Effect of Irrigation Intervals and Harvest Dates on Seed Yield and its Components of Alfalfa

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ABSTRACT

Background: Alfalfa, a key forage crop, thrives through growth stages like flowering and pod formation. Optimal irrigation intervals, especially during critical stages, improve water use efficiency and seed yield. Harvest date, such as at the yellow pod stage, enhances seed quality and quantity. Effective irrigation and harvest management boost productivity, particularly in arid regions. This study aims to improve these practices in Iraq to maximize seed yield under water scarce conditions.

Methods: The study investigated irrigation intervals and harvest dates on alfalfa seed yield in Baghdad, Iraq (33.3161N, 44.2129E) from Oct 2023 to Jul 2024. A randomized complete block design with a nested arrangement assessed four irrigation schedules synchronized with different growth stages and three harvest timings (6, 10, 14 days post last irrigation). Measured properties included stems per plant, pods per raceme, seed yield, biological yield and harvest index. Data were analyzed *via* ANOVA with LSD ($p<0.05$). Irrigation was regulated based on soil field capacity and fertilizers were applied at recommended rates.

Result: Irrigation significantly affected alfalfa productive properties, with irrigation treatment synchronized with flowering/pod stages yielding the highest stem count (12.2 plant^{-1}), mature racemes (13.2 stem^{-1}), pods (10.7 raceme^{-1}) and seed yield (465.3 kg ha^{-1}). Fixed weekly irrigation underperformed due to mismatched timing. The harvest date 10 days after last irrigation improved pod/seed yields by allowing full maturation. Seed weight remained stable across irrigation but increased with delayed harvest (14 days after last irrigation). Irrigation treatment synchronized with flowering/pod stages also achieved the highest harvest index (9.47%), showing efficient reproductive growth, while fixed irrigation promoted excessive vegetation. Optimal irrigation timing and harvest synchronization maximize productivity.

Key words: Alfalfa, Harvest date, Irrigation interval, Seed yield, Semiarid region.

INTRODUCTION

Alfalfa is a globally important forage crop, valued for its high nutritional content and its vital role in supplying protein rich feed for livestock. Khrbeet *et al.* (2019) identified several growth stages of the Alfalfa, including vegetative growth, bud emergence, flowering, pod formation and seed maturation. Understanding the critical growth stage is essential for enhancing seed yield, as it influences nutrient absorption and distribution within the plant. This, in turn, positively affects yield components such as stem count, pod formation and seed yield (Khrbeet, 2021).

Irrigation scheduling techniques is one of the suggested solutions for water scarcity problem (Al-Haddad and Bakr, 2013). The findings underscore the importance of optimizing irrigation intervals to support alfalfa yields, particularly in water scarce environments (Jiang *et al.*, 2022). Investigating the effects of different irrigation intervals can offer valuable insights into optimizing the balance between water conservation and crop productivity (Puppo *et al.*, 2024). Research indicates that reducing irrigation frequency, particularly in dry seasons, can conserve substantial amounts of water while preserving much of the crop yield (Orloff *et al.*, 2005). According to Renzi *et al.* (2011), low frequency irrigation improves water use efficiency while sustaining seed yield. Ehsas *et al.* (2018) demonstrated that irrigating alfalfa every 20 days resulted in the highest green forage yield and protein content, highlighting the critical role of irrigation scheduling in maximizing productivity. Jia *et al.* (2024) demonstrate that irrigation during critical growth stages particularly branching and flowering significantly improves both seed quality and yield.

The timing of harvest is a critical factor in determining seed quality and yield. Crookston *et al.* (2025) demonstrated that harvesting at optimal growth stages significantly enhances seed yield and its components. Fink *et al.* (2022) observed that choice of harvest date has a major impact on seed quality and quantity, especially when done at the yellow pod stage (Soufan *et al.*, 2019). Early harvests typically exhibit higher productivity and nutritional value (Orloff *et al.*, 2005). Research by Katanski *et al.* (2020) indicates that harvesting alfalfa in early flowering enhances nutritional value without reducing yield. In contrast, Renzi *et al.* (2011) observed that early harvesting leads to a higher

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proportion of immature and non-viable seeds, whereas harvesting at yellow pod stage enhances seed quality and germination rates.

