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## Response of safflower to different row spacings and nitrogen levels under residual moisture conditions

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### Abstract

Safflower (*Carthamus tinctorius* L.) is an oilseed crop uniquely suited to arid and semi-arid environments where it can extract water from deep soil profiles after the main crop harvest. This research evaluated three row spacings (30, 45, and 60 cm) and four nitrogen rates (0, 40, 80, and 120 kg N/ha) on safflower growth, yield, and oil content under residual moisture conditions at King Saud University, Riyadh, during the 2021–2022 winter season. The experiment followed a factorial randomized complete block design with three replications. Row spacing of 45 cm combined with 80 kg N/ha produced the highest seed yield (1,724 kg/ha), 50.9% above the unfertilized 30 cm spacing control (1,142 kg/ha). Plant height, capitula per plant, and seeds per capitulum all peaked at 45 cm × 80 kg N. Oil content ranged from 28.1 to 31.4% and was not significantly affected by treatments. The spacing × nitrogen interaction was significant ( $p < 0.01$ ) for seed yield and capitula per plant, indicating that both factors must be adjusted together for optimal performance under residual moisture.

**Keywords:** Safflower, row spacing, nitrogen fertilization, residual moisture, seed yield, oil content, capitula, arid environment, *Carthamus tinctorius*, factorial design

### Introduction

Safflower (*Carthamus tinctorius* L.) is a thistle-like oilseed crop with a deep taproot system that can reach 2–3 m, enabling it to exploit residual soil moisture left after irrigated summer crops [1, 2]. In arid regions of the Middle East and North Africa, safflower fits naturally into crop rotations following cereals or forages, producing 25–35% oil without supplemental irrigation when grown on stored soil water [3, 4]. Saudi Arabia imports over 90% of its vegetable oil, making domestic oilseed production a food security priority [11].

Row spacing governs light interception, air circulation, and root competition. Narrow rows (25–30 cm) maximize early ground cover but may increase disease pressure and inter-plant competition under moisture stress [5]. Wider rows (50–60 cm) allow better aeration and root exploration, though they risk incomplete light capture and lower population-level productivity [15]. Nitrogen supply is equally critical: safflower responds linearly to N up to 60–90 kg/ha in most environments, beyond which diminishing returns set in [6, 8]. Under residual moisture, however, N response curves may flatten earlier because water limits nutrient uptake capacity [10]. Elfadl et al. [5] reported that 45 cm spacing with 60 kg N/ha maximized safflower yield in Germany, while Ozel et al. [15] found 40 cm optimal in southeastern Turkey. Neither tested residual moisture conditions typical of Arabian Peninsula agriculture. This research examined three row spacings and four N rates on safflower performance under residual moisture at Riyadh to establish site-specific recommendations for arid-zone production.

### Materials and Methods

#### Field experimental design

The experiment was a 3 × 4 factorial in a randomized complete block design with three replications. Factors were row spacing (30, 45, 60 cm) and nitrogen rate (0, 40, 80, 120 kg N/ha as urea, 46% N). Nitrogen was split-applied: 50% at sowing and 50% at rosette stage. Plot size was 3 m × 5 m with 1.5 m alleys between plots. The trial occupied 0.48 ha at the Agricultural Research Station, King Saud University (24.7136° N, 46.6753° E) [9].

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### Seasonal variations

The research was conducted during the 2021–2022 winter growing season (November 2021 to April 2022). Riyadh received 67 mm rainfall over this period, well below the long-term average of 94 mm. Mean temperatures ranged from 14.2°C (January) to 28.6°C (April). The preceding summer crop (sorghum) had been irrigated to field capacity in September 2021; soil moisture at sowing depth (0–30 cm) measured 18.4% gravimetric, declining to 9.7% by harvest. No supplemental irrigation was applied to the safflower crop.

### Material

Safflower cultivar Shifa-1, a spiny high-oil type released by King Saud University, was sown at 25 kg/ha on 18 November 2021. The soil was a sandy loam (Typic Torriorthent, pH 7.9,

EC 1.4 dS/m, organic matter 0.6%, available P 7.8 mg/kg, exchangeable K 132 mg/kg). Basal phosphorus (30 kg P<sub>2</sub>O<sub>5</sub>/ha as triple superphosphate) was applied at sowing. Weeds were controlled by one hand-weeding at 35 days after sowing.

