



The Effect of Phosphorus Levels on Growth and Yield Components in Sunflower (*Helianthus annuus* L.)

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ABSTRACT

Background: Sunflower is a major oilseed crop globally, ranking second after soybean in terms of oil production. Sunflower seeds are important because they contain a high percentage of oil-over 50% in some improved cultivars-along with high palatability and nutritional value.

Methods: A field trial was conducted to evaluate the performance of three promising sunflower cultivars (Jude, Taqa1 and Taqa2) under three levels of phosphate fertilization (0, 100 and 150 kg P₂O₅ ha⁻¹). A split-plot design in a randomized complete block design (RCBD) with three replicates was used. Main plots included phosphate fertilization levels, while subplots contained three sunflower cultivars.

Result: Phosphate fertilization at 150 kg P₂O₅ ha⁻¹ significantly improved sunflower seed yield (2916.7 kg ha⁻¹) and oil yield (760.0 kg ha⁻¹), highlighting the role of phosphorus in enhancing productivity and oil formation. The Jude cultivar had the highest values for seed yield (3521.1 kg ha⁻¹), demonstrating its genetic competence in increasing seed productivity. Taqa1 and Taqa2 cultivars outperformed in terms of oil yield (799.99 and 738.95 kg ha⁻¹, respectively) and the lowest percentage of empty seeds. The interaction effect showed that the Taqa2 cultivar with 150 kg P₂O₅ ha⁻¹ had the highest oil yield (844.17 kg ha⁻¹). It can be suggested to sow Taqa1 and Taqa2 cultivars with the addition of 150 kg P₂O₅ ha⁻¹ to achieve the highest sunflower oil production in the experiment site.

Key words: Oil yield, Phosphatic fertilizer, Seed, Sunflower cultivars.

INTRODUCTION

Sunflower (*Helianthus annuus* L.) is considered one of the most important oilseed crops; seeds contain a high percentage of oil, exceeding 50% in some improved cultivars and the oil is highly palatable and nutritionally rich (Soomro *et al.*, 2023). This significance has increased recently due to a global shortage in oil production, especially since sunflower oil is widely used in human nutrition and enters into various industrial products (Al-Juheishy, 2025). Sunflower oil is the best dietary oil because of its richness in omega-3 fatty acids, as well as unsaturated fatty acids such as linoleic, oleic and palmitic acid.

Genetic differences play a significant role in enhancing the yield of various crops (Raheem *et al.*, 2023; Taha *et al.*, 2025). Therefore, selecting high-yielding genotypes is an essential factor that must be taken into consideration. In recent years, research centres focusing on evaluating imported genotypes from different origins have increased. This has resulted in valuable insights into the growth characteristics of these genotypes, with the intention to apply them on a wider field scale. Moreover, genotypes differ in their response to environmental conditions based on their genetic potential to convert assimilated nutrients from the source to the sink. Hence, selecting a high-yielding genotype represents a key approach, alongside proper soil and crop management, to achieving optimal production (Al-Mafarji *et al.*, 2024 and Sharif *et al.*, 2024a).

Phosphorus is an essential nutrient for sunflower plants, supporting several vital physiological processes. It plays a pivotal role in the nucleic acids (DNA and RNA) synthesis,

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in energy production through the formation of adenosine triphosphate (ATP) and in enhancing enzyme activity within plant cells (Maaruf and Raheem, 2024). Phosphorus deficiency in the soil leads to stunted growth, poor root development and reduced flowering and fruiting rates, negatively impacting final seed productivity (Al-Doori, 2023). This study aims to identify the most efficient varieties for absorbing and utilizing phosphorus, which will contribute to improving sunflower productivity and also evaluate the impact of interaction between genetic factors of cultivars and phosphate fertilization on plant growth and productive performance, thus providing a reliable scientific basis for developing the sunflower crop in the study site milieu.

MATERIALS AND METHODS

This trial was conducted in a farmer's field in the Hawija district of Kirkuk Governorate, Iraq, located at 43.87°E longitude and 35.38°N latitude, 190 m above sea level, during the fall growing season of 2024 under the irrigation water supply. The physical and chemical properties of soil samples were analysed at a depth of 30 cm before the experiment began. The results are offered in Table 1.