Forage production can be enhanced in terms of both quantity and quality through improved irrigation scheduling and optimal harvest timing (Puppo *et al.*, 2024). Effective irrigation and harvesting management enhance water use efficiency and maximize economic benefits (Orloff *et al.*, 2005). Irrigation intervals and harvest dates significantly influence the productivity and quality of Alfalfa seeds, these factors are expected to enhance water use efficiency and boost productivity, particularly in arid and semiarid regions (Miao *et al.*, 2025).

Previous studies provide valuable guidance for optimizing irrigation and harvesting practices to enhance seed yield, offering farmers key insights for achieving sustainability under water scarce conditions (Crookston *et al.*, 2025; Jia *et al.*, 2024). Investigating the effects of irrigation schedules and harvest timing on seed yield and their components can enhance fodder yield in Iraq. This study aims to optimize irrigation and harvest dates to maximize seed yield under water scarcity and variable climatic conditions in the region.

MATERIALS AND METHODS

Experiment site

The study was carried out in the experimental fields of Agricultural Engineering Sciences College, Abu Ghraib, Baghdad, Iraq (33.3161N, 44.2129E), between October 2023 to July 2024. The experiment was conducted to investigate the effects of irrigation intervals and harvest dates on the productivity of alfalfa seeds and their components. Prior to planting, soil samples (0-30 cm depth) were analyzed to determine their chemical and physical properties (Table 1).

Preparing the field and planting

The field was plowed and subdivided into 36 experimental units, each unit covering an area of 7.5 m^2 (3 m × 2.5 m).

Table 1: Selected physical and chemical properties of the soil prior to planting.

Property	Unit	Value
Sand	%	15
Clay	%	34
Silt	%	51
Texture class	-	Silty clay loam
Bulk density	$Mg.m^{-3}$	1.38
Organic matter	$g.kg^{-1}$	9
EC (1:1)	$dS.m^{-1}$	3.4
pH	-	7.8
$CaCO_3$	%	23
Available phosphorus	ppm	13
Available potassium	ppm	137
Available nitrogen	ppm	50

Local variety alfalfa seeds (*Medicago sativa* L.) were sown in early October 2023 at a density of 4-6 seeds per hole, spaced 20 cm apart. After two weeks, seedlings were thinned to two plants per hole. Phosphate and potassium fertilizers were applied as recommended, followed by a nitrogen booster two weeks after emergence (Khrbeet and Hashim, 2017).

Field crop management

Throughout the growing period until mid-May 2024, irrigation, mowing and weeding were performed regularly. Irrigation was conducted using pipes to precisely control the amount of water delivered to each experimental unit. Irrigation was applied to maintain optimal soil moisture near field capacity. The irrigation water depth was estimated using the following equation (Allen *et al.*, 1998):

$$d = (\theta fc - \theta i) \times D$$

Where,
d = Irrigation water depth (mm).
θfc = Volumetric moisture content at field capacity ($cm^3\ cm^{-3}$).
θi = Volumetric moisture content before irrigation ($cm^3\ cm^{-3}$).
D = Effective rooting depth (mm).

Experimental design

The experimental treatments were arranged in a randomized complete block design (RCBD) with a Nested arrangement. Irrigation intervals were assigned to main plots, while harvest dates were allocated to subplots. Each treatment combination was replicated three times.

Experimental treatments

After the last mowing in mid-May 2024, two experimental factors were introduced:

A- Irrigation intervals: Four irrigation treatments were implemented after the last mowing, with water applied scheduling determined by the crop's growth stages in each treatment.

