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RESEARCH ARTICLE Legume Research- An International Journal

Evaluation of Chickpea Production under Different Management of Irrigation and Nitrogen Fertilizer

Majid Mahmoudi[1], Seyedreza Amiri[2], Bahareh Parsa Motlagh[3]

10.18805/LR-5302

ABSTRACT

Background: Chickpea is a prominent leguminous crop cultivated in the West Asia and North Africa (WANA) region. Historically, it is planted during the spring season as a rainfed crop in the area, characterized by its unpredictable and frequently inadequate precipitation.

Methods: To examine the impact of various levels of irrigation and nitrogen fertilizer on the yield and yield components of the Adel cultivar of chickpea, a factorial experiment was conducted based on a randomized complete block design with four replications at the research farm in Esfarayen Region in Khorasan-Iran (36.92 N, 57.55E) throughout the 2022 and 2023 growing seasons. The experimental treatments included three levels of nitrogen: 30, 75 and 150 kg ha^{-1} as urea fertilizer. The irrigation was applied at three levels: full irrigation, one supplementary irrigation at the flowering stage and two supplementary irrigations at the flowering and pod filling stages. The studied traits included grain yield, biological yield, the number of pods per plant, and the number of seeds per pod.

Result: Our results showed that different levels of irrigation and nitrogen fertilizer had a significant effect on the number of seeds per pod, pods per plant and biological and grain yield. The interaction effect of irrigation and nitrogen fertilizer was significant for all studied traits. In this study, the interaction between the full irrigation treatment and 75 kg N ha^{-1} resulted in a significant increase in all traits (except biological yield) compared to other treatments. Furthermore, one irrigation at the flowering stage with 150 kg N ha^{-1} caused a significant decrease in all of the studied traits. The combination of full irrigation and 150 kg N ha^{-1} treatment had the highest biological yield (8.9 t ha^{-1}), while its grain yield was 1854 kg ha^{-1}. Therefore, by maintaining moisture levels during the critical period of chickpea growth and utilizing balanced nutritional levels, particularly nitrogen at rates of 30 and 75 kg ha^{-1}, the yield of chickpea can be increased.

Key words: Critical period, Flowering, Pod filling, Supplementary irrigation.

INTRODUCTION

Chickpea (*Cicer arietinum* L.) is a crop that is grown worldwide and is adaptable to different climatic conditions, ranging from mild to hot and humid to dry. Its characteristics, such as nitrogen fixation, deep rooting and the use of precipitation, make it an important crop in the production of sustainable agricultural systems. In some parts of the world, legumes are being substituted for fallow in wheat-fallow cropping systems with good success (Soltani *et al*., 2016). Chickpea is considered the third most important legume crop worldwide and the first in West Asia and North Africa. It is an important grain crop in the rainfed agricultural systems of these regions (Hajjarpoor *et al*., 2018). Chickpea is the most important legume crop in Iran, accounting for more than 50% of the area under legume cultivation (Anonymous, 2022; FAO, 2022). Iran has the largest cultivated area of chickpea in the world after India, Pakistan and Turkey, with 560,191 ha. However, it ranks 45th in terms of yield with an average yield of 463 kg ha^{-1} (FAO, 2022). Chickpea is more resistant to drought than other cold-tolerant legumes. However, drought stress is still considered one of the most important factors in yield reduction in this plant. This is caused by shedding of pods, which start to fall when the leaves begin to age due to lack of water. The decrease in grain yield caused by drought stress is due to the negative effects of this stress on the leaf area index, photosynthesis of plant cover, crop growth rate and yield components (Tomar *et al*., 2021).

In arid and semi-arid areas, water scarcity is the most significant limiting factor for increasing yield. Therefore, increasing water productivity compared to the product per unit of land is the best solution for rainfed agriculture. Efficient water management methods such as supplementary irrigation should be used in such situations. Supplementary irrigation is a high-efficiency method for increasing

[1]Department of Agriculture, Payame Noor University (PNU), P.O. BOX, 19395-4697, Tehran, Iran.
[2]Department of Production Engineering and Plant Genetics, Faculty of Agriculture, University of Saravan, P.O. Box 99516-34145, Saravan, Iran.
[3]Department of Agronomy and Plant Breeding, Faculty of Agriculture, University of Jiroft, Jiroft, Iran.

