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Effects of Urea Fertilizer Levels on Growth and Yield of Safflower (Carthamus tinctorius L.) Under Kabul Climatic Conditions

Hanifullah Abid[1*], Abdul Khalil Afghani[2], Hakmatullah Nimgarri[3]
Department of Agronomy, Faculty of Agriculture, Wardak University, Afghanistan[1]
Department of Agronomy, Faculty of Agriculture, Kabul University, Afghanistan[2]
Department of Plant Protection, Faculty of Agriculture, Wardak University, Afghanistan[3]
Corresponding Author: hanifullahabid22@gmail.com[1]

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Corresponding Author:

Hanifullah Abid
Department of Agronomy, Faculty of Agriculture, Wardak University, Afghanistan
Email:
hanifullahabid22@gmail.com

ABSTRACT

Safflower (*Carthamus tinctorius* L.) is an important oil-bearing crop with significant economic and medicinal value, well adapted to arid and semi-arid climates. Despite safflower's adaptability to arid environments, nitrogen management recommendations for Kabul agro-climatic conditions remain unavailable, limiting its wider adoption among Afghan farmers. Consequently, systematic research on optimal nitrogen fertilization for safflower under the specific climatic conditions of Kabul, Afghanistan, remains limited. This study evaluated the effects of six urea levels (0, 40, 60, 80, 100, and 120 kg ha^{-1}) on the growth and yield of safflower using a Randomized Complete Block Design (RCBD) with three replications at the Kabul University research farm during the spring season of 2025. Data were analyzed by analysis of variance (ANOVA), and treatment means were compared using the least significant difference (LSD) test at the 5% probability level. Results demonstrated that urea application significantly influenced plant height, number of leaves, number of branches, days to 50% flowering, number of capitula plant^{-1}, number of seeds capitulum^{-1}, thousand-seed weight (TSW), seed yield, and straw yield. The highest seed yield (1,650 kg ha^{-1}) and TSW (41.50 g) were recorded at T5 (100 kg urea ha^{-1}), whereas the highest straw yield (3,300 kg ha^{-1}) was obtained at T6 (120 kg urea ha^{-1}), albeit with a slight decline in seed yield and TSW. These findings indicate that 100 kg urea ha^{-1} represents the optimal nitrogen application rate for economically viable safflower production under Kabul conditions.

1. INTRODUCTION

Safflower (*Carthamus tinctorius* L.) is one of the oldest cultivated oil crops, with records of its use spanning several millennia across Asia, the Middle East, Africa, and the Americas. It belongs to the family Asteraceae, genus *Carthamus*, tribe Tubuliflorae, and has historically been cultivated both as a source of natural dye and as an edible oilseed crop (BİLMEZ ÖZÇINAR, 2021; Singh & Nimbkar, 2006). Archaeological evidence suggests that safflower was domesticated in the Fertile Crescent and subsequently disseminated along ancient trade routes, including the Silk Road, which traversed present-day Afghanistan. This historical connection underscores the crop's genetic suitability to the region's continental climate and its potential for reintroduction into modern Afghan cropping systems. Major safflower-producing countries today include India, Mexico, China, Australia, Turkey, and Iran, all of which exploit the crop for its seed oil, petals, and by-products (BİLMEZ ÖZÇINAR, 2021; Yar, F. G. M., et.al, 2022).

From an agronomic perspective, safflower offers several advantages for cultivation in marginal environments. Its deep, penetrating root system capable of extracting soil moisture from depths of up to four meters—confers exceptional drought tolerance and enables productive growth under water-limited conditions. The crop also demonstrates moderate salinity tolerance and provides a natural deterrent to livestock and wildlife due to its spiny leaves, thereby reducing crop losses in open-field settings. Moreover, safflower integrates effectively into cereal-based crop rotation systems, disrupting the disease cycles of pathogens that affect subsequent crops such as wheat and barley (Yar et al., 2025). In Afghanistan, where cereal monoculture dominates the rain-fed and irrigated production systems, the inclusion of safflower could enhance system diversity, improve soil health through its extensive root architecture, and provide farmers with a cash crop alternative to traditional staples. These attributes make it particularly attractive for dryland farming systems in countries such as Afghanistan, where water scarcity and limited agricultural inputs constrain crop diversification.