1. First treatment (I1)

- Irrigation 3 days after the last mowing.
- Irrigation at bud emergence.
- Irrigation at 25% flowering.
- Last Irrigation at 100% green pods.

2. Second treatment (I2)

- Irrigation 5 days after the last mowing.
- Irrigation at 10% flowering.
- Irrigation at pod formation.
- Last Irrigation at 10% brown pods.

3. Third treatment (I3)

- Irrigation 6 days after the last mowing.
- Irrigation at 20% flowering.
- Irrigation at 100% flowering.
- Irrigation at 50% green pods.
- Last Irrigation at 25% brown pods.

4. Fourth treatment (I4) -farmer method

- Irrigation 1 day after the last mowing.

- The next round of irrigation was applied seven times at weekly intervals, concluding when green pods were fully developed.

B- Harvest dates: Harvesting treatments were applied at three different periods after the last irrigation (6, 10 and 14 days).

Study properties and data collection: The following properties were measured post-harvest date in each treatment.

1. Reproductive stems per plant: From the middle rows, select a sample of plants. Count the stems on each sampled plant and calculate the average number of stems per plant.

2. Flower and pod counts per raceme: Using a random sample of twenty racemes per experimental unit, record the number of flowers and pods per raceme.

3. Seed yield components: Measurements were taken from forty randomly selected stems, including:

- Number of mature racemes per stem,
- Number of seeds per pod,
- Weigh thousand seeds.

4. Seed Yield: Harvest plants from the middle rows, air dries, clean the seeds and weigh them. Calculate yield in kg ha^{-1}.

5. Biological yield: The total dry weight of harvested seeds, plant residues and above ground plant parts, measured after air and sun drying, expressed in kg ha^{-1}.

6. Harvest index: Calculated the ratio of seed yield to biological yield, multiplied by one hundred.

Data and statistical analysis

Statistical analysis was performed using analysis of variance (ANOVA), with means compared by the least significant difference (LSD) test at $p<0.05$.

RESULTS AND DISCUSSION

Number of reproductive stems

The results indicated a significant effect of irrigation treatment on the number of reproductive stems in alfalfa. In contrast, the results remained consistent across harvest treatments, as shown in Table 2. The lowest average number of stems was observed in treatment I4 (7.4 stems $plant^{-1}$), while the highest average was recorded in treatment I1 (12.2 stems $plant^{-1}$). The superiority of treatment I1 is due to soil water availability with the plant's critical growth stages, Irrigation was applied at start of flowering and full formation of green pods, creating optimal conditions for stem formation. This process enhanced reproductive growth by promoting the production of growth hormones, which supports the formation of new stems. Puppo *et al.* (2024) indicated that irrigation during the flowering stage increases the efficiency of photosynthesis and nutrient distribution. The fixed weekly irrigation (I4) does not meet the plant's needs in the critical stages, which leads to loss water in stages when the plants do not need a lot of water. The study by Orloff *et al.* (2005) showed that Alfalfa productivity can be reduced by up to 30% due to poor irrigation. There is no significant effect of harvest treatments on the reproductive stem number, as concluded from (Table 2). Harvest date has a weaker effect than irrigation, Due to the efficiency of the scheduling irrigation making the harvest date less influential on the stem number.

Mature racemes per stem

The number of mature racemes was significantly affected by irrigation, harvesting treatments and their interaction, as presented in Table 3. The results demonstrate a clear and significant superiority of treatment I1, which produced the highest average number of racemes (13.2 racemes $stem^{-1}$). Additionally, the table reveals that H2 (12.5 raceme $stem^{-1}$) significantly outperformed the other harvest treatments.