Corresponding Author: Seyedreza Amiri, Department of Production Engineering and Plant Genetics, Faculty of Agriculture, University of Saravan, P.O. Box 99516-34145, Saravan, Iran.
Email: amiriseyedreza86@gmail.com; r.amiri@saravan.ac

How to cite this article: Mahmoundi, M., Amiri, S., Motlagh, B.P. (2024).Evaluation of Chickpea Production under Different Management of Irrigation and Nitrogen Fertilizer. Legume Research. 1-6. doi: 10.18805/LR-5302.

Submitted: 02-02-2024 **Accepted:** 27-09-2024 **Online:** 12-11-2024

agricultural yields and significantly improving water productivity through integrated and coordinated management of farm resources (Attia *et al*., 2016). Chickpea yield has been shown to increase by 44% under dry Mediterranean environments with supplementary irrigation. In India, supplementing irrigation during the early vegetative growth period in sandy soil with low water holding capacity or late vegetative growth in the early pod filling stage in deep soil has been found to increase chickpea yield (Varol *et al*., 2020).The study by Amiri *et al*., (2016) showed that chickpea yield increased with supplementary irrigation, with the highest grain yield achieved by irrigation during the flowering stage. As the flowering and beginning of seed filling stages are the most sensitive stages to moisture stress in chickpea, additional irrigation during these stages of plant growth is expected to reduce the severity of drought stress and increase yield.

Research conducted in West Asia and India has shown that in order to achieve high yields of chickpea plants, the application of high levels of nitrogen is necessary. This is because nodulation is poor in these areas and the situation is similar to that of an uninoculated plant in an area where the native rhizobium population is low. It is true that multiple applications of nitrogen are better than a single application. This is because the chickpea plant absorbs nitrogen throughout the growing season and multiple applications ensure that the plant has access to nitrogen when it needs. During the growing season, the chickpea plant absorbs 60 to 200 kg N ha^{-1}, 5 to 15 kg P ha^{-1} and 60 to 170 kg K ha^{-1} (Mustafa *et al*., 2023; Oweis *et al*., 2005). Studies have shown that the use of nitrogen starter fertilizer has been shown to increase yield components such as leaf area, soybean production, dry matter production and final grain yield per unit area (Gai *et al*., 2017; Rani *et al*., 2016; Kalkal *et al*., 2017). Similarly, the yield and yield components of pea increased with increasing nitrogen levels. Nitrogen application significantly affected yield components such as the number of pods, seed weight per plant and thousand seed weight and allocation of more photosynthetic assimilates to reproductive organs may have been a contributing factor (Janusauskaite and Daiva (2023). Nitrogen consumption also significantly increased plant height, number of lateral branches and biological yield more than not using nitrogen. Khan *et al*. (2019) reported that grain yield increased up to the highest amount of applied nitrogen, while also increasing the total number of pods and the number of fertile pods. However, it is important to note that these studies were conducted in different regions and under different conditions and this study specifically focused on investigating the impact of different levels of irrigation and nitrogen fertilizer on the yield and yield components of the adel cultivar of chickpea in the climatic conditions of Esfarayen Region District in Khorasan-Iran.

MATERIALS AND METHODS

The experiment was conducted in the form of a completely randomized block design with factorial arrangement in four replications in the research field of Esfarayen Region in Khorasan-Iran (36.92°N, 57.55°E) during the 2022 and 2023 growing seasons (two years). Adel cultivar was used as an early maturity cultivar in this study. The experiment had three levels of pure nitrogen fertilizer (30, 75 and 150 kg ha^{-1}) and three levels of irrigation (full irrigation, one supplementary irrigation at the flowering stage, two supplementary irrigations at the flowering and pod development stages) considered as factors. Full irrigation was done during the growing season, after planting and at intervals of 10 days. Irrigation was done in the flowering and podding stages when 50% of the plants in each plot had entered the flowering and podding phase. In the full irrigation treatment, irrigation was conducted when 35% of the soil moisture available at a depth of 20 cm was depleted. The duration of irrigation ranged from 6 to 22 days, depending on prevailing weather conditions. In the control treatment, soil moisture was replenished to field capacity at a depth of 50 cm during each irrigation event. The soil moisture deficit was determined by employing Equation (1) for calculation purposes.