Beyond its agronomic resilience, safflower possesses considerable nutritional and pharmaceutical importance. Its seed oil is characterized by a high content of linoleic acid (omega-6), which supports favorable fatty acid profiles in human diets and serves as a functional ingredient to reduce saturated fat consumption (Botella-Martínez et al., 2023). The oil is also used in the production of ointments, margarines, and structured lipid emulsions (Almeida et al., 2022). Furthermore, safflower contains bioactive phytochemicals—including hydroxysafflor yellow A, carthamin, and polyphenolic compounds that underpin its extensive application in traditional and modern pharmacotherapy, particularly in treatments for cardiovascular disorders and inflammatory conditions (Cheng et al., 2024). Owing to mounting global demand for alternative vegetable oils and bioactive compounds, safflower has emerged as a promising candidate to complement conventional oilseed crops such as sunflower and soybean in sustainable production systems (Chermahini et al., 2024; Mursalykova et al., 2023).

Nitrogen is the most critical macronutrient governing the growth and productivity of safflower. It is an essential constituent of chlorophyll, amino acids, proteins, and key metabolic enzymes, and it directly regulates the rate of photosynthesis, leaf area development, and the partitioning of assimilates to reproductive organs (Marschner, 2011; Taiz & Zeiger, 2014). Urea ($CO(NH_2)_2$) is the most widely used and economically accessible nitrogenous fertilizer globally. Its proper application has been shown to increase plant height, leaf area index, branch number, and dry matter accumulation, ultimately enhancing reproductive yield in safflower (Talebbeigi et al., 2018). Recent investigations further demonstrate that both conventional and nano-urea formulations can significantly improve physiological indicators such as chlorophyll content, leaf greenness (SPAD values), and overall crop vigor in safflower. Nitrogen use efficiency (NUE) in safflower is also influenced by the rate, timing, and placement of urea, with optimal nitrogen management improving both the economic yield and the environmental sustainability of fertilizer use (Abbadi & Gerendás, 2009; Nazari-Sendi et al., 2026). However, excessive nitrogen application can lead to vegetative luxuriance, delayed maturity, lodging susceptibility, and reduced harvest index, thereby diminishing the economic returns of fertilization.

Previous research has examined nitrogen and urea effects on safflower under various environmental conditions. Talebbeigi et al., (2018) reported that split-applied nitrogen sources improved NUE and seed quality in Iran. Dordas & Sioulas, (2009) demonstrated that nitrogen fertilization enhanced dry matter accumulation and partitioning in safflower under Mediterranean conditions. Koutroubas et al., (2021) found that elevated nitrogen promoted vegetative biomass but reduced seed production efficiency beyond a certain threshold. Sreekanth, N., et.al, (2021) identified optimal nitrogen levels for growth and yield in Indian safflower environments, while Haliloglu, (2019) reported the interacting effects of nitrogen and zinc on yield under semi-arid Turkish conditions. Genan et al., (2025) recently confirmed that nitrogen level and irrigation regime jointly determine yield outcomes. However, despite the growing body of evidence on nitrogen-safflower interactions globally, systematic research under the specific agro-climatic conditions of Kabul, Afghanistan characterized by a temperate continental climate, distinct seasonal temperature extremes, and predominantly loamy soils remains absent from the scientific literature. This research gap is particularly consequential because nitrogen recommendations developed for Mediterranean, South Asian, or semi-arid Turkish environments may not be directly transferable to the high-altitude, continental conditions of the Kabul plateau, where thermal regimes, evaporative demand, and soil fertility status differ markedly.

