

STUDYING AND UTILIZATION OF PLANT GENETIC RESOURCES

Original article

UDC 633.34:581.543(470.311)

DOI: 10.30901/2227-8834-2025-3-57-67



The effect of the starting nitrogen dose under different irrigation regimes on the yield of Kabuli chickpeas

Hussein H. B. Al-Allo¹, Mohsen Janmohammadi¹, Mohsen Kheyrkhah², Naser Sabaghnia¹¹ University of Maragheh, Maragheh, Iran² Agriculture Organization of Qazvin Province, Iran**Corresponding author:** Mohsen Janmohammadi, mjanmohammadi@maragheh.ac.ir

Background. The aggravation of the water shortage problem caused by climate change in drought-prone areas emphasizes the use of climate-smart plants and climate-smart agriculture practices. Thus, the management of nitrogen fertilizers and controlling the amount of water consumed by crops seem very important issues.

Materials and methods. A field trial was aimed to evaluate chickpea phenology, morphology, and yield under different doses of nitrogen (0, 20, and 40 kg ha⁻¹) and irrigation regimes (I₁: well-watered, I₂: rainfed, I₃: supplemental irrigation during the flowering, I₄: supplemental irrigation during the flowering and seed setting) in chickpea drylands of Kermanshah, Western Iran. **Results.** Although N application slightly delayed the phenological stages, soil moisture deficiency significantly accelerated flowering and maturity. The highest rooting depth was recorded for I₂ + N₄₀, and the lack of soil moisture increased the longitudinal root growth. However, the number of root nodules (created by symbiotic relationship) under rainfed (I₂) and one-time supplemental irrigation (I₃) showed the lowest values of 7.30 and 6.70, respectively. Supplemental irrigation (SI) improved the grain yield components compared to the rainfed condition, but the difference in grain yield between SI and I₁ was still evident. The highest amounts of vegetative growth and yield were recorded under I₁ + N₂₀ and I₁ + N₄₀. The highest values of water-use efficiency for grain yield (WUE_G) resulted under I₂ + N₄₀.

Conclusion. WUE_G under rainfed conditions was 41%, 17% and 24% higher than I₁, I₃, and I₄, respectively. The highest biomass-based water use efficiency (WUE_B) was obtained under I₁ + N₄₀ and I₂ + N₀ or N₂₀. Although I₄ produced a lower grain yield than well-watered conditions (ca. 400 kg ha⁻¹), due to the water scarcity in the semi-arid regions, I₄ with the N application of 20 or 40 kg ha⁻¹ is still recommended for small-scale farmers as an efficient smart-agriculture practice.

Keywords: rainfed, reproductive growth, supplemental irrigation, water deficit, grain and biomass yield, water-use efficiency of plants

Acknowledgements: the presented results are part of the thesis No. 1918228. The authors thank the financial support provided by University of Maragheh. We are also grateful for the cooperation and assistance of the Graduate Education Department and the Research and Technology Department of the said university. We thank the local experts for their cooperation in collecting agricultural data and conducting field irrigation.

The authors thank the reviewers for their contribution to the peer review of this work.

For citation: Al-Allo H.H.B., Janmohammadi M., Kheyrkhah M., Sabaghnia N. The effect of the starting nitrogen dose under different irrigation regimes on the yield of Kabuli chickpeas. *Proceedings on Applied Botany, Genetics and Breeding*. 2025;186(3):57-67. DOI: 10.30901/2227-8834-2025-3-57-67

ИЗУЧЕНИЕ И ИСПОЛЬЗОВАНИЕ ГЕНЕТИЧЕСКИХ РЕСУРСОВ РАСТЕНИЙ

Научная статья

DOI: 10.30901/2227-8834-2025-3-57-67

Влияние начальной дозы азота при различных режимах орошения на урожайность нута сортотипа Кабули

Х. Х. Б. Аль-Алло¹, М. Джанмохаммади¹, М. Хейрха², Н. Сабагния¹

¹ Университет Мараге, Мараге, Иран

² Сельскохозяйственная организация провинции Казвин, Казвин, Иран

Автор, ответственный за переписку: Мохсен Джанмохаммади, mjanmohammadi@maragheh.ac.ir

Актуальность. Усугубление проблемы нехватки воды, вызванное изменением климата в засушливых районах, подчеркивает необходимость использования климатически умных растений и климатически умной агротехники. В этом контексте важно регулировать нормы азотных удобрений и контролировать количество воды, потребляемой сельскохозяйственными культурами.

Материалы и методы. Оценивали фенологические, морфологические показатели, рост корней и урожайность нута при различных дозах азота (0, 20 и 40 кг/га) и режимах орошения (I_1 – обильный полив, I_2 – богарный, I_3 – дополнительное орошение во время цветения, I_4 – дополнительное орошение во время цветения и завязывания семян) на плантациях нута на засушливых землях Керманшаха в западном Иране.

Результаты. Хотя внесение азота немного задержало фенологические стадии, дефицит почвенной влаги значительно ускорил цветение и созревание. Наибольшая глубина корней зафиксирована в условиях $I_2 + N_{40}$, а недостаток почвенной влаги увеличил длину корней. Однако количество корневых клубеньков при низкой почвенной влажности (I_2 и I_3) показало наименьшие значения: 7,30 и 6,70 соответственно. Дополнительное орошение (SI) улучшило компоненты урожая зерна по сравнению с богарой; разница в урожайности между режимами SI и I_1 была достоверна. Наибольший вегетативный рост и урожайность зафиксированы в условиях $I_1 + N_{20}$ и $I_1 + N_{40}$. Самые высокие значения эффективности использования воды для урожайности зерна (WUE_c) отмечали в условиях $I_2 + N_{40}$.

Заключение. WUE_c в богарных условиях была на 41%, 17% и 24% выше, чем при режимах орошения I_1 , I_3 и I_4 соответственно. Наивысшая эффективность использования воды по урожайности биомассы (WUE_b) получена при $I_1 + N_{40}$ и $I_2 + N_0$ или N_{20} . Хотя урожай зерна при I_4 был ниже, чем в хорошо орошаемых условиях (около 400 кг/га), из-за нехватки воды в полусухих регионах для мелких фермеров рекомендуется I_4 с внесением 20 или 40 кг/га азота как эффективная практика умного сельского хозяйства.

Ключевые слова: богарный, репродуктивный рост, дополнительное орошение, дефицит воды, урожайность зерна и биомассы, эффективность использования воды растениями

Благодарности: представленные результаты являются частью диссертации № 1918228. Авторы признательны Университету Мараге за финансовую поддержку, а также Департаменту послевузовского образования и Департаменту исследований и технологий вышеназванного университета за сотрудничество и помощь. Мы благодарим местных экспертов за сотрудничество в сборе сельскохозяйственных данных и проведении полевого орошения. Авторы благодарят рецензентов за их вклад в экспертную оценку этой работы.