$$\text{SMD control} = (qFC - qs) \times Dr............(1)$$

Where, SMD, qFC,qs and Dr represent the amount of moisture deficit (mm), content of soil moisture in the field capacity, (20.5), the content of soil moisture at the depth of 20 cm before irrigation and the effective depth of chickpea root (50 cm), respectively.

Further, the amount of irrigation water for each plot in the control treatment was calculated from Equation (2):

$$\text{I control} = \text{SMD control} \times A.................. (2)$$

Where Icontrol, SMD control and A represent the amount of irrigation water (mm), the amount of moisture deficit (mm) calculated in Equation (1) and the plot area (m^2), respectively. For each millimeter of moisture deficit per square meter, 1 L of water was applied using a flooded irrigation method. The maximum amount of nitrogen fertilizer was considered to be 150 kg ha^{-1} in order to achieve the potential yield, as chickpea plants require between 50 and 70 kg of nitrogen from the soil to produce each ton of yield. Also, based on the gathered data, farmers typically use nitrogen at sowing. Additionally, using a small amount of nitrogen to stimulate growth and increase yield in sandy and sandy loam soils (Table 1) that are poor in nitrogen is effective, hence 30 kg of starter fertilizer was used following regional customs. An economic review of 123 fertilizer experiments has shown that using 30 to 34 kg ha^{-1} N is beneficial for chickpea. The next fertilizer treatment was also used between these two levels, at 75 kg ha^{-1}.

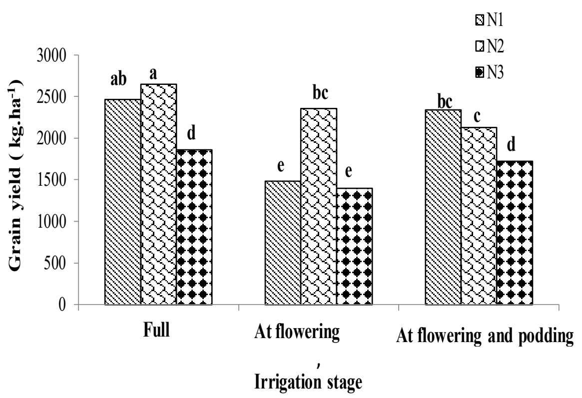
Table 1: Physical and chemical characteristics of soil before the experiment of 2022.

Soil texture	pH	EC (dS/m)	K (ppm)	P (ppm)	Total N (%)
Silty loam	7.40	2.5	286	20	0.087

Table 2: Analysis of variance (MS) for yield and yield components of chickpea at different levels of irrigation and nitrogen fertilizer during 2022 and 2023 growing season.

S.O.V.	d.f.	Seeds per pod	Pods per plant	Grain yield	Biological yield
			2022		
Replication	2	0.034*ns*	3.9*ns*	8200*ns*	221302*ns*
Nitrogen	2	1.372**	312.0**	1125472**	1314858**
Irrigation	2	0.498**	61.6**	511082**	1056713**
Irrigation × Nitrogen	4	0.454**	71.0**	413806**	516613**
Error	16	0.019	0.763	42546	123216
C.V		9.71	6.8	8.11	12.01
			2023		
Replication	2	0.039*ns*	4.1*ns*	711*ns*	232746*ns*
Nitrogen	2	1.611**	243.8**	1324471**	1387321**
Irrigation	2	0.823**	59.3**	632512**	1039879**
Irrigation × Nitrogen	4	0.597**	65.2**	328913**	509624**
Error	16	0.023	0.957	35881	108752
C.V		10.17	5.07	6.61	8.99

ns: Non-significant, *and **: Significant at α= 0.05 and α= 0.01, respectively.