The significant superiority of treatment I1 can be attributed to the precise synchronization of irrigation with flowering stage, which increased the number of buds. This aligns with the findings of Jia *et al.* (2024), who linked improved pollination efficiency to optimal soil water availability. The I1 treatment involved synchronizing irrigation with the physiological growth stages. This alignment was particularly evident in H2, where irrigation supported raceme growth completion before abscission began. The small number of mature racemes in the I4 treatment results from fixed weekly irrigation schedule fails to synchronize water supply with critical growth stages, particularly flowering, further limiting raceme development, leading to significant bud abscission. The results in the table demonstrate the significant superiority of treatment H2. This suggests that the optimal time for harvesting is after peak raceme maturity, once pollination is complete and

Table 2: Effect of irrigation intervals on the number of reproductive stems of alfalfa at different harvest dates.

Irrigation	Harvest			Irr. means
	H1	H2	H3	
I1	12.2	12.6	11.9	12.2
I2	11.3	11.8	11.4	11.5
I3	9.8	9.8	8.1	9.2
I4	7.4	7.5	7.2	7.4
$LSD_{0.05}$		N. S		1.01
Har. means	10.2	10.4	9.6	
$LSD_{0.05}$		N. S		

pod formation has begun, thereby minimizing the risk of pod drop. This was evident in a significant 19% increase in the number of racemes compared to H1. Harvesting too early (H1) may result in problems like underdeveloped crops and lower yields than expected. Early harvest (bud formation) maximizes protein content but sacrifices dry matter yield, whereas later harvests (seed maturation) optimize biomass at the cost of feed quality (Karayilanli and Ayhan, 2016). Data in Table 3 show that irrigation synchronized with growth stage (I1) enhances mature raceme count by 40% over traditional methods. Harvesting ten days after irrigation at 100% green pods results in the highest reproductive efficiency, with 15.6 raceme stem^{-1}.

Number of pods per raceme

Table 4 shows a significant effect of irrigation treatment on the number of pods per raceme in alfalfa. Treatment I1 produced the highest average (10.7 pods raceme^{-1}), with a peak at H2 (12.6 pods raceme^{-1}), demonstrating significant superiority. This was likely due to well-timed irrigation during critical growth stages, specifically at 25% of flowering and 100% green pods formation, which created optimal conditions for pod formation. Jia *et al.* (2024) demonstrated that irrigation during flowering stage enhances pod formation efficiency, as soil water availability at critical growth stages improves photosynthesis, thereby increasing pod yield. Treatment I4 yielded the lowest number of pods (8.0 pods raceme^{-1}), due to its incompatibility with alfalfa's growth stages. The fixed weekly irrigation schedule did not match the plant's water requirements, causing stress and inefficient water use during less critical stages. Drought is the most limiting factor that reduces agricultural production in arid and semiarid regions of the world which cover more than 40% of global land (Al-Hussaini and Alsaadawi, 2013). Orloff *et al.* (2005) found that unregulated irrigation leads to a pod productivity decline of up to 35%. Treatment I3 showed a slight improvement over H1 (10.1 pods raceme^{-1}), because delayed last irrigation (at 25% brown pods) may have caused partial drying before full pod formation. The I2 treatment yielded satisfactory results (10.0 pods raceme^{-1}), though lower than I1. This difference may be attributed to the delayed second irrigation (at 10% flowering), which reduced its effectiveness in promoting pod formation compared to I1. Table 4 results show a significant effect of harvest treatments, with H2 performing best due to optimal maturity. Ten days after the last irrigation (H2) allowed complete pod formation without drought stress (as in H3) or premature harvest (as in H1). These findings align with Yang *et al.* (2019), who reported that harvesting after 10-12 days maximizes pod and seed yields. Values at H1 were lower because premature harvesting prevented complete pod formation, resulting in fewer pods.

Table (4) reveals no significant differences in most interaction coefficients (*e.g.*, H1 and H3 in I3). The results also demonstrate stability in I4 across different harvest coefficients, due to the limited impact of traditional irrigation. The inefficiency of traditional irrigation reduces the influence of harvest date on pod numbers, suggesting that irrigation has a stronger effect than harvest timing in determining pod production. The results indicate that combining I1 with H2 approach maximizes pod and seed yield. Conversely,

Table 3: Effect of irrigation intervals on mature racemes per stem of alfalfa at different harvest dates.