Для цитирования: Аль-Алло Х.Х.Б., Джанмохаммади М., Хейрха М., Сабагния Н. Влияние начальной дозы азота при различных режимах орошения на урожайность нута сортотипа Кабули. *Труды по прикладной ботанике, генетике и селекции*. 2025;186(3):57-67. DOI: 10.30901/2227-8834-2025-3-57-67

Introduction

Chickpea is one of the cold-season food legumes with the scientific name *Cicer arietinum* L., which is also known as gram, garbanzo, and chana (Sharma et al., 2013). Archaeological studies indicate that the development of chickpeas took place in the Mediterranean regions of Asia, such as Syria, and the records of planting this crop go back to 8000 BC (Zhang et al., 2024). Due to its relatively high compatibility with such environmental stresses as heat stress and drought, its ability to biologically fix atmospheric nitrogen and the high percentage of seed protein, this plant has been the focus of researchers' attention in Mediterranean areas and developing countries (Karalija et al., 2022). In recent decades, with the intensification of climate change, such as decreasing rainfall and increasing temperature in semi-arid regions, the necessity of using climate-smart plant species and efficient and climate-compatible agricultural practices has become more evident (Benitez-Alfonso et al., 2023).

However, one of the major chickpea-producing areas is the semi-arid regions in the West Asia to North Africa, gravely affected by climate change, and the implementation of smart climate management in these areas should be followed seriously (Mohammed et al., 2016). Winter cereals are the predominant crops in the semi-arid regions, and the low variety of plant species in crop rotations has caused these agroecosystems to be fragile and highly vulnerable (Ryan et al., 2008). Therefore, replacing drought-resistant plant species in crop rotations that have an ideal growth form and reasonable economic production in drought-prone areas can be a solution. At first glance, the focus should be directed toward the selection and investigation of new plants or underutilized or forgotten plants. The former plants have been discarded due to incomplete breeding processes and low performance under the intensive farming conditions. However, the adverse conditions caused by climate change in the mentioned areas have created a necessity for a return to these plants. Cool-season food legumes have unique features that can place them among climate-smart plants. Relatively short growth period, suitable for planting in areas with moderate winters and exploitation of winter rains, appropriate rooting depth, and ability to adapt phenological and morphophysiological characteristics to water shortage conditions are among the efficient climate-compatible strategies (Andrews, Hodge, 2010).

However, semi-arid rainfed areas have poor soils, exhibiting very low organic matter, high pH, coarse-grained texture, nutrient deficiency in the rhizosphere environment, low water holding capacity, low cation-exchange capacity, shallow soil depth, high soil compaction, and low permeability, undesirably impact performance of cold-season food legumes, such as chickpeas (Ayangbenro, Babalola, 2021). In such soils, careful nutritional management, such as nitrogen application, is important. Starter fertilizer refers to the use of small amounts of nutrients in the soil during planting to meet the plant's nutritional needs until the complete seedling establishment, root development in the soil, and the formation of nitrogen-fixing nodules (Galpottage Dona et al., 2020).

Although legumes are atmospheric nitrogen fixers, it seems that providing nutrients through fertilizers is essential until the plant is fully established and provided there are suitable and compatible symbiotic diazotrophic bacteria strains. This means that the production of chickpeas in semi-arid areas has many limitations, such as the insufficient population of indigenous soil rhizobia, unsuitable temperature conditions and low soil moisture, soil with low fertility, insufficient and unscientific fertilizer utilization, and asymmetrical distri-

bution of rainfall and other similar restrictions (Gopalakrishnan et al., 2018). Therefore, under the mentioned conditions, the initial application of N fertilizers will help to improve the seedling growth and accelerate the establishment process. However, identifying the appropriate doses of N for starter fertilizer in each agroclimatic zone will need to be investigated. In the western regions of Iran, which are the main production areas of rainfed chickpeas, due to the irregular distribution of rainfall and the concentration of rainfall during the cold months, the plant faces a soil water deficit during the reproductive stages (Kheiri et al., 2021). This situation has become more complicated during the last decades with climate changes. Due to the limitation of available water sources for irrigation, the irrigation scheduling should be considered carefully under irrigated conditions.

Studies show that using one- or two-time irrigation during the sensitive stages of chickpeas under rainfed conditions can mitigate the effect of terminal drought stress (Shamsi et al., 2010; Oujii et al., 2016; Janmohammadi et al., 2024). The mentioned technique is called supplementary irrigation (SI). However, the amount of water used and the growth stage of the plant, the environmental and edaphic conditions, and the genotype of the plant can affect the efficiency of SI (Chauhan et al., 2019). The present experiment was conducted to evaluate the use of different doses of nitrogen starter and supplementary irrigation during different stages on the growth and performance of chickpeas in Western Iran.

Material and methods

This experiment was conducted during the 2023/2024 crop season on a farm in the Sararood-Kermanshah (34°33'N, 47°32'E; 1356 m above sea level) in the west of Iran. Long-term meteorological data in the tested area indicate that the average rainfall was 485 mm. The mean annual air temperature was 13.85°C. The maximum temperature was 39°C. The minimum air temperature was -19°C, the number of rainy days was 78 days, the number of days with sub-zero temperatures was 88 days, and the number of sunny hours was 1618. Temperature conditions and monthly rainfall during the growing season are shown in Fig. 1. According to the FAO classification, the soils in the studied area were the Lixisols, and the soil moisture and temperature regimes in this area were dry xeric and mesic, respectively. Based on the soil analysis and the data available at the station, the soil texture was silty loam up to 40 cm deep and included 22% of sand, 47% of silt, and 31% of clay. The chemical characteristics of the soil were as follows: electrical conductivity: 0.56 ds m⁻¹; total N: 0.13%; K: 256 mg kg⁻¹; organic matter: 0.82 g kg⁻¹; available P: 11.39 mg kg⁻¹, pH: 7.2. Soil moisture content during different periods of the growing season was evaluated using methods based on the time-domain reflectometry (TDR).