N1, N2 and N3 refer to nitrogen levels of 30 kg ha^{-1}, 75 kg ha^{-1} and 150 kg ha^{-1}, respectively.

Fig 1: Effect of irrigation and nitrogen interactions on grain yield (α= 0.05).

All experimental plots received urea fertilizer exclusively. Seedbed preparation was conducted in March using plowing, disking and leveling. Sowing was done on March 25 using plots that measured 2.5 × 5 m^2, each containing 5 rows. The spacing between each plant in the row was 10 cm. The planting density was 33 plants per m^2 and the depth of planting was 5 cm. To prevent water leakage to adjacent plots, two unplanted rows (50 cm) were left between adjacent plots. To achieve the desired density, the plots were thinned 15 days after emergence. Field weeds were controlled only manually twice during the growing season, at 25 and 50 days after planting.

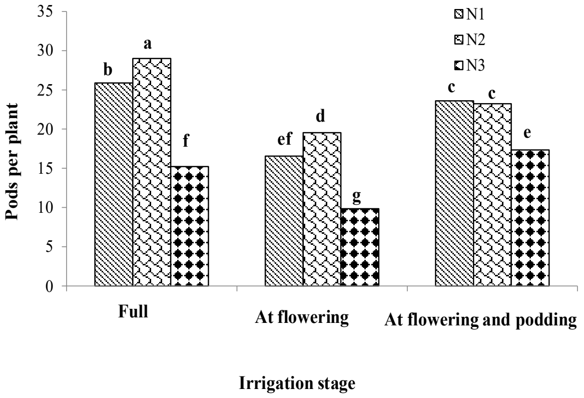
The plants were harvested at the end of the chickpea growing season, on May 20 and May 17 in 2022 and 2023, respectively. The harvested plants were transported to the laboratory to determine their grain and biological yield. The obtained data was analyzed statistically using SAS statistical software version 9.1 and the mean values were compared using Duncan's multiple-range test at the 5% probability level.

RESULTS AND DISCUSSION

Based on the results of the analysis of variance, it was found that both the simple and interaction effects of nitrogen fertilizer and irrigation had a significant impact on all studied traits of chickpea (Table 2). Consequently, we will only discuss the interaction effects of the studied traits in the following sections.

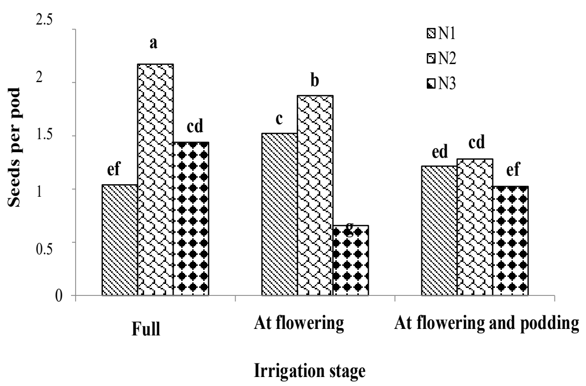
Grain yield

The highest grain yield was obtained in the full irrigation treatment with nitrogen level of 30 kg ha^{-1} (2645 kg ha^{-1}) (Fig 1). After this treatment, the highest grain yield was observed in the interacton of full irrigation and nitrogen level of 75 kg ha^{-1}. Under full irrigation and low nitrogen levels at the beginning of the growing season, chickpea appear to establish faster in the field. This is important before the plant becomes self-sufficient in nitrogen fixation. Moreover, the irrigation in the flowering stage with a nitrogen level of 75 kg ha^{-1} (2356 kg ha^{-1}) and the irrigation treatment in the flowering and podding stage with a nitrogen level of 30 kg ha^{-1} (2338 kg ha^{-1}) were ranked next and did not differ significantly from each other (Fig 1). Considering that the majority of chickpea in Iran, are rainfed and experience drought stress during the flowering stage, it results in a reduction in the length of the flowering period, the number of flowers and grain yield (Pasandi *et al*., 2014). Therefore, by employing one or two supplementary irrigation methods during the critical stages of the plant's growth (flowering and podding) and utilizing 30 kg N ha^{-1} as a starter fertilizer, it is possible to achieve high yields that are comparable to those under full irrigation conditions. Moreover, this approach enhances water use efficiency. In this experiment, the lowest grain yield was associated with the irrigation treatment during the flowering stage and nitrogen level, which were 150 kg ha^{-1} (1395 and 1481 kg ha^{-1} respectively). Consequently, as the irrigation amount is decreased, the plant's response to nitrogen also diminishes (Shaban *et al.,* 2011). This occurs because the application of excessive nitrogen fertilizer in arid and semi-arid regions promotes vegetative