The trial was laid out in a split-plot design using a randomized complete block design (RCBD) with three replications. Main plots included three levels of phosphate fertilizer (0, 100 and 150 kg P₂O₅ ha⁻¹), while subplots contained three promising sunflower cultivars (Jude, Taqa1 and Taqa2). The land was ploughed twice-vertically and horizontally-using a disc plough, then levelled (Ashraa Kalee and Raheem, 2024) and phosphate fertilizer was applied once before planting. Planting was done on 3 July 2024 at a spacing of 0.75 m × 0.25 m. Each sub-plot measured 2 m in length and 3 m in width and contained four rows. Each subplot had an area of 6 m². A 1.5 m distance was separated between blocks and between subplots. Urea fertilizer was applied at a rate of 260 kg ha⁻¹ (46% N) (Sharif *et al.*, 2024b; AlShamary *et al.*, 2025).

The studied traits included vegetative parameters such as period to 75% flowering, plant height (cm), number of leaves per plant height (cm), number of leaves per plant, Leaf area index (LAI) was calculated by dividing the leaf area per plant (cm²) by the land area occupied by the plant (cm²) and stem diameter (mm). Production traits included the number of seeds per disc (seed disc⁻¹), empty seed percentage, which was calculated by dividing No. of empty seeds by the total No. of seeds disc⁻¹ and then multiplied by 100, the weight of 1000 seeds (g) and the total seed yield (kg ha⁻¹) was estimated by weighing the seed yield from each subplot and then converting it to kg ha⁻¹. Oil yield (kg ha⁻¹) was estimated using a Soxhlet apparatus in the laboratories of the College of Medicinal and Industrial Plants, University of Kirkuk. The oil percentage of seeds was multiplied by the seed yield and divided by 100 to obtain the oil yield for each sub-experimental unit. Analysis of variance (ANOVA) for the collected data was done by statistical analysis software SAS 9.0 to determine significant differences among treatments. Treatment means were compared using Duncan's multiple range test at P≤0.05.

RESULTS AND DISCUSSION

Period to 75% flowering (days)

The findings in Table 2 show that increasing phosphorus levels led to an acceleration of flowering, reducing the

period to 75% flowering. The value decreased from 62.97 days when no fertilizer was added to 51.40 days when 150 kg P₂O₅ ha⁻¹ was added, with a percentage of 18.4%. This significant difference indicates that phosphorus has a substantial effect on stimulating early flowering. The Taqa1 and Taqa2 cultivars significantly outperformed in reducing the period to 75% flowering (55.82 and 55.07 days, respectively) compared with the Jude cultivar (59.05 days). This suggests that the Jude cultivar has relatively late-flowering characteristics compared to the other cultivars, which could be useful in regions with high temperatures or in hybridization programs targeting late-flowering characteristics. The interactions between phosphorus fertilizer and cultivars showed that the period to 75% flowering was shorter in the Taqa2 cultivar at 150 kg P₂O₅ ha⁻¹ (49.30 days), while the Jude cultivar at 0 kg P₂O₅ ha⁻¹ took more days to reach 75% flowering (65.16 days). This result indicates a significant interaction between phosphorus fertilizer and the genetic makeup of the cultivar that affected flowering timing. These outcomes are in agreement with (Chillab and ALKhanasa, 2016 and Singh *et al.*, 2017) outcomes.

Plant height (cm)

Table 3 results indicate that an increase in the phosphorus level to 150 kg P₂O₅ ha⁻¹ resulted in the Jude cultivar recording the highest plant height (151.23 cm), followed by the 100 kg P₂O₅ ha⁻¹ (144.95 cm), while the no fertilized treatment registered the lowest average in plant height (117.51 cm). This indicates the positive effect of phosphate fertilization on plant growth due to its role in enhancing the plant's biological processes, particularly cell division and elongation. The highest plant height was significantly obtained by the Jude cultivar (155.66 cm), while the lowest plant height was obtained by Taqa1 (124.19 cm). In terms of interaction, the Jude cultivar recorded the highest plant height, 167.73 and 167.52 cm at 150 and 100 kg P₂O₅ ha⁻¹, respectively, indicating its distinct genetic traits that interact well with phosphate fertilization. In comparison, the Taqa2 cultivar recorded the lowest plant height with a mean of 108.48 cm at the control treatment. These results are consistent with (Kumar *et al.*, 2016; Hammad *et al.*, 2021; Raheem *et al.*, 2024).