Afghanistan’s agricultural sector faces persistent challenges, including input scarcity, limited access to soil fertility data, and dependence on a narrow range of staple crops. Introducing safflower as an economically viable oilseed crop requires generating locally calibrated agronomic recommendations, particularly regarding fertilizer management. Improper nitrogen application not only reduces crop yield but also contributes to nitrate leaching, soil acidification, and greenhouse gas emissions, underscoring the need for evidence-based fertilization guidelines suited to local conditions. Therefore, this research intends to fill this critical knowledge gap by systematically evaluating urea fertilizer effects on safflower productivity under Kabul’s agro-climatic conditions. The objectives of this study are (1) to assess the influence of different urea application rates on vegetative growth parameters, (2) to determine the effects on yield and yield components of safflower, and (3) to identify the optimal urea rate that maximizes seed yield under Kabul climatic conditions. The hypothesis is that urea application will have a significant, dose-dependent, and nonlinear effect on safflower growth and yield, with an identifiable optimal rate that produces superior economic yield compared to lower and higher application levels.

2. METHOD

Study Site and Environmental Conditions

This study was conducted during the spring agricultural season of 2025 at the research farm of the Agronomy Department, Faculty of Agriculture, Kabul University, Kabul

Province, Afghanistan. The experimental site is geographically situated at 34.5184° N latitude and 69.1394° E longitude, at an altitude of 1,810 m above sea level (Safi et al., 2016). The region experiences a temperate continental climate with hot, dry summers and cold winters (Salari et al., 2020). Temperature during the growing season (May–September) ranged between 18°C and 36°C, and total seasonal precipitation was minimal, necessitating supplementary irrigation.

Before the experiment commenced, composite soil samples were collected from six randomly selected locations within the experimental area at a depth of 0–30 cm. Samples were air-dried, sieved through a 2 mm mesh, and analyzed for key soil physical and chemical properties following standard procedures. The soil was characterized as a sandy loam (USDA classification) with the following properties: pH 7.8 (1:2.5 soil: water suspension), electrical conductivity (EC) 0.42 dS m^{-1}, organic matter content 1.12% (Walkley–Black method), total nitrogen 0.06% (Kjeldahl method), available phosphorus 12.4 mg kg^{-1} (Olsen method), available potassium 186 mg kg^{-1} (ammonium acetate extraction), and bulk density 1.35 g cm^{-3}. These values indicate a moderately fertile soil with low native nitrogen status, typical of the alluvial-derived agricultural lands in the Kabul valley. The cropping history of the experimental land over the preceding four years comprised wheat (2021), barley (2022), maize wheat (2023), and barley (2024), ensuring that no previous safflower residues were present that could confound treatment effects.

Experimental Design and Treatments

The experiment was established on a total area of 54 m^2 using a Randomized Complete Block Design (RCBD) with six treatments and three replications, yielding 18 experimental plots in total. Each plot measured 1.5 m × 2.0 m (3.0 m^2). Treatments consisted of six urea application rates: T1 = 0 kg urea ha^{-1} (unfertilized control), T2 = 40 kg ha^{-1}, T3 = 60 kg ha^{-1}, T4 = 80 kg ha^{-1}, T5 = 100 kg ha^{-1}, and T6 = 120 kg ha^{-1}. Urea (46% N) was used as the sole source of nitrogen and was applied as a single basal dose incorporated into the soil before planting. To provide baseline soil organic matter and phosphorus, all plots received a uniform application of 15 t ha^{-1} of well-decomposed farmyard manure (FYM) two weeks before sowing.

Crop Establishment and Management

Safflower seeds of a locally adapted variety were sown on 27 May 2025 at a seeding rate of 10 kg ha^{-1}. Seeds were placed in rows spaced 40 cm apart, with an inter-plant spacing of 25 cm, at a sowing depth of 2.5 cm, following thorough seedbed preparation involving deep ploughing, harrowing, and levelling. Initial irrigation was provided ten days after sowing to ensure uniform germination and establishment. Thereafter, supplemental irrigations were applied at 15-day intervals throughout the growing season, with the total number of irrigations adjusted to prevent moisture stress. All other agronomic practices (weeding, pest management) were performed uniformly across all plots to eliminate confounding effects.

Data Collection

Data were recorded at appropriate growth stages. From each plot, six plants were randomly selected at the beginning of the growing season and marked for repeated measurements. Parameters recorded included: plant height (cm), number of leaves plant^{-1}, number of branches plant^{-1}, days to 50% flowering, number of capitula plant^{-1}, number of seeds capitulum^{-1}, thousand-seed weight (TSW, g), seed yield (kg ha^{-1}), and straw yield (kg ha^{-1}). At physiological maturity, plants in each plot were harvested by hand. Plot-level samples were kept separate for post-harvest measurement of yield components and yield. Seed yield was measured after threshing and cleaning, then adjusted to 10% moisture content. Straw yield was calculated as total aboveground dry biomass minus seed yield.