N_1, N2, and N3 refer to nitrogen levels of 30 kg ha^{-1}, 75 kg ha^{-1}, and 150 kg ha^{-1}, respectively.

Fig 2: Effect of irrigation and nitrogen on number of pods per plant (α= 0.05).



N_1, N_2 and N_3: 30,75 and 150kg N ha^{-1}respectively.

Fig 3: Effect of irrigation and nitrogen on seeds per pod (α=0.05).

growth, but leads to drought stress towards the end of the growing season, resulting in a significant decrease in yield. Drought stress can lead to a reduction in nitrogen fixation, nodule respiration and stem dry weight. One of the causes for the decline in yield under semi-arid conditions is the disturbance of the plant's nutritional balance in such circumstances. In severe drought stress, aging is often accelerated. This effect is particularly more severe in higher nitrogen levels. Consequently, a reciprocal relationship exists between drought stress and nitrogen, where nitrogen consumption under dry conditions negatively impacts grain yield.

Number of pods per plant

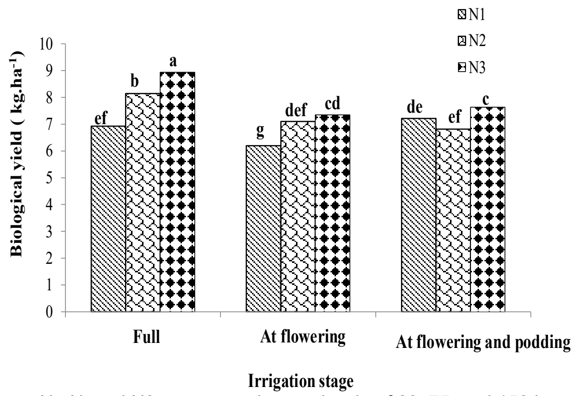
In the evaluation of the interaction effect between nitrogen fertilizer and irrigation, the highest number of pods per plant (29 pods per plant) were obtained under full irrigation with an application of 75 kg ha^{-1} of nitrogen. Conversely, the lowest number of pods (9 pods per plant) was observed when using irrigation at flowering treatment-along with 150 kg ha^{-1} of nitrogen (Fig 2). High levels of nitrogen application led to increased vegetative growth during the initial stages of plant growth, resulting in rapid drainage of soil moisture. As a result, the application of supplementary irrigation did not prove to be very effective in increasing the number of pods. However, by using more irrigation water and maintaining balanced levels of nitrogen fertilizer, the plant will develop a larger canopy capable of nourishing larger sinks and allocating an adequate amount of dry matter to them. Consequently, the number of pods in the plant increases. Shortened pollination period due to drought stress can also lead to a reduction in pod numbers. Drought adversely affects flower-producing buds during the reproductive stages, resulting in the shedding of flowers and ultimately leading to a decrease in pod production (Gusmao *et al*., 2012). According to Kashfi *et al.* (2010), the chickpea plant produced the highest number of pods per plant under full irrigation with the application of 50 kg N ha$^{-1.}$ Conversely, the lowest number of pods was observed when no nitrogen was applied. The availability of moisture and balanced levels of nitrogen increases the development of the plant canopy, leading to an increase in yield components such as the number of pods per plant (Halagalimath and Rajkumara, 2018; Venkatesh *et al.,* 2023).