Number of leaves plant⁻¹

Table 4 shows that phosphorus fertilizer had a significant effect on the number of leaves per plant, where 150 kg P₂O₅ ha⁻¹ achieved the highest average of 26.56 leaves plant⁻¹, whereas 0 kg P₂O₅ ha⁻¹ had the lowest average with 22.28 leaves plant⁻¹. The Jude cultivar significantly outperformed the other cultivars (Table 4) and recorded the maximum

Table 1: Chemical and physical traits of the experiment soil site.

	pH	EC	Available nitrogen	Available phosphorus	Available potassium	O.M.	Soil texture
Values	7.51	0.91	6.13	1.98	89.31	0.98	Sandy loam
Measuring unit	-	DS M ²	Mg kg ⁻¹	Mg kg ⁻¹	Mg kg ⁻¹	%	-

average of 28.18 leaves plant⁻¹, whereas the Taqa1 cultivar recorded the least average of 22.64 leaves plant⁻¹. The interaction effect indicated that the interaction of 150 kg P₂O₅ ha⁻¹ × Jude cultivar gave the highest number of plant leaves, which was 31.20 leaves plant⁻¹, superior to all other interactions, while the interaction 0 kg P₂O₅ ha⁻¹ × Taqa1 resulted in the least number of plant leaves, 20.26 leaves plant⁻¹. This indicates that the Jude cultivar showed genetic stability and a clear response to phosphate fertilization, making it the most distinguished in terms of vegetative growth, while the response of the Taqa1 and Taqa2 varieties was relatively limited despite the slight improvement at the levels of 100 and 150 kg P₂O₅ ha⁻¹. The similar results are obtained by Manzoor *et al.*, 2024a and Khoso *et al.*, 2024.

Leaf area index

The results in Table 5 show that the two levels of 100 and 150 kg P₂O₅ ha⁻¹ gave the highest values (0.50 and 0.52, respectively) in plant leaf area index and outperformed the level of 0 kg P₂O₅ ha⁻¹ (0.48). The Jude cultivar significantly outperformed the other cultivars, as its average plant leaf area index reached 0.79, while no significant differences were found between the Taqa1 and Taqa2 cultivars, which recorded the lowest average (0.36 for each). In terms of the interaction effect, it was noted that the highest value of plant leaf area index was recorded by the Jude cultivar at the level of 150 kg P₂O₅ ha⁻¹ (0.82), while the lowest value of interaction was by the Taqa2 cultivar under the no fertilizer added treatment (0.33). These results highlight the Jude cultivar's superiority in increasing leaf area, with the positive role of phosphate fertilization in increasing it, which positively impacts the plant's photosynthetic capacity and enhances plant growth. These results are harmonious with (Ramadhan *et al.*, 2020; Asif *et al.*, 2023; Khan *et al.*, 2023 and Abdullah *et al.*, 2024) results.

Stem diameter (mm)

The data in Table 6 prove that stem diameter was not significantly affected by phosphorus fertilizer levels. However, significant differences in stem diameter were observed among the studied cultivars, with the Jude cultivar significantly outperforming Taqa1 and Taqa2 cultivars, with an average stem diameter of 8.92 mm, compared with 5.57 mm and 4.99 mm for the other two cultivars, respectively. In considering the interaction effect, it is noted that the highest stem diameter value was recorded when 150 kg P₂O₅ ha⁻¹ interacted with the Jude cultivar (9.33 mm), while the lowest values were in the interactions of no-fertilizer treatment with the Taqa1 and Taqa2 cultivars (4.35 and 4.67 mm, respectively). These results reflect the genetic variation among cultivars in cellular expansion capacity and tissue growth, as well as the relatively limited role of phosphorus in influencing this trait. These results are compatible with the Abody *et al.* (2021) results.

Number of seeds disc⁻¹

The findings in Table 7 show that phosphorus fertilizer levels did not significantly affect the number of seeds per

Table 2: Phosphorus fertilizer and cultivars effect on period to 75% flowering (days).