The initial tillage including plowing was done by a moldboard plow during October 2023. Farmyard manure was distributed over the soil at the rate of 20 t ha⁻¹ after initial tillage. In the third decade of March 2024, the second tillage including crushing of clods through disk plows and a rotary cultivator was completed. After determining the area of the main plots, the range of the main and secondary plots was determined through the border disc. Harrows and trowels were used to soften the soil surface before planting seeds. The soil was formed as ridge-furrow configuration through a furrower. Phosphorus was provided by triple superphosphate through furrow digging in the ridge area at the rate of 80 kg ha⁻¹. N starter fertilizers were also used in sub-plots at the rate of 0, 20, and 40 kg ha⁻¹ of nitrogen through urea fer-

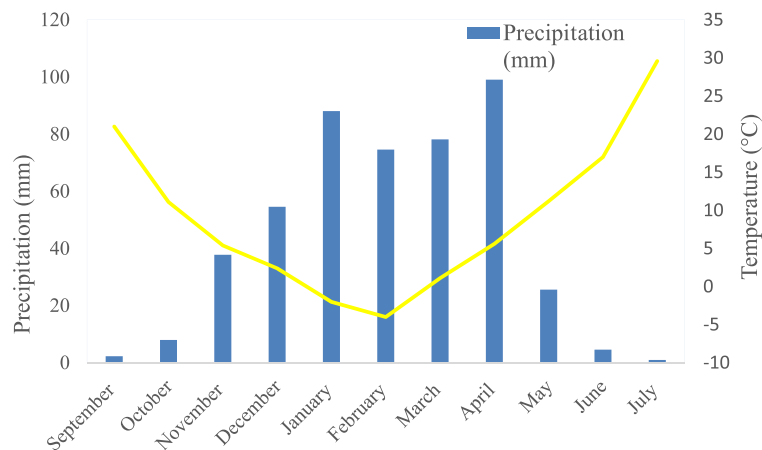


Fig. 1. Distribution of temperatures and precipitation amounts during the 2023/2024 cropping season

Рис. 1. Распределение температуры и количества осадков в период вегетации 2023/2024 г.

tillizer. The 'Arman' chickpea cultivar (FLIP 90-96 C) was provided by the Dryland Agricultural Research Institute (DARI). Cv. 'Arman' has a higher yield compared to other local cultivated varieties and is also resistant to blight disease. This cultivar is relatively tall, suitable for mechanized harvesting, and well adapted to the northern and western regions of Iran. The cultivar can be grown in autumn in subtropical regions. Seed planting was done manually and with a ridge and furrow planting pattern on top of the ridges with a depth of 10 cm. Inter- and intra-row spacing was 25 and 5 cm, respectively. Seeds were sown in rows in March. Each experimental plot had an area of 16 m² (4 × 4). The weeds were controlled by hand weeding during different periods. Water was supplied to the plots through polyethylene pipes equipped with volume-measuring meters. Field trial designed as a split-plot based on the arbitrary complete blocks design with 5 replications. Experimental treatments included different irrigation regimes at 4 levels and the utilization of starter nitrogen fertilizer at 3 doses. Irrigation regimes were as follows: I₁ – well-irrigated; I₂ – rainfed (without irrigation); I₃ – supplementary irrigation in the flowering stage (150 mm); I₄ – supplementary irrigation in the flowering and seed setting stages (250 mm). Irrigation levels were assigned to the main plots. The sub-plots contained different doses of nitrogen starter fertilizer (0, 20, and 40 N kg ha⁻¹). The field was periodically and regularly monitored and the phenological stages, such as the number of days to germination, the number of days from planting to reaching 50% flowering, and the number of days from planting to reaching physiological maturity, were recorded.

The chlorophyll content of the leaf was measured through a chlorophyll meter (SPAD-502, Minolta, Japan) at the full flowering stage. At the end of the flowering stage, by digging pits, the maximum amount of root penetration into the soil depth was checked and measured. In the maturity stage, the entire shoots above the soil surface were cut from the ground and after drying at 70 °C for 72 hours, their weight was measured and reported as dry biomass. Using a quadrat, plants were randomly harvested in an area of 1 m² and grain yield components were measured. Water use efficiency was calculated from the ratio of grain yield to water used and reported as grain yield-level water use efficiency (WUE_c). Biomass-water use efficiency (WUE_b) was calculated as the ratio of total dry matter produced above the soil surface to the amount of water consumed. Canopy spread was obtained by measuring the canopy diameter from left to right at the seed filling stage, assuming that the canopy was elliptical. Evapotranspiration

(EVP) from soil was measured by Time Domain Reflectometry techniques (TDR-420, USA). The number of root nodules per plant (RNN) was determined by digging out the soil next to the plant and gently pulling the roots out of the soil. LSD mean comparison was done through SPSS Statistics. Component analysis (PCA) and clustering of treatments were made with the SAS and Genstat software. The matrix of means of traits × treatment combinations were used for multivariate analysis, such as cluster analysis, PCA, and TT biplot. Ward's method was used for clustering, with considering Euclidean distances between clusters.

Results and discussion

The evaluation of plant vegetative growth characteristics, such as plant height, canopy width, and dry biomass, indicated significant interaction effects of N × I (Table 1). The tallest plants were recorded under the conditions of I₁ + N₄₀ (43.7 cm), and the shortest plants were observed under rainfed conditions without nitrogen application (25.6 cm). Plant height increased with increasing nitrogen consumption at all irrigation levels. A similar tendency was observed for canopy width (plant lateral growth). Application of twofold supplementary irrigation could produce a canopy width similar to plants grown under full irrigation. I₁, I₃, and I₄ increased canopy height by 48%, 24%, and 50% versus the rain conditions. The dry biomass produced in the grown plants with the application of 20 and 40 kg ha⁻¹ of nitrogen had no significant differences (see Table 1).

However, the highest amount of biomass was observed under I₁ + N₄₀ conditions (6068 kg ha⁻¹) and the lowest amount was related to rainfed conditions (2525 kg ha⁻¹). The evaluation of root characteristics showed that, regardless of the application rate, nitrogen utilization increased the rooting depth significantly (12%). The comparison of rooting depth between irrigation regimes indicated that I₂, I₃, and I₄ increased the rooting depth by 39%, 37%, and 36% compared to full irrigation conditions (see Table 1).

Utilization of 20 and 40 kg ha⁻¹ increased the number of root nodules by 4% and 13% compared to the control. The highest number of root nodules was recorded under full irrigation conditions with the N application of 20 or 40 kg ha⁻¹ (16.62, and 18.04). Fertilizer application under I₄ conditions decreased the number of nodules by 22% and 26%, while the application of N₄₀ under rainfed conditions increased the number of root nodules by 36% (see Table 1). Plant phenology monitoring showed that the numbers of days to flower-

Table 1. The effects of nitrogen doses and irrigation regimes on vegetative growth characteristics of chickpea**Таблица 1.** Влияние доз азота и режимов орошения на вегетативные характеристики роста нута