Irrigation	Harvest			Irr. means
	H1	H2	H3	
I1	11.7	15.6	12.3	13.2
I2	10.8	14.6	12.8	12.7
I3	11.3	10.4	9.2	10.3
I4	8.1	9.4	10.6	9.4
$LSD_{0.05}$		2.14		1.19
Har. means	10.5	12.5	11.2	
$LSD_{0.05}$		1.17		

Table 4: Effect of irrigation intervals on the number of pods per raceme in alfalfa at different harvest dates.

Irrigation	Harvest			Irr. means
	H1	H2	H3	
I1	9.3	12.6	10.3	10.7
I2	8.7	11.4	10	10
I3	10.1	9.7	8.4	9.4
I4	7.6	8.2	8.2	8.0
$LSD_{0.05}$		1.25		0.96
Har. means	8.9	10.5	9.2	
$LSD_{0.05}$		0.57		

traditional irrigation (I4) should be avoided due to its inefficiency, as it wastes water and reduces productivity.

Seed count per pod

The results in Table 5 show that irrigation treatment significantly affected the average number of seeds per pod in alfalfa. Treatment I1 yielded the highest average (4.6 seeds pod^{-1}), while I4 produced the lowest (3.0 seeds pod^{-1}). As shown in Table 5, treatment I1 outperformed others due to its synchronization with growth stages. Applying irrigation at 25% flowering and 100% green pods ensured ideal seed formation conditions. Adequate moisture during flowering improves pollination, increasing seeds. Treatment I4 had a low seed count, since fixed weekly irrigation did not provide adequate water for optimal seed formation. Miao *et al.* (2025) observed that a lack of water during seed formation reduces seed number by as much as 40%. In the I3 treatment, the last irrigation at 25% brown pods did not provide optimal moisture conditions during critical seed formation stages, potentially hindering complete seed development. I2 yielded satisfactory results (4.2 seeds pod^{-1}) but performed slightly worse than I1, likely because the second irrigation was delayed (10% flowering), possibly affecting seed formation efficiency.

A thousand seeds' weight

Table 6 shows that seed weight remained stable across different irrigation treatments (I1-I4), due to strong genetic control, as seed weight is a consistent genetic property with limited influence from environmental factors such as irrigation (Renzi *et al.*, 2011). Additionally, the plant adapts to stress by adjusting physiological mechanisms, including nutrient redistribution, thereby maintaining stable seed weight despite varying irrigation conditions. Regarding harvest dates, harvesting treatments had a significant effect, difference between the highest (H3: 2.6 g) and lowest (H1: 2.4 g) values. Seed weight increased slightly at H3 due to complete physiological maturity, as delayed harvesting allows for full nutrient accumulation in the seeds. Katanski *et al.* (2020) observed a similar trend, reporting a 5-7% increase in seed weight when harvesting was postponed until full maturity. In contrast, decrease at H1 resulted from incomplete seed formation, as early harvesting may disrupt nutrient deposition.

Seed yield

Table 7 indicates that irrigation and harvesting treatments significantly influenced the seed yield of plants. Among the irrigation treatments, I1 yielded the highest productivity (465.3 kg ha^{-1}), whereas I4 resulted in the lowest (348.2 kg ha^{-1}). Seed yield varied significantly among harvest treatments, demonstrating its sensitivity to harvest date. The highest mean yield was observed in H2 (431.1 kg ha^{-1}), while H1 recorded the lowest (379.6 kg ha^{-1}). The H2 treatment is optimal for complete seed formation with nutrients while minimizing mature seed loss. The H1 treatment significantly reduced seed yield due to fewer seeds per pod (3.7 seed pod^{-1}) and lower seed weight (2.4 g per one thousand seeds).

The results in Table 7 confirm a significant interaction effect between irrigation and harvesting treatments. Specifically, the I1 treatment at H2 achieved a seed yield of

Table 5: Effect of irrigation intervals on number of seed per pod in alfalfa at different harvest dates.