Cultivars	P ₂ O ₅ (kg ha ⁻¹)			Mean
	0	100	150	
Jude	65.16 ^a	58.23 ^c	53.76 ^d	59.05 ^a
Taqa1	62.43 ^b	53.90 ^d	51.13 ^e	55.82 ^b
Taqa2	61.33 ^b	54.60 ^d	49.30 ^f	55.07 ^b
Mean	62.97 ^a	55.57 ^b	51.40 ^c	

Table 3: Phosphorus fertilizer and cultivars effect on plant height (cm).

Cultivars	P ₂ O ₅ (kg ha ⁻¹)			Mean
	0	100	150	
Jude	131.73 ^{cd}	167.52 ^a	167.73 ^a	155.66 ^a
Taqa1	112.34 ^e	128.4 ^d	131.82 ^{cd}	124.19 ^c
Taqa2	108.48 ^e	138.93 ^c	154.14 ^b	133.85 ^b
Mean	117.51 ^b	144.95 ^a	151.23 ^a	

Table 4: Phosphorus fertilizer and cultivars effect on number of leaves plant⁻¹.

Cultivars	P ₂ O ₅ (kg ha ⁻¹)			Mean
	0	100	150	
Jude	24.80 ^c	28.56 ^b	31.20 ^a	28.18 ^a
Taqa1	20.26 ^f	23.56 ^d	24.10 ^{cd}	22.64 ^c
Taqa2	21.80 ^e	23.56 ^d	24.40 ^{cd}	23.25 ^b
Mean	22.28 ^c	25.23 ^b	26.56 ^a	

Table 5: Phosphorus fertilizer and cultivars effect on leaf area index.

Cultivars	P ₂ O ₅ (kg ha ⁻¹)			Mean
	0	100	150	
Jude	0.77 ^b	0.78 ^b	0.82 ^a	0.79 ^a
Taqa1	0.34 ^d	0.38 ^c	0.36 ^{cd}	0.36 ^b
Taqa2	0.33 ^d	0.36 ^{cd}	0.38 ^c	0.36 ^b
Mean	0.48 ^b	0.50 ^a	0.52 ^a	

Table 6: Phosphorus fertilizer and cultivars effect on stem diameter (mm).

Cultivars	P ₂ O ₅ (kg ha ⁻¹)			Mean
	0	100	150	
Jude	8.67 ^a	8.75 ^a	9.33 ^a	8.92 ^a
Taqa1	4.35 ^c	5.07 ^{bc}	5.56 ^b	4.99 ^b
Taqa2	4.67 ^c	4.41 ^c	4.63 ^c	5.57 ^b
Mean	5.90 ^a	6.08 ^a	6.51 ^a	

disc, while there a significant differences among the cultivars, where the Jude cultivar significantly outperformed Taqa1 and Taqa2 cultivars, as the average number of seeds reached 540.92 seeds disc⁻¹, in contrast, the other two cultivars recorded fewer number of seeds disc⁻¹ 441.76 and 489.45, respectively. As for the interactions, the interaction of 150 kg P₂O₅ ha⁻¹ with the Jude cultivar significantly recorded more seeds disc⁻¹, reaching 638.65, fewer seeds disc⁻¹ were recorded by the interaction of 150 kg P₂O₅ ha⁻¹

with Taqa1, reaching 446.24 seeds. These results reflect the genetic competence of the Jude cultivar in producing fertile flowers and its ability to utilize phosphate fertilizers more effectively, resulting in increased seed yield, consistent with findings of Singh *et al.* (2017), Hammad *et al.* (2021) and Khoso *et al.* (2024).

Percentage of empty seeds disc⁻¹

Table 8 shows that the percentage of empty seeds disc⁻¹ was not significantly affected by the studied phosphorus fertilizer levels. The significant variations found in empty seeds percentage among the cultivars, the Taqa1 and Taqa2 cultivars recording the highest empty seed disc⁻¹ percentages of 10.74% and 10.37%, respectively, while in the Jude cultivar, the percentage of empty seeds disc⁻¹ decreased significantly to 7.53%. Regarding the interactions, the interaction of 150 kg P₂O₅ ha⁻¹ with the Taqa1 cultivar records the highest percentage of empty seeds disc⁻¹ (11.78%), while 150 kg P₂O₅ ha⁻¹ with the Jude cultivar records the lowest percentage of empty seeds disc⁻¹ (5.44%). The low percentage of empty seeds disc⁻¹ in the Jude cultivar in high-level application of phosphorus fertilizer may be attributed to its efficiency in flower pollination and more ovum fertility, which reduces the formation of empty seeds; other cultivars may suffer from weak efficiency under certain environmental or nutritional conditions. These outcomes are consistent with those of (Abody *et al.*, 2021; Khan *et al.*, 2023 and Manzoor *et al.*, 2024b).