Seeds per pod

In the investigation of the interaction effect between nitrogen fertilizer and irrigation, the highest number of seeds in the pod was observed under the full irrigation treatment along with 75 kg ha^{-1} of nitrogen (2.17 seeds per pod and 2076 seeds m^{-2}). On the other hand, the lowest number of seeds was associated with the flowering irrigation treatment and 150 kg ha^{-1} of nitrogen (0.65 seeds per pod and 193 seeds m^{-2}) (Fig 3). Providing moisture during the plant growth period, along with a balanced level of nitrogen (75 kg in this experiment), enhances vegetative growth and subsequently increases the number of seeds in the pod. However, if irrigation is carried out during the flowering stage and high levels of nitrogen are applied, it can lead to excessive vegetative growth and make the plants more susceptible to drought towards the end of the season. Consequently, this may result in a decrease in the number of seeds in the pod (Jagdale and Dalve, 2010). Increasing the amount of irrigation water results in an increase in pod numbers and maturity occurring over a longer period. Additionally, leaves senescence at a slower rate, resulting in an increased number of seeds in the pod. Conversely, a decrease in the amount of irrigation water, coupled with an increase in temperature, leads to premature aging of the plant (Lobell *et al*., 2012). Optimal soil moisture influences the duration of the reproductive growth period and the level of photosynthesis, which in turn affects the number of flowers formed on the plant and ultimately leads to the development of fertile pods and increased seed production (Amiri dehahmadi *et al.,* 2010a).

Biological Yield

The highest biological yield (8900 kg ha^{-1}) was observed in the full irrigation treatment and 150 kg N ha^{-1}, while a significant decrease in biological yield was observed with reduced irrigation and nitrogen fertilizer. The irrigation



N_1, N_2 and N3 represent nitrogen levels of 30, 75, and 150 kg N ha^{-1}, respectively.

Fig 4: Effect of irrigation and nitrogen on biological yield (α= 0.05).

treatment during the flowering stage and the nitrogen level of 30 kg ha^{-1} resulted in the lowest biological yield (6600 kg ha^{-1}) (Fig 4). In chickpea, the availability of moisture and nitrogen increases vegetative dry matter, resulting in an increase in biological yield, as it leads to an increase in the length of the vegetative growth period, effective depth of the canopy, absorption of active photosynthetic radiation and the formation of seeds. Drought stress can lead to a reduction in biological yield due to a decrease in the length of the growth period, crop growth rate reduction, and flower and pod drop. Adequate moisture supply during the flowering stage is crucial for chickpea, as it experiences active vegetative growth during this period. Chickpeas exhibit rapid vegetative growth after flowering, followed by a subsequent decrease during the podding phase. The reduction in plant transpiration under drought stress facilitates a proper balance between transpiration and the maintenance of the critical leaf area index required for photosynthesis. Reducing the leaf area becomes an important adaptive mechanism as it is the plant′s initial response to water scarcity (Amiri dehahmadi *et al.,* 2010b; Chauhan *et al*., 2019; Parsa *et al*., 2012).

CONCLUSION

The study findings suggest that combining full irrigation with a nitrogen level of 75 kg ha^{-1} resulted in a significant increase in all measured traits (except biological yield). However, applying supplementary irrigation during the flowering stage with 150 kg N ha^{-1} promoted vegetative growth but subjected the plant to drought stress at the end of the growing season, leading to a reduction in grain yield. On the other hand, the combination of full irrigation and a nitrogen level of 150 kg ha^{-1} increased the biological yield mainly in the vegetative growth of the plant, with a lesser impact on grain yield. Providing sufficient moisture during critical stages of chickpea growth (flowering and podding) and applying balanced nitrogen levels enhance optimal vegetative growth before the reproductive phase, leading to increased chickpea yield in the studied areas. However, there is a lack of accurate knowledge regarding the required amount of biologically stabilizing nitrogen in these areas.

Author contributions

Majid Mahmoudi: Writing- review and editing. Seyedreza Amiri: Methodology, Evaluation, Writing-original draft. Bahareh Parsa Motlagh: Writing and editing.

Conflict of Interest

The authors state that they have no known financial interests or personal relationships that could have influenced the work reported in this paper.

Data Availability

Data will be made available on request.

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