Effect	PE	RD	RNN	LCH	CS	DFL
Nitrogen						
N ₀	31.92c	47.8b	9.50b	49.95c	26.78c	66.78c
N ₂₀	34.59b	52.3a	9.83ab	55.18a	33.54b	71.11b
N ₄₀	37.09a	54.35a	10.68a	52.21b	35.85a	74.12a
Irrigation						
I ₁	41.04a	40.13b	15.95a	60.83a	36.30a	74.71a
I ₂	27.26d	55.73a	7.30c	41.78d	24.49c	63.21d
I ₃	33.94c	55.33a	6.70c	52.27c	30.49b	71.54c
I ₄	35.90b	54.73a	10.05b	54.90b	36.96a	73.21a
Combined						
I ₁ N ₀	37.64bc	38.6f	13.2b	57.41c	0.90e	369.9de
I ₁ N ₂₀	39.62a	41.2f	16.62a	64.07a	34.91c	73.82bc
I ₁ N ₄₀	45.88a	40.6f	18.04a	61.02b	43.10a	80.424a
I ₂ N ₀	25.23h	49e	6.31f	39.31g	20.88h	59.208h
I ₂ N ₂₀	27.33gh	56.4abcd	6.28f	44.67f	26.83f	64.38g
I ₂ N ₄₀	29.24g	61.8a	9.34de	41.38g	25.75fg	66.06fg
I ₃ N ₀	32.12f	52.8cde	6.444f	48.74e	23.932g	68.34ef
I ₃ N ₂₀	34.48def	54bcde	6.4f	54.16d	33.94cd	72.3cd
I ₃ N ₄₀	35.22cde	59.2ab	7.28ef	53.91d	33.62cde	74bc
I ₄ N ₀	32.70ef	50.8de	12.06bc	54.37d	31.44de	69.68de
I ₄ N ₂₀	36.96bcd	57.60abc	10.04cd	57.83c	38.5b	73.94bc
I ₄ N ₄₀	38.06bc	55.80bcd	8.07def	52.53d	40.95ab	76.02b
Significance level						
I	**	**	**	**	**	**
N	**	**	Ns	**	**	**
I × N	**	Ns	**	**	**	Ns

Note: N₁, N₂, and N₃: application of 0, 20 and 40 kg ha⁻¹ as starter fertilizers, respectively. I₁: full irrigation; I₂: rainfed; I₃: one-time irrigation in the flowering stage (150 mm), I₄: two-time irrigation in the flowering and seed setting stages (250 mm). PE: plant height; RD: rooting depth; RNN: number of root nodules per plant; LCH: Chlorophyll content in leaves; CS: canopy spread; DFL: number of days from seed planting to 50% flowering. Ns: statistically insignificant; ** and *: significant at the 1% and 5% level, respectively

Примечание: N₁, N₂, N₃ – стартерные удобрения в дозировках 0, 20 и 40 кг/га соответственно. I₁ – полное орошение; I₂ – богара; I₃ – однократный полив в фазе цветения (150 мм); I₄ – двукратный полив в фазе цветения и завязывания семян (250 мм). PE – высота растений; RD – глубина укоренения; RNN – число корневых клубеньков на одно растение; LCH – содержание хлорофилла в листьях; CS – распространение полога; DFL – количество дней от посева до 50-процентного цветения. Ns – статистически недостоверно; ** и * – достоверно при уровнях 1% и 5% соответственно

ing (DF) and maturity (DM) were influenced by the main effects of irrigation and nitrogen. Consumption of 20 and 40 kg ha⁻¹ of N delayed DF by 4.33 days and 7.34 days. Increasing the volume and frequency of irrigation also caused a significant increase in DF. I₁, I₃, and I₄ delayed DF by 18%, 13%, and 15%, respectively, compared to the rainfed conditions. The maximum length of the development period (DM) with the application of 40 and 20 kg of nitrogen under full irrigation conditions was recorded as 118 days (Table 2). Re-

sults showed that soil water deficit under rainfed conditions accelerated the maturity, and the lowest DM was recorded under I₂ + N₀ conditions (91 days). Applying supplemental irrigation I₃ and I₄ delayed DM by 10 and 13 days compared to rainfed conditions.

With the increase in the frequency of irrigation and the nitrogen dose, yield components, such as the number of grains per plant and the number of pods, increased. The highest grain yield was obtained by the application of N₂₀ or N₄₀

Table 2. Yield and water use efficiency in chickpea under different nitrogen doses and irrigation regimes in Western Iran**Таблица 2. Урожайность и эффективность использования воды в посевах нута при разных дозах азота и режимах орошения на западе Ирана**

Effect	DM	PPL	ABG	GY	WUE _G	WUE _B
Nitrogen						
N ₀	103.97b	24.97c	3754.61b	1203.17b	2.43b	7.50b
N ₂₀	107.00a	27.54b	4127.74a	1377.4a	2.79a	8.37a
N ₄₀	109.08a	28.89a	4226.41a	1413.40a	2.86a	8.37a
Irrigation						
I ₁	117.47a	33.90a	5584.22a	1807.09a	2.27c	7.04c
I ₂	95.06d	20.86d	2525.88d	878.40d	3.27a	9.40a
I ₃	105.37c	25.50c	3564.75c	1213.40c	2.70b	7.93b
I ₄		28.26b	4470.14b	1426.42b	2.53b	7.94b
Combined						
I ₁ N ₀	115.35ab	29.6c	4870.4c	1627.07b	2.00g	6.00g
I ₁ N ₂₀	118.32a	34.8b	5796b	1903.41a	2.40ef	7.31ef
I ₁ N ₄₀	118.75a	37.32a	6086.3a	1890.8a	2.42ef	7.81de
I ₂ N ₀	90.89f	19.16h	2517.8h	872.6e	3.19ab	9.21ab
I ₂ N ₂₀	96.36e	22.24g	2596.80h	856e	3.21ab	9.71a
I ₂ N ₄₀	97.94e	21.19g	2463h	906.6e	3.41a	9.28a
I ₃ N ₀	103.41d	24.4f	3250.4g	1061.8d	2.35ef	7.19f
I ₃ N ₂₀	104.99d	24.8f	3532.8f	1237.4c	2.77cd	7.92d
I ₃ N ₄₀	107.72cd	27.32de	3911e	1341c	2.98bc	8.69bc
I ₄ N ₀	106.25d	26.72e	4379.8d	1251.2c	2.17fg	7.60def
I ₄ N ₂₀	108.35cd	28.32cd	4585.3d	1512.8b	2.81cd	8.52c
I ₄ N ₄₀	111.93bc	29.76c	4445.30d	1515.2b	2.62de	7.69def
Significance level						
I	**	**	**	**	**	**
N	**	**	**	**	**	**
I × N	Ns	**	**	*	*	**

Note: N₁, N₂, and N₃: application of 0, 20 and 40 kg ha⁻¹ as starter fertilizers, respectively; I₁: full irrigation; I₂: rainfed; I₃: one-time irrigation in the flowering stage (150 mm); I₄: two-time irrigation in the flowering and seed setting stages (250 mm); DM: number of days from planting to maturity. PPL: number of pods per plant; ABG: aboveground biomass; GY: grain yield; WUE_G: grain-water use efficiency; WUE_B: biomass-water use efficiency. Ns: statistically insignificant; ** and * are significant at 1 and 5% level, respectively