Weight of 1000 seeds (g)

Table 9 results about sunflower 1000 seed weight confirm a clear significant variation among phosphorus levels. The no phosphorus addition treatment achieved the highest 1000 seed weight of 96.40 g, compared with 100 kg P₂O₅ ha⁻¹, which recorded the lowest 1000 seed weight of 55.42 g. The Jude cultivar was significantly superior, recording the highest 1000-seed weight average of 93.16 g, while the Taqa1 cultivar had the lowest 1000-seed weight with 61.84 g. The interaction effect confirms that the Jude cultivar was significantly superior at the 0 kg. P₂O₅ ha⁻¹ and recorded the highest 1000 seed weight, amounting to 132.29 g, while the lowest value was when Taqa1 interacted with 100 kg P₂O₅ ha⁻¹ (49.89 g). This variation reflects genetic differences in nutrient efficiency absorption by cultivars and may also be related to structural or physiological characteristics related to seed formation in each cultivar. These results are consistent with (Chillab and ALKhanasa, 2016; Kumar *et al.*, 2016; AL-Azee *et al.*, 2023; Hilli and Immadi, 2025).

Seed yield (kg ha⁻¹)

Table 10 findings demonstrate significant differences in the seed yield among the phosphorus fertilizer levels, as the 150 kg. P₂O₅ ha⁻¹ gave the highest seed yield (2916.7 kg ha⁻¹) compared with 100 kg (2634.4 kg ha⁻¹) and 0 kg P₂O₅ ha⁻¹ (2592.2 kg ha⁻¹), indicating an improvement in the

Table 7: Phosphorus fertilizer and cultivars effect on number of seeds disc⁻¹.

Cultivars	P ₂ O ₅ (kg ha ⁻¹)			Mean
	0	100	150	
Jude	438.15 ^b	545.97 ^{ab}	638.65 ^a	540.92 ^a
Taka1	429.11 ^b	449.94 ^b	446.24 ^b	441.76 ^b
Taka2	424.54 ^b	545.64 ^{ab}	498.17 ^{ab}	489.45 ^b
Mean	430.60 ^a	513.85 ^a	527.68 ^a	

Table 8: Phosphorus fertilizer and cultivars effect on empty seeds (%).

Cultivars	P ₂ O ₅ (kg ha ⁻¹)			Mean
	0	100	150	
Jude	9.66 ^b	7.50 ^c	5.44 ^d	7.53 ^b
Taqa1	10.40 ^{ab}	10.03 ^{ab}	11.78 ^a	10.74 ^a
Taqa2	10.69 ^{ab}	10.08 ^{ab}	10.35 ^{ab}	10.37 ^a
Mean	10.25 ^a	9.20 ^a	9.19 ^a	

Table 9: Phosphorus fertilizer and cultivars effect on weight of 1000 seeds (g).

Cultivars	P ₂ O ₅ (kg ha ⁻¹)			Mean
	0	100	150	
Jude	132.29 ^a	58.62 ^{de}	88.58 ^{bc}	93.16 ^a
Taqa1	59.01 ^{de}	49.89 ^e	76.63 ^{cd}	61.84 ^c
Taqa2	97.91 ^b	57.75 ^{de}	77.72 ^{cd}	77.79 ^b
Mean	96.40 ^a	55.42 ^c	80.98 ^b	

Table 10: Phosphorus fertilizer and cultivars effect on seed yield (kg ha⁻¹).

Cultivars	P ₂ O ₅ (kg ha ⁻¹)			Mean
	0	100	150	
Jude	3133.3 ^a	3403.3 ^a	3846.7 ^a	3521.1 ^a
Taqa1	2356.7 ^b	2343.3 ^b	2353.3 ^b	2351.1 ^b
Taqa2	2106.7 ^b	2156.7 ^b	2550.0 ^b	2271.1 ^b
Mean	2592.2 ^b	2634.4 ^b	2916.7 ^a	

Table 11: Phosphorus fertilizer and cultivars effect on oil yield (kg ha⁻¹).