Statistical Analysis

All collected data were subjected to one-way analysis of variance (ANOVA) using STAR statistical software (Biometrics and Breeding Informatics, IRRI). Treatment means were separated using the Least Significant Difference (LSD) test at the 5% probability level ($p \leq 0.05$). Treatment effects were considered statistically significant when $p \leq 0.05$ and highly significant when $p \leq 0.001$. The coefficient of variation (CV%) was computed for each variable to assess experimental precision.

3. RESULTS AND DISCUSSION

Plant Height

The analysis of variance revealed highly significant differences in plant height among treatments ($p \leq 0.001$; Table 1). Application of urea progressively increased plant height across all treatment levels compared to the unfertilized control. The maximum plant height (104.10 cm) was recorded in T6 (120 kg urea ha^{-1}), followed closely by T5 (100.13 cm). The minimum plant height (83.03 cm) was observed in T1 (0 kg urea ha^{-1}). The LSD test (5%) separated treatments into statistically distinct groups (Table 1), with T1 and T2 forming the lowest group and T5–T6 the highest. These findings are consistent with the physiological role of nitrogen in promoting cell division, elongation, and chlorophyll synthesis, thereby stimulating internode extension and overall plant stature. Similar results were reported by Sreekanth, N. et.al, (2021) and Haliloglu and Beyyavas (2019), who found progressive increases in safflower plant height with increasing nitrogen doses.

Number of Leaves plant^{-1}

Highly significant treatment effects were observed for the number of leaves plant^{-1} ($p \leq 0.001$; Table 1). Leaf number increased systematically from 93.10 in T1 to 107.07 in T6. T5 (105.00 leaves plant^{-1}) and T6 (107.07) were statistically comparable (same LSD group), while both were significantly superior to T1, T2, and T3. The positive response of leaf number to nitrogen is attributed to the role of N in promoting axillary bud development and leaf primordium initiation. Increased leaf number expands the photosynthetically active surface area, which is a prerequisite for greater assimilate production and improved yield potential (Taiz & Zeiger, 2014). Dordas & Sioulas, (2009) similarly observed enhanced leaf area development in safflower as nitrogen supply increased.

Number of Branches plant^{-1}

Urea application had a highly significant effect on the number of branches plant^{-1} ($p \leq 0.001$; Table 1). Branch number increased from 16.33 in the unfertilized control (T1) to a maximum of 21.50 in T5 and T6, which were statistically equivalent. T4 (20.00 branches plant^{-1}) was intermediate, while T1 and T2 formed the lowest-performing group. The positive effect of nitrogen on branching reflects its role in stimulating lateral bud break and vegetative partitioning. Increased branching is associated with a larger number of capitula-bearing sites, which is a key driver of yield. However, as observed with other parameters, branching plateaued at T5, suggesting that nitrogen luxury consumption above 100 kg ha^{-1} does not translate into further branching gains.

Days to 50% Flowering

The number of days to 50% flowering increased progressively with urea level, from 69 days in T1 to 84 days in T6 ($p \leq 0.001$; Table 1). All treatments were significantly different from one another, as evidenced by the LSD test grouping. The prolongation of the vegetative phase under high nitrogen conditions is a well-documented physiological phenomenon. Elevated nitrogen promotes vigorous vegetative growth, delaying the transition to the reproductive phase as carbon and nitrogen pools remain devoted to leaf and stem development. While delayed flowering can extend the growing season and potentially increase biomass, it may also expose the crop to late-season heat stress or water limitation. In the present study, T5 (81 days) appeared to provide a balanced phenological window, combining adequate vegetative development with timely reproductive transition. Koutroubas et al., (2021) also reported nitrogen-induced delays in safflower flowering under Mediterranean conditions.