Примечание: N₁, N₂, N₃ – стартерные удобрения в дозировках 0, 20 и 40 кг/га соответственно. I₁ – полное орошение; I₂ – богара; I₃ – однократный полив в фазе цветения (150 мм); I₄ – двукратный полив в фазе цветения и завязывания семян (250 мм); DM – количество дней от посева до созревания. PPL – количество бобов на растении; ABG – зеленая масса; GY – урожайность зерна; WUE_G – эффективность использования воды по зерну; WUE_B – эффективность использования воды по зеленой массе. Ns – статистически недостоверно; ** и * – достоверно при уровнях 1% и 5% соответственно

under I_1 conditions (1890 and 1903 kg ha⁻¹). The lowest seed yield was recorded under rainfed conditions (878.2 kg ha⁻¹). Under I_2 and I_3 conditions, nitrogen application had no significant effect on yield. Under I_4 conditions, using 20 and 40 kg ha⁻¹ of N increased grain yield by 20% and 22% compared to the control condition (see Table 2). WUE_G increased with nitrogen application. However, no significant difference was observed between N_{20} and N_{40} . Examining this component between irrigation regimes showed that it significantly decreased with an increasing irrigation volume (Fig. 2). The highest value of WUE_G was recorded under rainfed conditions (3.27 kg mm⁻¹ ha⁻¹) and the lowest value was recorded under full irrigation conditions (2.27 kg mm⁻¹ ha⁻¹). It is interesting to note that one- and two-time supplemental irrigation increased the WUE by 19% and 11% compared to I_1 . The lowest value of WUE_G was recorded under $I_1 + N_0$ conditions (2.27 kg mm⁻¹ ha⁻¹).

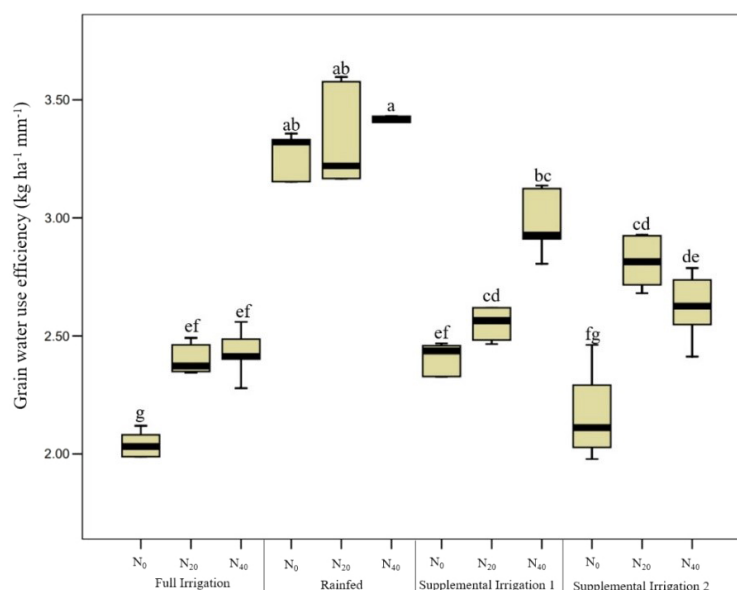


Fig. 2. Water use efficiency of chickpea plants under different doses of starter nitrogen (0, 20, and 40 kg ha⁻¹) and various soil moisture regimes in the semi-arid region

Рис. 2. Эффективность использования воды нутом в посевах в полусухом регионе в зависимости от различных доз стартового азота (0, 20 и 40 кг/га) при разных режимах полива

The correlation between traits is shown in Figure 3. Attributes that are close to each other and have sharp angles demonstrated a positive and significant correlation. The results indicated that dry biomass, chlorophyll, number of days to maturity, number of pods, number of grains per plant, and plant height positively correlated with grain yield. However, water consumption efficiency showed a significant correlation with rooting depth.

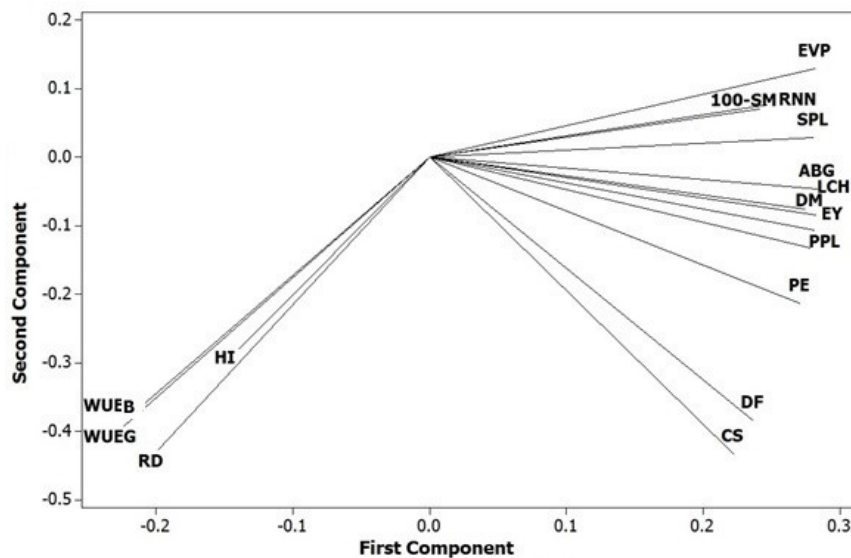
The clustering of treatment compounds in terms of similarity in affecting the assessed traits is shown in Figure 4. This clustering indicated that the effect of irrigation regimes was much stronger than nitrogen application. Cluster 1 included full irrigation treatments and different levels of nitrogen application. The highest vegetative growth and grain yield were obtained under the conditions of full irrigation and application of nitrogen fertilizers. Cluster 2 included supplemental irrigation treatments and different doses of nitrogen, which had average performance for most of the examined traits. Cluster 3 included the application of different doses of nitrogen under rainfed conditions, which showed the lowest values except WUE .

A biplot analysis was used to explain the effect of treatment combinations and how traits are influenced by treatments (Fig. 5). The findings showed that the first component separated the optimal soil moisture conditions from other soil moisture regimes. In this analysis, the closeness of combined treatments to traits indicated their high effectiveness on mentioned traits. $I_1 + N_{20}$ and $I_1 + N_{40}$ caused the highest values of root nodule number, chlorophyll, pod number, seed number, biomass, days to flowering, days to maturity, and seed yield.