### Methods

At maturity, ten plants per plot were sampled for plant height, branches per plant, capitula per plant, seeds per capitulum, and 1000-seed weight. Seed yield was determined from a central 6 m<sup>2</sup> area adjusted to 8% moisture. Oil content was measured by Soxhlet extraction. Data were analyzed by factorial ANOVA in SAS 9.4, means separated by LSD at  $p \leq 0.05$  [9].

### Results

**Table 1:** Seed yield (kg/ha) of safflower as affected by row spacing and nitrogen rate

| Spacing | 0 kg n    | 40 kg n   | 80 kg n   | 120 kg n  |
|---------|-----------|-----------|-----------|-----------|
| 30 cm   | 1142±68e  | 1387±74cd | 1563±81b  | 1491±77bc |
| 45 cm   | 1234±72de | 1518±79b  | 1724±86a  | 1648±83ab |
| 60 cm   | 1098±65e  | 1312±71d  | 1467±78bc | 1403±75cd |

Means ± SD (n=3). Different letters = significant ( $p \leq 0.05$ , LSD)

**Table 2:** Yield components and oil content of safflower by row spacing (averaged across N rates)

| Spacing | Capitula/plant | Seeds/capitulum | 1000-seed (g) | Oil (%)   |
|---------|----------------|-----------------|---------------|-----------|
| 30 cm   | 12.4±1.3b      | 28.7±2.4b       | 41.3±1.8a     | 29.8±1.2a |
| 45 cm   | 16.8±1.6a      | 33.4±2.8a       | 42.7±2.1a     | 30.4±1.4a |
| 60 cm   | 18.2±1.9a      | 31.6±2.6ab      | 40.8±1.7a     | 29.2±1.1a |

Means ± SD (n=3). Different letters within a column = significant ( $p \leq 0.05$ , LSD)

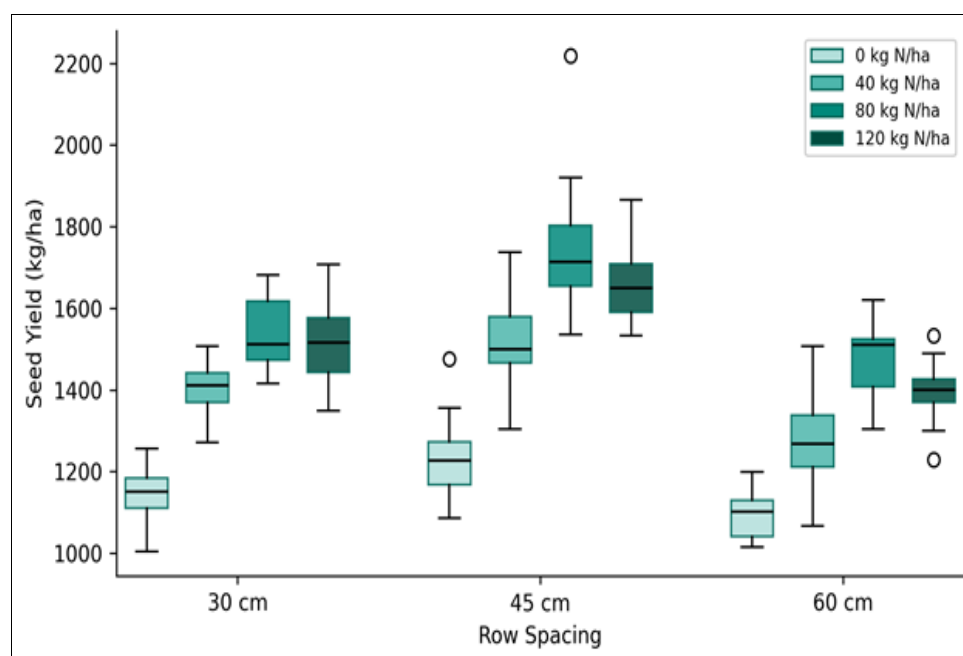


**Fig 1:** Distribution of safflower seed yield across row spacings and nitrogen rates. Colors represent N levels: lightest = 0 kg N/ha, darkest = 120 kg N/ha