Irrigation	Harvest			Irr. means
	H1	H2	H3	
I1	4.2	4.9	4.6	4.6
I2	3.9	4.6	4.0	4.2
I3	3.9	3.7	3.6	3.7
I4	2.8	3.0	3.2	3.0
$LSD_{0.05}$		N. S		0.47
Har. means	3.7	4.0	3.9	
$LSD_{0.05}$		N. S		

Table 6: Effect of irrigation intervals on a thousand seeds' weight in alfalfa at different harvest dates.

Irrigation	Harvest			Irr. means
	H1	H2	H3	
I1	2.4	2.4	2.6	2.5
I2	2.4	2.5	2.6	2.5
I3	2.5	2.5	2.6	2.5
I4	2.5	2.6	2.7	2.6
$LSD_{0.05}$		N.S		N.S
Har. means	2.4	2.5	2.6	
$LSD_{0.05}$		0.05		

538.3 kg ha^{-1}, the highest among other treatments. This can be attributed to the synchronization of irrigation intervals with critical growth stages, which promoted flowering and green pod formation. Consequently, seed formation improved, alongside increased seed size and weight. These factors collectively enhanced water use efficiency. Jia *et al.* (2024) found that optimal irrigation practices can improve water use efficiency by 35%. The positive interaction between I1 and H2 treatments ensures complete maturation while preventing seed loss. However, the lower seed yield observed in I4, particularly with H1 (312.4 kg ha^{-1}), Fixed weekly irrigation fails to meet the plant's water requirements during critical stages like flowering and seed formation, leading to significant seed loss. Additionally, early harvesting (H1) disrupts the full maturation cycle. These findings align with Miao *et al.* (2025), who reported that unscheduled irrigation reduces productivity by 40-45%.

Biological yield

As shown in Table 8, both irrigation and harvesting treatments, as well as their interaction, had a significant effect on biological yield. The highest biological yield was recorded in treatment I4 (5391 kg ha^{-1}), whereas the lowest was observed in I1 (4925 kg ha^{-1}). Among the other treatments, H3 achieved the highest overall average (5306 kg ha^{-1}), while H1 was the least productive (4759 kg ha^{-1}).

Results in Table (8) show that I4 performed best in biological yield. This discrepancy can be attributed to factors such as excessive vegetative growth, delayed maturity and low biomass to seed conversion efficiency. Frequent weekly irrigation I4 promotes vegetative growth over reproductive formation, boosting biomass but reducing seed yield. Soufan *et al.* (2019) found that excessive irrigation delays reproductive maturity, extending the vegetative stage. The findings indicate that treatment I1 struck an optimal balance in performance, sustaining a robust biological yield alongside an elevated seed yield (465.3 kg ha^{-1}). By emphasizing reproductive stage support, I1 achieved high conversion efficiency and an equilibrium between vegetative and reproductive growth.

The results of the harvest treatments presented in Table 8 confirm the significant superiority of H3, as delayed harvest allowed for complete dry matter accumulation, increased leaf area and enhanced metabolic processes. However, despite the increase in biomass, feed quality declined with harvest delay. Early harvest (H1) also presented challenges, such as insufficient carbohydrate accumulation, as this treatment interrupted the growth cycle before completion.

Harvest index

The results in Table (9) show that treatment I1 significantly outperformed the others, achieving the highest harvest index (9.47%). In contrast, treatment I4 had the lowest performance, with a harvest index of only 6.46%. Additionally, harvest timing significantly influenced the results, with treatment H2 (8.87%) demonstrating clear superiority over the other dates. According to the data in (Table 9), the I1 treatment demonstrated significantly better results. This can be attributed to the effective synchronization of irrigation with critical growth stages (*e.g.*, 25% flowering), which enhanced

Table 7: Effect of irrigation intervals on seed yield (kg ha^{-1}) in alfalfa at different harvest dates.