In the studied area, in addition to unfavorable soil conditions, the amount of monthly rainfall decreased significantly after April. However, it seems that in addition to the stress of nutrient deficiencies, the plants also faced the water shortage and heat stress at the end of the season. Nitrogen application significantly increased the characteristics related to vegetative growth. Consumption of 20 or 40 kg ha⁻¹ of N increased

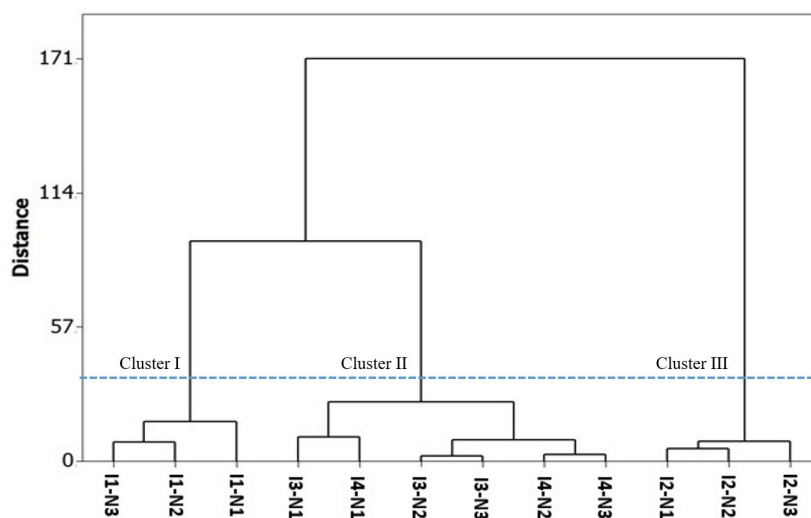
the longitudinal and lateral growth of the chickpea canopy compared to the control. This was associated with an increase in chlorophyll content. From the physiological point of view of source-sink relationships, such an expansion means increasing the photosynthetic area and supplying more photoassimilates to the growing or filling sink organs. This is while sink strength is defined as the ability of the sink organ to receive and transport photoassimilates produced in the process of photosynthesis (current photosynthesis) or photosynthetic products temporarily stored in the stem (remobilization). The sink strength depends on the photoassimilate pool sizes in sink cells and the physiological circumstances of the plant (Smith et al., 2018). In this study, it was found that the use of the supplemental irrigation during the flowering stage can have a positive and stimulating effect on the size and number of grain yield components. On the other hand, it seems that the use of nitrogen increased the sink strength to receive photoassimilates by affecting the physiological state of the plant and the ratio of phytohormones (Mu, Chen, 2021).

Also, the use of irrigation under rainfed conditions had a significant effect on the effectiveness of nitrogen, and the



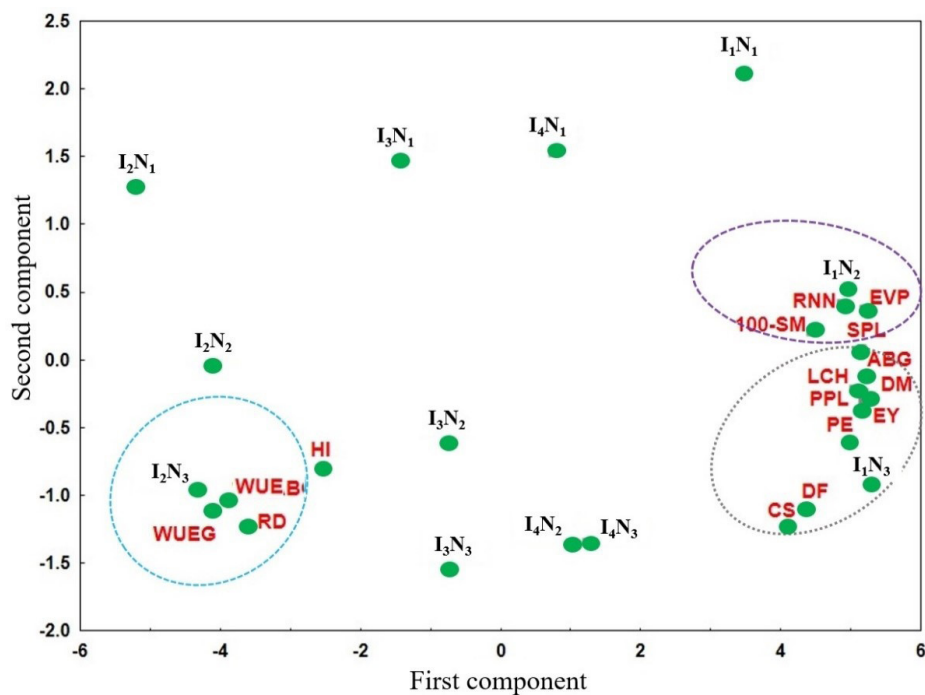
A small angle indicates that the traits are positively correlated. 100-SM: 100-seed weight, SPL: seed number per plant; RNN: number of root nodules per plant; LCH: chlorophyll content in leaves; DM: number of days from planting to maturity; EY: grain yield; PPL: number of pods per plant; PE: plant height; DF: number of days from seed planting to 50% flowering; CS: canopy spread; RD: rooting depth; HI: harvest index; WUE_G: grain-water use efficiency; WUE_B: biomass-water use efficiency / Небольшой угол указывает на положительную корреляцию признаков. 100-SM – масса 100 семян; SPL – количество семян на растение; RNN – число корневых клубеньков на одно растение; LCH – содержание хлорофилла в листьях; DM – количество дней от посева до созревания; EY – урожайность зерна; PPL – количество бобов на растение; PE – высота растения; DF – количество дней от посева до 50-процентного цветения; CS – распространение полога; RD – глубина корней; HI – индекс урожая; WUE_G – эффективность использования воды по зерну; WUE_B – эффективность использования воды по зеленой массе

Fig. 3. Monoplot principal component analysis (PCA) for understanding the relationships between agronomic and morphophysiological variables of chickpea cultivated under different N fertilizer doses and irrigation regimes
Рис. 3. Применение анализа главных компонент для понимания взаимосвязей между агрономическими и морфофизиологическими признаками нута, выращиваемого при различных дозах азотных удобрений и режимах орошения



N₁, N₂, and N₃ – 0, 20, and 40 kg ha⁻¹. I₁ – full irrigation; I₂ – rainfed; I₃ – supplemental irrigation in the flowering stage; I₄ – supplemental irrigation in the flowering and seed setting stages / N₁, N₂, N₃ – 0, 20 и 40 кг/га. I₁ – полное орошение; I₂ – богара; I₃ – дополнительное орошение в фазе цветения; I₄ – дополнительное орошение в фазе цветения и завязывания семян

Fig. 4. Classification of nitrogen doses x irrigation regimes combined treatments in terms of similarity in influencing the evaluated agronomic traits of chickpea grown in Western Iran
Рис. 4. Классификация комбинаций доз азота x режима орошения по сходству их влияния на оцениваемые агрономические признаки нута, выращиваемого на западе Ирана