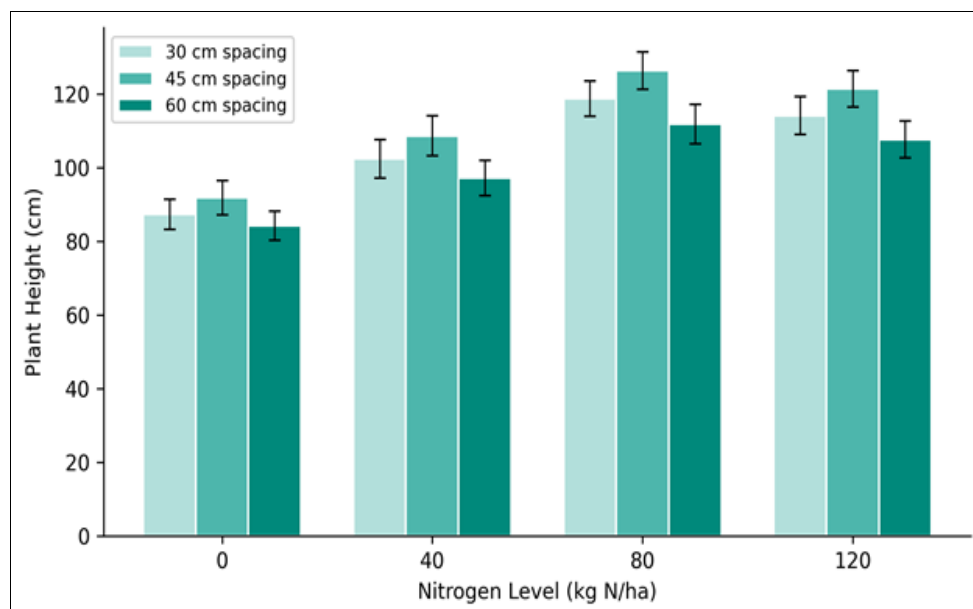


Fig 2: Plant height of safflower as influenced by row spacing and nitrogen rate. Error bars = SD

### Comprehensive interpretation

The spacing  $\times$  nitrogen interaction was significant ( $p < 0.01$ ) for seed yield and capitula per plant. The 45 cm  $\times$  80 kg N combination produced 1,724 kg/ha, 50.9% above the unfertilized 30 cm control (Table 1, Figure 1). Increasing N from 0 to 80 kg/ha raised yield by 36.8–39.7% across all spacings, but the jump from 80 to 120 kg N added only 4.4–5.2%, indicating diminishing returns. The 45 cm spacing produced the most capitula (16.8/plant) and seeds per capitulum (33.4), while 60 cm gave more capitula (18.2) but lower total yield due to fewer plants per unit area (Table 2). Plant height peaked at 45 cm  $\times$  80 kg N (126.3 cm; Figure 2). Oil content was statistically uniform across treatments (28.1–31.4%).

### Discussion

The superiority of 45 cm row spacing reflects an optimal compromise between individual plant vigor and population density under residual moisture. At 30 cm, inter-row root competition likely intensified water stress during the critical reproductive period (February–March), when soil moisture dropped below 12% [10]. The 60 cm spacing reduced this competition but couldn't compensate through branching alone because residual moisture limited the total biomass each plant could support [13]. Elfadl et al. [5] reached a similar conclusion under German conditions, though their optimal spacing (also 45 cm) was driven by light interception rather than moisture dynamics.

The N response plateau at 80 kg/ha is consistent with the water-limited N uptake model described by Koutroubas et al. [8]. Under residual moisture, root-zone water declines progressively, reducing mass flow of nitrate to roots. Beyond 80 kg N, the additional fertilizer likely remained in the upper soil layers as moisture retreated deeper, explaining the minimal yield gain from 80 to 120 kg N [6]. The stable oil content across treatments agrees with Gecgel et al. [12], who found oil percentage in safflower to be primarily cultivar-dependent.

### Conclusion

Row spacing of 45 cm with 80 kg N/ha maximized safflower seed yield (1,724 kg/ha) under residual moisture in Riyadh. This combination balanced inter-plant competition, capitula production, and nitrogen use efficiency within the constraints of

declining soil moisture. Applying more than 80 kg N/ha provided negligible yield benefit and is not economically justified under these conditions. Oil content was unaffected by spacing or nitrogen treatments. Safflower growers in arid regions relying on residual moisture should adopt 45 cm row spacing with moderate N fertilization as a baseline practice.

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