irrigation intervals reflects better reproductive development supported by sustained photosynthetic activity and assimilate supply. Moisture stress under prolonged irrigation intervals likely reduced flower retention and increased reproductive abortion. Similar findings were reported by EL-Shimy et al. (2017), Istanbulluoglu et al. (2015), and Zare et al. (2023), confirming the importance of irrigation timing for reproductive success in flax. However, contrasting results have been reported, indicating that irrigation does not consistently increase flax seed yield across environments. Bauer et al. (2015) reported that although irrigation increased straw yield in some growing seasons, its effect on seed yield was not statistically significant under normal planting conditions. These findings suggest that the response of flax to irrigation is highly dependent on seasonal rainfall distribution and environmental variability, resulting in inconsistent yield responses across studies.

The non-significant response of seeds per pod and seed weight suggests that these traits are relatively stable and less sensitive to moderate variations in irrigation frequency. These yield components are likely more genetically controlled than environmentally influenced under the tested conditions. Similar stability in these traits has been reported by Istanbulluoglu et al. (2015) and Philip et al. (2014), indicating that irrigation mainly affects yield through pod number rather than individual seed formation.

The significant variation in grain yield across irrigation intervals reflects the cumulative effect of vegetative and reproductive responses to water availability. The highest grain yield (1856.67 kg ha^{-1}) obtained under the 12-day irrigation interval indicates that this irrigation schedule maintained adequate soil moisture during critical growth stages, including flowering, capsule development, and seed filling. Adequate soil moisture during these stages enhances photosynthetic activity, nutrient uptake, assimilate production, and translocation to developing reproductive organs, ultimately resulting in greater grain yield. In contrast, the lower grain yield recorded under the 20-day irrigation interval was most likely associated with prolonged moisture stress, which reduced vegetative growth, restricted photosynthesis, impaired assimilate partitioning, and limited reproductive development. Water deficit during reproductive stages may also accelerate leaf senescence and reduce flower retention and seed set, leading to lower final grain production.

The superior grain yield observed under the 12-day irrigation interval reflects the combined effects of improved vegetative growth, greater branch production, and increased pod number, all of which contributed to higher productivity. Since grain yield is the cumulative expression of several growth and yield components, favourable irrigation conditions throughout the growing season are essential for maximizing crop performance. These findings are consistent with Mirshekari et al. (2012) and EL-Shimy et al. (2017), who reported that optimized irrigation scheduling significantly improves flax yield by maintaining favourable physiological conditions throughout the growth period.

The present study was conducted over a single growing season and evaluated only one flax genotype under a specific agro-climatic environment. Therefore, the results may not fully represent long-term or multi-environmental variability. Additionally, soil moisture dynamics and physiological indicators were not directly measured, which could have provided deeper insight into plant–water relationships.

Future research should focus on multi-season and multi-location trials involving different flax genotypes, irrigation levels, and soil types. Integration of irrigation management with nutrient optimization and water-use efficiency analysis would further enhance understanding of sustainable flax production systems under water-limited conditions.

CONCLUSION

This study evaluated the effects of different irrigation intervals on the growth attributes and grain productivity of flax under the agro-climatic conditions of Kabul, Afghanistan. The findings demonstrated that irrigation interval is an important management factor influencing flax performance. Appropriate irrigation scheduling improved vegetative growth, reproductive development, and overall grain productivity, whereas prolonged irrigation intervals reduced crop performance because of inadequate soil moisture availability. Among the irrigation treatments evaluated, the 12-day irrigation interval provided the most favourable conditions for achieving optimum growth and grain yield.

The study contributes to the limited information available on flax irrigation management under the semi-arid conditions of Afghanistan and provides practical evidence that optimizing irrigation intervals can improve crop productivity while supporting more efficient use of irrigation water. These findings may serve as a useful reference for farmers, researchers, and agricultural extension services in developing appropriate irrigation strategies for flax production under similar environmental conditions. Based on the findings of this study, a 12-day irrigation interval can be recommended for flax cultivation under agro-climatic conditions similar to those of Kabul to achieve higher grain yield and more efficient use of irrigation water. Further research should evaluate different flax genotypes across multiple growing seasons, locations, and soil types. Future studies should also investigate the combined effects of irrigation intervals, irrigation amounts, and nutrient management on growth, yield, and water-use efficiency to develop more sustainable flax production systems.

RECOMMENDATIONS

Based on the findings of this study, it is recommended that a 12-day irrigation interval be adopted for flax production under agro-climatic conditions similar to Kabul, as it resulted in optimum plant growth and grain yield. This irrigation schedule can improve water use efficiency and support sustainable crop production in water-limited environments.

Furthermore, farmers should be encouraged to adopt proper irrigation scheduling during critical growth stages to minimize water stress and enhance crop performance. Agricultural extension services should play an important role in disseminating these recommendations and training farmers on efficient irrigation management practices. Future research should focus on evaluating flax performance under different genotypes, irrigation levels, and multi-location conditions to further refine irrigation recommendations and improve productivity under diverse environmental conditions.

Authors Contributions: The author contributed entirely to all aspects of the study, including conceptualization, fieldwork, data analysis, and manuscript preparation.

Acknowledgements: The author sincerely expresses gratitude to Professor Abdul Ghani Ayubi for his valuable guidance, continuous support, and constructive suggestions throughout this research. The author also acknowledges the academic staff of the Department of Agronomy, Faculty of Agriculture, Kabul University, for their assistance and encouragement during the study period.

Funding Information: This study did not receive any external funding.

Conflict of Interest Statement: The author declares no conflict of interest.

Data Availability Statement: The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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Cite this Article: Hasand, M.A., Ayub, A.G. (2026). Effects of Irrigation Intervals on the Growth and Yield of Flax under Kabul Climate Conditions. International Journal of Current Science Research and Review, 9(8), pp. 4338-4345. DOI: https://doi.org/10.47191/ijcsrr/V9-i8-13