Traits close to treatment compounds were most affected by those treatments. 100-SM: 100-seed weight; SPL: seed number per plant; RNN: number of root nodules per plant; LCH: chlorophyll content in upper leaves; DM: number of days from planting to maturity; EY: grain yield; PPL: number of pods per plant; PE: plant height; DF: number of days from seed planting to 50% flowering; CS: canopy spread; RD: rooting depth; HI: harvest index; WUE_G : grain-water use efficiency; WUE_B : biomass-water use efficiency. N_1 , N_2 , and N_3 : 0, 20, and 40 kg ha⁻¹. I_1 : full irrigation; I_2 : rainfed; I_3 : supplemental irrigation in the flowering stage (150 mm); I_4 : supplementary irrigation in the flowering and seed setting stages (250 mm) / Признаки, близкие к способам выращивания посевов, были наиболее сильно затронуты проведенными обработками. 100-SM – масса 100 семян; SPL – количество семян на растение; RNN – число корневых клубеньков на одно растение; LCH – содержание хлорофилла в верхних листьях; DM – количество дней от посева до созревания; EY – урожайность зерна; PPL – количество бобов на растение; PE – высота растения; DF – количество дней от посадки семян до 50-процентного цветения; CS – распространение полога; RD – глубина корней; HI – индекс урожая; WUE_G – эффективность использования воды по зерну; WUE_B – эффективность использования воды по зеленой массе. N_1 , N_2 , N_3 – 0, 20 и 40 кг/га. I_1 – полное орошение; I_2 – богара; I_3 – дополнительное орошение в фазе цветения; I_4 – дополнительное орошение в фазе цветения и завязывания семян

Fig. 5. Principle component analysis for treatment compounds and cultivar traits evaluated in chickpea

Рис. 5. График анализа основных компонент, построенный для совместного исследования взаимосвязей между различными способами выращивания посевов и оцененными признаками сортов нута

greatest effect of nitrogen was recorded under full irrigated conditions or supplementary irrigation. These results indicate that in the studied area, in addition to the sharp drop in rainfall at the end of the growing season, the soil moisture reserves were not enough to support the growth and production of economic and reasonable chickpeas. Previous studies also indicated that supplementary irrigation in the flowering stage greatly improved the efficiency of nitrogen used in wheat (Liu et al., 2022).

The amount of rainfall during the chickpea growing period was 210 mm and the annual precipitation was 473 mm. However, the amount of evapotranspiration during March–September in the region is estimated to be around 690 mm (Varvani et al., 2019). The mentioned data point to the fact that in the regional conditions under study, rainfed cultivation cannot be considered a suitable option for spring chickpeas. In the mentioned circumstances, irrigation regimes I_3 or I_4 with one- or two-time supplemental irrigations during the sensitive stages of reproduction could alleviate the effects of drought stress. This study confirmed our previous findings regarding the effectiveness of supplemental irrigation during the reproductive stages of chickpeas in the semi-arid region of Hamadan (Janmohammadi et al., 2024). In this experiment,

by measuring the amount of water consumed, the soil moisture, and the amount of evapotranspiration, WUE was calculated based on seeds or biomass.

The use of nitrogen through the improvement of plant processes, such as the increase of pigments and the rate of photosynthesis, and the greater effect on the production of dry matter caused an increase in WUE. Those results were consistent with the reports of other researchers. In this regard, Bouras et al. (2023) reported that under low application of N fertilizer, WUE and nitrogen use efficiency increased in chickpea in a semi-arid region. However, the highest WUE was recorded under rainfed conditions. This is partially due to the activation of adaptive systems in the plant to prevent water wastage through transpiration and more optimal use of absorbed water. Under rainfed conditions, half-closing of the stomata, increasing the rooting depth, reducing the hydraulic resistance of the roots, increasing the facility of water transport in the vessels, better and more efficient absorption of the roots developed in the deep soil can improve WUE (Fernández-García et al., 2013).

The insignificant difference between the effects of 20 and 40 kg ha⁻¹ of N on some evaluated agronomic traits can be attributed to the deficiency of other nutrients, such as sulfur,

phosphorus, or micronutrients, which prevented the full emergence of the effects of nitrogen. The main effects of a primary nutrient appear more in balanced nutritional environments and with optimal availability of secondary nutrients (Grzebisz et al., 2022). This refers to the existence of synergistic relationships among some nutrients. Therefore, the application of 20 kg ha⁻¹ of starter nitrogen along with providing the minimum required soil moisture, especially during the reproductive period, can produce an acceptable economic performance.

Conclusion

Evaluations showed that the application of a nitrogen starter improved the rooting depth, increased the number of root nodules, enhanced the chlorophyll content, elongated vegetative growth period, and finally improved the seed yield and water consumption efficiency. However, in many cases, no significant difference was observed between the doses of 20 and 40 kg ha⁻¹. On the other hand, the effectiveness of nitrogen was strongly affected by soil moisture status. The highest positive and improving effect of nitrogen on the evaluated agronomic characteristics was recorded under the full irrigation conditions and two supplemental irrigations during the reproductive period. Our findings suggest that in order to achieve a reasonable economic performance of chickpeas, at least two supplemental irrigations and the use of starter nitrogenous fertilizers with amounts of 20 or 40 kg ha⁻¹ should be included in dryland chickpea production systems.