Number of Capitula plant^{-1}

Nitrogen application significantly affected the number of capitula plant^{-1} ($p \leq 0.001$; Table 1). The highest number of capitula (20.00) was recorded in T5, which was significantly superior to T1, T2, and T3. T6 produced 19.10 capitula plant^{-1} statistically comparable to T5 while T4 (18.17) was intermediate. The lowest capitula counts were observed in T1 (15.23) and T2 (16.23), which did not differ significantly from each other. The number of capitula is a critical yield component because each capitulum ultimately contributes seeds to the final yield. Adequate nitrogen ensures sufficient branch production and resource availability for floral initiation on each branch apex. The slight decrease in capitula from T5 to T6 may reflect source–sink competition under excess nitrogen conditions, where excessive vegetative sink activity limits reproductive resource allocation (Abbadi & Gerendás, 2009).

Table 1. Effect of different levels of urea fertilizer on growth parameters of safflower (Effect of different urea levels on growth parameters of safflower (*Carthamus tinctorius* L.) under Kabul climatic conditions, spring 2025.

Treatment	Plant Height (cm)	Number of Leaves plant^{-1}	Number of Branches plant^{-1}	Days to 50% Flowering	Number of Capitula plant^{-1}
T1	83.03 e	93.10 e	16.33 d	69 f	15.23 d
T2	86.00 de	95.07 de	17.77 cd	72 e	16.23 d
T3	90.10 cd	99.03 cd	18.90 bc	75 d	17.50 c
T4	95.07 bc	102.00 bc	20.00 b	78 c	18.17 bc
T5	100.13 ab	105.00 ab	21.50 a	81 b	20.00 a
T6	104.10 a	107.07 a	21.50 a	84 a	19.10 ab
LSD (5%)	5.09	4.99	1.44	2.32	1.22
Significance	***	***	***	***	***
CV (%)	1.93	1.76	2.62	1.07	2.43

*Means within a column followed by different lowercase letters are significantly different (LSD test, $p \leq 0.05$). *** $p \leq 0.001$. CV = coefficient of variation. TSW = thousand-seed weight.*

Number of Seeds capitulum^{-1}

Highly significant differences were observed among treatments for the number of seeds capitulum^{-1} ($p \leq 0.001$; Table 2). The highest seed number per capitulum (27.77) was recorded in T5, followed by T6 (27.13); these two treatments were not significantly different. T4 (26.50) was intermediate, while T3 (25.17), T2 (23.77), and T1 (22.50) ranked progressively lower. The positive response to nitrogen likely reflects improved pollination conditions, enhanced carbohydrate supply for seed set, and greater sink strength during the grain-filling phase. However, the lack of significant improvement from T5 to T6 reinforces the notion that seed number per capitulum reaches saturation at moderate nitrogen levels. These findings align with those of Talebbeigi et al., (2018), who reported optimal seed-per-capitulum counts at intermediate nitrogen application rates in safflower.

Thousand-Seed Weight

The TSW showed a significant response to urea application, increasing from 29.50 g in T1 to a maximum of 41.50 g in T5 ($p \leq 0.001$; Table 2). T6 (39.17 g) recorded a significant decrease in TSW compared to T5, confirming that nitrogen rates above 100 kg ha^{-1} are counterproductive for seed weight accumulation. The intermediate treatments T3 (34.00 g) and T4 (37.00 g) demonstrated a clear linear increase. Seed weight is primarily determined by the rate and duration of photoassimilate supply to the seed during the filling period. Adequate nitrogen enhances the source capacity (leaf area and chlorophyll content) and maintains active phloem transport to seeds. However, excess nitrogen prolongs vegetative growth, creating an unfavorable source sink ratio during grain filling, which impairs individual seed weight (Dordas & Sioulas, 2009; Marschner, 2011).