Irrigation	Harvest			Irr. means
	H1	H2	H3	
I1	422.8	538.3	434.7	465.3
I2	377.5	478.9	428.7	428.4
I3	405.8	361.3	367.6	378.2
I4	312.4	345.8	386.3	348.2
$LSD_{0.05}$		39.49		24.17
Har. means	379.6	431.1	404.3	
$LSD_{0.05}$		20.77		

Table 8: Effect of irrigation intervals on biological yield (kg ha^{-1}) in alfalfa at different harvest dates.

Irrigation	Harvest			Irr. means
	H1	H2	H3	
I1	4828	4831	5116	4925
I2	4339	4911	5035	4762
I3	4896	4628	4968	4830
I4	4972	5096	6105	5391
$LSD_{0.05}$		289.8		131.7
Har. means	4759	4867	5306	
$LSD_{0.05}$		165.2		

Table 9: Effect of irrigation intervals on harvest index (%) in alfalfa at different harvest dates.

Irrigation	Harvest			Irr. means
	H1	H2	H3	
I1	8.76	11.14	8.50	9.47
I2	8.71	9.75	8.53	9.00
I3	8.29	7.80	7.40	7.83
I4	6.29	6.78	6.32	6.46
$LSD_{0.05}$		0.724		0.523
Har. means	8.01	8.87	7.69	
$LSD_{0.05}$		0.346		

minimize excessive vegetative growth losses. The application of harvest treatment H2 to treatment I1 resulted in an 11.14% rate of complete seed formation while effectively minimizing seed loss. The lower yield index in treatment I4 resulted from excessive vegetative growth.

According to the data in (Table 9), treatment H2 demonstrated significant superiority due to its ideal harvest date, which balanced complete nutrient accumulation in the seeds while avoiding seed loss. As a result, the harvest index increased by 22% compared to H1. In contrast, early harvest (H1) led to insufficient carbohydrate accumulation and incomplete seed maturation.

The results in Table 9 demonstrate that irrigation (I1) synchronized with growth stage enhances biomass to seed conversion efficiency by 46% compared to traditional irrigation. Among harvest treatments, H2 yielded the highest harvest index due to optimal biological balance. In contrast, traditional irrigation (I4) resulted in a 35% resource loss in nonproductive plant parts.

CONCLUSION

This approach provides a practical solution for enhancing Alfalfa production in semiarid regions such as Iraq. The results reveal a critical balance between vegetative and reproductive growth, offering a framework for optimizing cultivation based on the intended use (fodder or seed). We recommend I1 irrigation scheduling, which is synchronized with growth stages, as it balances biomass and seed yield more effectively than traditional methods. Avoiding traditional irrigation (I4) is crucial, as it wastes water and reduces productivity while I4 favors biomass accumulation, it significantly lowers seed yield. For optimal results, irrigation should prioritize flowering and pod formation stages, followed by harvesting 10 days after the last irrigation. This strategy can boost seed yield to 538 kg ha^{-1} a 56% increase over traditional methods.

Conflict of interest

We have no conflicts of interest to disclose.

REFERENCES

Al-Haddad, A.H. and Bakr, T.S. (2013). Irrigation scheduling effect on water requirements. *Journal of Engineering*. **19(01):** 96-145.

Al-Hussaini, M. and Alsaadawi, I. (2013). Mitigation of drought stress effect on growth and productivity of mung bean by foliar application of sorghum water extract. *Iraqi Journal of Science*. **54(3):** 560-568.

Allen, R.G., Pereira, L.S., Raes, D. and Smith, M. (1998). Crop Evapotranspiration-Guidelines for Computing Crop Water Requirements-FAO Irrigation and drainage paper 56. FAO, Rome. **300:** 26-188.

Crookston, B.S., Boren, D., Yost, M., Sullivan, T., Creech, E., Barker, B. and Reid, C. (2025). Irrigation technology, irrigation dose and crop genetic impacts on alfalfa yield and quality. *Agricultural Water Management*. **311:** 109366.