Cultivars	P ₂ O ₅ (kg ha ⁻¹)			Mean
	0	100	150	
Jude	501.42 ^c	503.12 ^c	599.82 ^{bc}	534.79 ^b
Taqa1	775.22 ^{ab}	787.98 ^a	836.78 ^a	799.99 ^a
Taqa2	671.15 ^{abc}	701.53 ^{ab}	844.17 ^a	738.95 ^a
Mean	649.26 ^b	664.21 ^{ab}	760.25 ^a	

seed yield with increasing phosphorus rates through a boost in seed yield components. The Jude cultivar was significantly superior to the other two cultivars, recording the uppermost average seed yield of 3521.1 kg ha⁻¹, while the Taqa1 and Taqa2 cultivars declined, recording the lowest averages of 2351.1 and 2271.1 kg ha⁻¹, respectively. In terms of interactions, the interaction between 150 kg P₂O₅

ha⁻¹ and the Jude cultivar was distinguished, which recorded the uppermost seed yield of 3846.7 kg ha⁻¹, while the lowest seed yield was recorded when 0 kg P₂O₅ ha⁻¹ interacted with Taqa2, which amounted to 2106.7 kg ha⁻¹. These results indicate that the high performance of the Jude cultivar is due to its genetic efficiency in responding to phosphate fertilization compared with the other two cultivars, which enhances the possibility of growing it in similar environments to achieve high productivity. These consequences are consistent with the results of (Khoso *et al.*, 2024; Manzoor *et al.*, 2024a; Manzoor *et al.*, 2024b; Aziz and Ali, 2024).

Oil yield (kg ha⁻¹)

The results of Table 11 reveals that the increase in phosphorus fertilizer levels significantly affected the sunflower oil yield, since the 150 kg rate showed the maximum oil yield of 760.25 kg ha⁻¹, followed with the 100 kg rate (664.21 kg ha⁻¹), while the 0 kg P₂O₅ ha⁻¹ showed the lowest oil yield (649.26 kg ha⁻¹). The Taqa1 and Taqa2 cultivars produced significantly higher oil yield, since they recorded the highest average of 799.99 and 738.95 kg ha⁻¹, respectively, than the Jude cultivar, which recorded the lowest average of 534.79 kg ha⁻¹, due to the low oil content of its seeds. For interactions, the 150 kg P₂O₅ ha⁻¹ with the Taqa2 cultivar interaction recorded the highest oil yield (844.17 kg ha⁻¹), which did not differ considerably from interaction of the same phosphorus fertilizer level with the Taqa1 cultivar (836.78 kg ha⁻¹) and the lowest oil yield was recorded by interaction of 0 kg P₂O₅ ha⁻¹ with the Jude cultivar (501.42 kg ha⁻¹). These results indicate that the Taqa1 and Taqa2 cultivars were genetically effective in yielding oil from stored material in the seed when phosphorus levels increased. The results concur with (Rasoulzadeh *et al.*, 2020; Al-Doori, 2023; Manzoor *et al.*, 2024b).

CONCLUSION

This study concludes that both phosphorus fertilizer and cultivar significantly influenced most of the studied sunflower traits. The 150 kg P₂O₅ ha⁻¹ phosphorus level resulted in the highest values for most traits studied, indicating that increased phosphorus levels contribute to enhanced sunflower growth, seed and oil yield. The Jude cultivar significantly outperformed the others in seed number per disc, 1000-seed weight, seed yield and oil yield and oil yield, indicating its high genetic efficiency in improving these production traits. The interaction of 150 kg P₂O₅ ha⁻¹ × Jude cultivar was the best for seed yield and 150 kg P₂O₅ ha⁻¹ × Taqa1 and Taqa2 for oil yield, highlighting the importance of this genotype-fertilizer interaction in improving sunflower productivity under similar environmental conditions. Based on these findings, it is recommended to grow the Jude cultivar with 150 kg P₂O₅ ha⁻¹ fertilizer to achieve the highest seed and oil yields.

Conflict of interest

I declare on behalf of all co-authors in the research work for manuscript that they have no conflicts of interest.

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