Seed Yield

Seed yield responded significantly to urea application levels, following a classic optimum-response curve ($p \leq 0.001$; Table 2). Yield increased progressively from 740.00 kg ha^{-1} in T1 to a maximum of 1,650.00 kg ha^{-1} in T5, representing a 123% improvement over the control. At T6 (120 kg urea ha^{-1}), seed yield declined to 1,556.67 kg ha^{-1}, a statistically non-significant difference from T5 but representing a clear downward trend. T3 (1,160.00 kg ha^{-1}) and T4 (1,376.67 kg ha^{-1}) were significantly different from both the control and the higher-performing treatments. The quadratic response of seed yield to nitrogen dose reflects the interplay between improved vegetative capacity at moderate N levels and the onset of luxury consumption and source–sink imbalance at higher rates. These findings corroborate those of Koutroubas et al., (2021), who identified a similar yield plateau in safflower near 100 kg N ha^{-1}, and of Genan et al., (2025), who reported maximum yields at intermediate nitrogen rates under irrigated conditions. Appropriate nitrogen management promotes efficient carbohydrate and protein translocation to the seeds during the grain-filling stage, directly increasing economic yield (Abbadi & Gerendás, 2009).

Straw Yield

In contrast to seed yield, straw yield increased monotonically across all urea levels, from 1,976.67 kg ha^{-1} in T1 to a maximum of 3,300.00 kg ha^{-1} in T6 ($p \leq 0.001$; Table 2). This represents an increase of 1,323.33 kg ha^{-1} (67%) over the unfertilized control. All treatment means were significantly separated by the LSD test (Table 2). The continuous increase in straw yield with nitrogen dose even beyond T5 clearly demonstrates that excess nitrogen preferentially promotes vegetative biomass (leaves, stems, branches) at the expense of seed fill. This divergence between straw and seed yield responses highlights the agronomic importance of distinguishing biological yield from economic yield. An increase in biological yield alone is not agronomically sufficient; optimizing the harvest index requires targeting nitrogen rates that maximize the proportion of assimilates partitioned to the seeds. These findings are consistent with those of Dordas & Sioulas, (2009), who demonstrated that high nitrogen primarily expanded above-ground biomass, and of Stavropoulos et al., (2022), who reported similar straw biomass patterns under various tillage and urea combinations.

Table 2. Effect of different urea levels on yield parameters of safflower (*Carthamus tinctorius* L.) under Kabul climatic conditions, spring 2025.

Treatment	**Number of Seeds capitulum^{-1}**	**TSW (g)**	**Seed Yield (kg ha^{-1})**	**Straw Yield (kg ha^{-1})**
T1	22.50 e	29.50 f	740.00 d	1976.67 f
T2	23.77 d	31.50 e	913.33 d	2190.00 e
T3	25.17 c	34.00 d	1160.00 c	2450.00 d
T4	26.50 b	37.00 c	1376.67 b	2823.33 c
T5	27.77 a	41.50 a	1650.00 a	3150.00 b

T6	27.13 ab	39.17 b	1556.67 a	3300.00 a
LSD (5%)	0.68	0.93	114.30	86.60
Significance	***	***	***	***
CV (%)	1.54	1.45	5.10	1.80

*Means within a column followed by different lowercase letters are significantly different (LSD test, $p \leq 0.05$). *** $p \leq 0.001$. CV = coefficient of variation. TSW = thousand-seed weight.*

4. CONCLUSION

This study provides the first systematic evidence that urea fertilization exerts a highly significant, dose-dependent effect on the growth, yield components, and economic yield of safflower (*Carthamus tinctorius* L.) under the agro-climatic conditions of Kabul, Afghanistan. All measured vegetative and reproductive parameters responded positively to increasing urea rates up to 100 kg ha^{-1}, beyond which seed yield and thousand-seed weight declined despite continued increases in straw yield. The T5 treatment (100 kg urea ha^{-1}) consistently produced the highest seed yield (1,650 kg ha^{-1}) and TSW (41.50 g), confirming that this rate optimally balances nitrogen supply with the plant's capacity for reproductive partitioning.

The declining efficiency at T6 highlights the risk of nitrogen luxury consumption, whereby excess nitrogen diverts assimilates toward vegetative tissues at the expense of economically valuable grain. Based on these findings, a urea application rate of 100 kg ha^{-1} is recommended for safflower production under Kabul's climatic and soil conditions. Future research should investigate the interaction of nitrogen rates with phosphorus and potassium fertilization, irrigation regimes, and safflower genotypes to further refine fertilizer management recommendations and enhance the crop's contribution to Afghanistan's agricultural diversification and edible oil self-sufficiency.

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