References / Литература

- Andrews M., Hodge S. Climate change, a challenge for cool season grain legume crop production. In: S.S. Yadav, D.L. McNeil, R. Redden, S.A. Patil (eds). *Climate Change and Management of Cool Season Grain Legume Crops*. Dordrecht: Springer; 2010. p.1-9. DOI: 10.1007/978-90-481-3709-1_1
- Ayangbenro A.S., Babalola O.O. Reclamation of arid and semi-arid soils: The role of plant growth-promoting archaea and bacteria. *Current Plant Biology*. 2021;25:100173. DOI: 10.1016/j.cpb.2020.100173
- Benitez-Alfonso Y., Soanes B.K., Zimba S., Sinanaj B., German L., Sharma V. et al. Enhancing climate change resilience in agricultural crops. *Current Biology*. 2023;33(23):1246-1261. DOI: 10.1016/j.cub.2023.10.028
- Bouras F.Z., Hadjout S., Haddad B., Malek A., Aitmoumene S., Gueboub F. et al. The effect of nitrogen supply on water and nitrogen use efficiency by wheat-chickpea intercropping system under rain-fed Mediterranean conditions. *Agriculture*. 2023;13(2):338-345. DOI: 10.3390/agriculture13020338
- Chauhan Y.S., Ryan M., Chandra S., Sadras V.O. Accounting for soil moisture improves prediction of flowering time in chickpea and wheat. *Scientific Reports*. 2019;9(1):7510. DOI: 10.1038/s41598-019-43848-6
- Fernández-García P., López-Bellido L., Muñoz-Romero V., López-Bellido R.J. Chickpea water use efficiency as affected by tillage in rainfed Mediterranean conditions. *Agricultural Water Management*. 2013;129:194-199. DOI: 10.1016/j.agwat.2013.07.022
- Galpottage Dona W.H., Schoenau J.J., King T. Effect of starter fertilizer in seed-row on emergence, biomass and nutrient uptake by six pulse crops grown under controlled environment conditions. *Journal of Plant Nutrition*. 2020;43(6):879-895. DOI: 10.1080/01904167.2020.1711945
- Gopalakrishnan S., Srinivas V., Vemula A., Samineni S., Rathore A. Influence of diazotrophic bacteria on nodulation, nitrogen fixation, growth promotion and yield traits in five cultivars of chickpea. *Biocatalysis and Agricultural Biotechnology*. 2018;15:35-42. DOI: 10.1016/j.bcab.2018.05.006
- Grzebisz W., Zielewicz W., Przygocka-Cyna K. Deficiencies of secondary nutrients in crop plants – A real challenge to improve nitrogen management. *Agronomy*. 2022;13(1):66. DOI: 10.3390/agronomy13010066
- Janmohammadi M., Kouchakkhani H., Sabaghnia N. The effect of supplemental irrigation and exogenous application of glycine betaine on chickpea performance in the semi-arid region. *Ege Üniversitesi Ziraat Fakültesi Dergisi*. 2024;61(2):189-199. DOI: 10.20289/zfdergi.1402726
- Karalija E., Vergata C., Basso M.F., Negussu M., Zaccari M., Grossi-de-Sa M.F. et al. Chickpeas' tolerance of drought and heat: Current knowledge and next steps. *Agronomy*. 2022;12(10):2248. DOI: 10.3390/agronomy12102248
- Kheiri M., Kambouzia J., Deihimfard R., Yaghoobian I., Movahhed Moghaddam S. Response of rainfed chickpea yield to spatio-temporal variability in climate in the North-west of Iran. *International Journal of Plant Production*. 2021;15(2):499-510. DOI: 10.1007/s42106-021-00153-5
- Liu S., Lin X., Wang W., Zhang B., Wang D. Supplemental irrigation increases grain yield, water productivity, and nitrogen utilization efficiency by improving nitrogen nutrition status in winter wheat. *Agricultural Water Management*. 2022;264:107505. DOI: 10.1016/j.agwat.2022.107505
- Mohammed A., Tana T., Singh P., Molla A. Modeling climate change impact on chickpea production and adaptation options in the semi-arid North-Eastern Ethiopia. *Journal of Agriculture and Environment for International Development*. 2016;110(2):377-395. DOI: 10.12895/jaeid.20162.510
- Mu X., Chen Y. The physiological response of photosynthesis to nitrogen deficiency. *Plant Physiology and Biochemistry*. 2021;158:76-82. DOI: 10.1016/j.plaphy.2020.11.019
- Ouji A., El-Bok S., Mouelhi M., Ben Younes M., Kharrat M. Yield and yield components of chickpea (*Cicer arietinum* L.) as influenced by supplemental irrigation under semi-arid region of Tunisia. *World Journal of Agricultural Research*. 2016;4(5):153-157. DOI: 10.12691/wjar-4-5-5
- Ryan J., Singh M., Pala M. Long-term cereal-based rotation trials in the Mediterranean region: Implications for cropping sustainability. *Advances in Agronomy*. 2008;97:273-319. DOI: 10.1016/S0065-2113(07)00007-7
- Shamsi K., Kobraee S., Haghparast R. Drought stress mitigation using supplemental irrigation in rainfed chickpea (*Cicer arietinum* L.) varieties in Kermanshah, Iran. *African Journal of Biotechnology*. 2010;9(27):4197-4203.
- Sharma S., Upadhyaya H.D., Roorkiwal M., Varshney R.K., Gowda C.L. Chickpea. In: M. Singh, H.D. Upadhyaya, I.S. Bisht (eds). *Genetic and Genomic Resources of Grain Legume Improvement*. London; Waltham, MA: Elsevier; 2013. p.81-111.
- Smith M.R., Rao I.M., Merchant A. Source-sink relationships in crop plants and their influence on yield development and nutritional quality. *Frontiers in Plant Science*. 2018;9:1889. DOI: 10.3389/fpls.2018.01889
- Varvani H., Farhadi B.B., Sharifi M.A. Integration of Landsat 8 satellite images and MODIS sensor to estimate actual crop evapotranspiration of maize during the growing period (case study: Mahidasht, Kermanshah province). *Iran – Water Resources Research*. 2019;15(1):257-266.
- Zhang J., Wang J., Zhu C., Singh R.P., Chen W. Chickpea: Its origin, distribution, nutrition, benefits, breeding, and symbiotic relationship with *Mesorhizobium* species. *Plants*. 2024;13(3):429. DOI: 10.3390/plants13030429

Information about the authors

Hussein Hamadi Baqer Al-Allo, MSc, University of Maragheh, Amirkabir Hwy., Maragheh 83111-55181, Iran, alaloo.hussein@gmail.com, <https://orcid.org/0009-0009-8351-2848>

Mohsen Janmohammadi, PhD, Professor, University of Maragheh, Amirkabir Hwy., Maragheh 83111-55181, Iran, mjanmohammadi@maragheh.ac.ir, <https://orcid.org/0000-0002-6121-6791>

Mohsen Kheyrkhah, PhD, Member of the Scientific Faculty, Agriculture Organization of Qazvin Province, Felestin St., Qazvin 72M3+M82, Iran, kheyrkhah523@gmail.com, <https://orcid.org/0009-0005-0492-7270>

Naser Sabaghnia, PhD, Professor, University of Maragheh, Amirkabir Hwy., Maragheh 83111-55181, Iran, sabaghnia@maragheh.ac.ir, <https://orcid.org/0000-0001-9690-6525>

Информация об авторах

Хусейн Хамади Бакер Аль-Алло, магистр, Университет Мараге, 83111-55181 Иран, Мараге, шоссе Амиркабир, alaloo.hussein@gmail.com, <https://orcid.org/0009-0009-8351-2848>

Мохсен Джанмохаммади, доктор философии, профессор, Университет Мараге, 83111-55181 Иран, Мараге, шоссе Амиркабир, mjanmohammadi@maragheh.ac.ir, <https://orcid.org/0000-0002-6121-6791>

Мохсен Хейрха, доктор философии, член научного факультета, Сельскохозяйственная организация провинции Казвин, 72M3+M82 Иран, Казвин, ул. Фелестин, kheyrkhah523@gmail.com, <https://orcid.org/0009-0005-0492-7270>

Насер Сабагния, доктор философии, профессор, Университет Мараге, 83111-55181 Иран, Мараге, шоссе Амиркабир, sabaghnia@maragheh.ac.ir, <https://orcid.org/0000-0001-9690-6525>

Contribution of the authors: the authors contributed equally to this article.

Вклад авторов: все авторы сделали эквивалентный вклад в подготовку публикации.

Conflict of interests: the authors declare no conflicts of interests.

Конфликт интересов: авторы заявляют об отсутствии конфликта интересов.

The article was submitted on 17.01.2025; approved after reviewing on 17.06.2025; accepted for publication on 11.08.2025. Статья поступила в редакцию 17.01.2025; одобрена после рецензирования 17.06.2025; принята к публикации 11.08.2025.