Ehsas, N., Iqbal, M.A. and Ahmadi, S.M. (2018). Effect of irrigation intervals on forage production and quality of different alfalfa varieties under semiarid conditions. *International Journal of Environment, Agriculture and Biotechnology*. **3(6):** 2043-2050.

Fink, K.P., Grassini, P., Rocateli, A., Bastos, L.M., Kastens, J., Ryan, L.P. and Lollato, R.P. (2022). Alfalfa water productivity and yield gaps in the US central great plains. *Field Crops Research*. **289:** 108728.

Jia, Z., Ou, C., Sun, S., Sun, M., Zhao, Y., Li, C. and Mao, P. (2024). Optimizing drip irrigation managements to improve alfalfa seed yield in semiarid region. *Agricultural Water Management*. **297:** 108830.

Jiang, L., Shan, H., Xu, W. and Zhang, W. (2022). Influence of alfalfa (*Medicago sativa* L.) at various growing years on the physico-chemical properties and microbiology of irrigated desert soils. *Legume Research-An International Journal*. **45(6):** 711-718. doi: 10.18805/LRF-676.

Karayilanli, E. and Ayhan, V. (2016). Investigation of feed value of alfalfa (*Medicago sativa* L.) harvested at different maturity stages. *Legume Research-An International Journal*. **39(2):** 237-247. doi: 10.18805/lr.v0iOF.9292.

Katanski, S., Milić, D., Ćupina, B., Zorić, M., Milošević, B. and Živanov, D. (2020). Effect of harvest maturity stage and seeding rate on alfalfa yield and quality. *Ratarstvo i povrtarstvo/ Field and Vegetable Crops Research*. **57(2):** 35-42.

Khrbeet, H.K. (2021). Effect of humic acid concentration and spraying stages on seeds yield and its components of alfalfa. *Iraqi Journal of Agricultural Sciences*. **52(6):** 1541-1548.

Khrbeet, H.K., Al-Beiruty, R.Z. and Bahia, M.H.S. (2019). Effect of potassium concentration and spraying stages on seed yield and its components of alfalfa. *International Journal of Agricultural and Statistical Sciences*. **15(2):** 781-787.

Khrbeet, H.K. and Hashim, K.I. (2017). Forage Crops. University of Baghdad. College of Agriculture. Printed in Alam. Al-Marifa. Press. p 298.

Miao, X., Wang, G., Xu, B., Li, R., Tian, D., Ren, J. and Xu, Q. (2025). Study on alfalfa water use efficiency and optimal irrigation strategy in Agro-Pastoral Ecotone, Northwestern China. *Agronomy*. **15(2):** 258.

Orloff, S., Putnam, D., Hanson, B. and Carlson, H. (2005). Implications of deficit irrigation management of alfalfa. In Proceeding of California Alfalfa and Forage Symposium (pp. 12-14).

Puppo, L., Hayashi, R., Beretta, A. and Morales, P. (2024). Efecto del riego y el pastoreo sobre la producción de una pastura de alfalfa (*Medicago sativa* L.). *Agrocienc Urug*. **28:** e1422.

Renzi, J.P., Lasa, J.C. and Cantamutto, M.A. (2011). Influence of maturity at harvest on the quality of alfalfa (*Medicago sativa* L.) seeds. *Riarev. Investig. Agropecu*. **37:** 261-267.

Soufan, W., Okla, M.K. and Al-Ghamdi, A.A. (2019). Effects of irrigation with treated wastewater or well water on the nutrient contents of two alfalfa (*Medicago sativa* L.) cultivars in Riyadh, Saudi Arabia. *Agronomy*. **9(11):** 729.

Yang, H., An, F., Yang, F. and Wang, Z. (2019). The impact of irrigation on yield of alfalfa and soil chemical properties of saline-sodic soils. *Peer J*. **7:** e7148.