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CHEMICAL FERTILIZERS AND THEIR IMPACT ON SUNFLOWER GROWTH, YIELD AND OIL QUALITY

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Abstract. *Sunflower (Helianthus annuus L.) is a major global oilseed crop, valued for its high-quality edible oil and adaptability to diverse pedoclimatic conditions. Among agronomic inputs, chemical fertilization remains a key driver of biomass accumulation, yield formation, and oil composition, yet its benefits depend strongly on balanced nutrient supply and site-specific management. This review synthesizes current evidence on how mineral fertilizers—primarily nitrogen (N), phosphorus (P), potassium (K), and selected micronutrients (especially boron)—influence sunflower growth, yield components, and oil quality traits. The literature indicates that N is closely linked to vegetative growth and protein synthesis and can modify oil concentration and fatty acid composition; however, excessive N may shift assimilate allocation and influence the oil–protein trade-off. Phosphorus supports early root development and reproductive performance, while responses to P are strongly conditioned by soil P availability and crop demand. Potassium contributes to osmotic regulation and stress tolerance, particularly under drought, and has been associated with improvements in seed quality traits and fatty acid profiles. Boron is frequently identified as critical for reproductive development and seed set in B-deficient environments. Overall, integrated NPK management—guided by soil testing, nutrient interactions, and crop phenology—offers the best pathway to improve yield and maintain desirable oil quality while reducing environmental losses. Future research should emphasize nutrient use efficiency, fertilizer placement strategies, and the alignment of fertilization regimes with genotypic differences and climate-driven stress patterns.*

Keywords*: sunflower; chemical fertilization; nitrogen; phosphorus; potassium; micronutrients; boron; oil quality; fatty acids; nutrient use efficiency*

INTRODUCTION

Sunflower is cultivated worldwide as an oilseed crop whose economic value derives from both seed yield and oil quality. Achieving stable productivity under variable climate conditions (e.g., drought or heat episodes) requires agronomic strategies that support both growth and reproductive development. Plant nutrition is central to these processes because nutrient availability shapes canopy development, photosynthetic capacity, assimilate partitioning, and ultimately the formation of seed number and seed weight—key determinants of yield in sunflower.

Chemical fertilization (mineral fertilization) remains widely used due to its predictable nutrient supply and the possibility of tailoring nutrient rates and timing to crop demand. However, sunflower responses to fertilizers vary across environments, soil fertility status, cultivar type (e.g., high-oleic vs. linoleic types), and the interaction between nutrients and water availability. Therefore, a review focused on the links between chemical fertilization and (i) growth, (ii) yield and yield components, and (iii) oil concentration and fatty acid profile is relevant for both agronomic optimization and quality assurance in sunflower production systems.

The objective of this review is to synthesize evidence regarding the role of N, P, K and selected micronutrients in sunflower nutrition and to discuss their effects on plant growth,

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yield formation, and oil quality. The paper also highlights nutrient interactions and environmental considerations that influence fertilizer efficiency.

MATERIAL AND METHODS

1. Literature search strategy

This review is based on a critical analysis of scientific literature addressing the role of chemical fertilization in sunflower (*Helianthus annuus L.*) cultivation. The selected sources include peer-reviewed research articles, review papers, and authoritative book chapters that examine the effects of mineral nutrient supply on sunflower growth, yield formation, and oil quality parameters. Priority was given to studies that provide physiological, agronomic, and biochemical interpretations of nutrient responses under different pedoclimatic conditions.

The literature considered in this review covers a broad temporal range in order to capture both foundational knowledge and recent advances in sunflower nutrition and fertilizer management. Studies focusing on macronutrients (nitrogen, phosphorus, and potassium) as well as key micronutrients, particularly boron, were included to ensure a comprehensive perspective on nutrient interactions and their implications for crop performance and oil quality. This approach allows for an integrated synthesis of current knowledge and supports the discussion of fertilization strategies relevant to modern sunflower production systems.

2. Inclusion and exclusion criteria

Included studies met at least one of the following criteria: (i) field or controlled environment experiments evaluating mineral fertilizer effects on sunflower growth/yield/oil traits; (ii) analyses of nutrient use efficiency or nutrient–quality relationships; (iii) meta-analyses or reviews relevant to sunflower fertilization. Studies focused exclusively on organic amendments without mineral fertilizer context were excluded. Articles providing fertilizer placement/management insights with physiological interpretation were retained.

3. Evidence synthesis

The evidence was summarized qualitatively by nutrient category (N, P, K, micronutrients) and by outcome domain (growth, yield components, oil quality). Emphasis was placed on consistent patterns across studies and on factors explaining variability (soil fertility, water availability, cultivar differences, and nutrient interactions).l

RESULTS AND DISCUSSIONS

1 Nitrogen fertilization: effects on growth and yield formation

Nitrogen is a primary driver of vegetative growth due to its central role in amino acids, proteins, chlorophyll, and enzymes supporting photosynthesis. In sunflower, adequate N supply tends to increase leaf area development and biomass accumulation, which can improve radiation interception and the source capacity for seed filling.

However, N effects are frequently non-linear and context dependent. Excessive N may promote overly vegetative growth, delay maturation, or shift assimilate allocation in ways that do not proportionally increase seed yield. This is especially relevant in environments where water becomes limiting during reproductive stages, because larger canopies can exacerbate water demand. In addition, sunflower yield is strongly influenced by the balance between seed number (related to successful flowering and fertilization) and individual seed weight, and N impacts both via canopy development and reproductive physiology.

Evidence also indicates that N fertilization can alter seed composition. Ali & Ullah (2012) discuss how N availability is linked to changes in oil traits and unsaturated fatty acids (notably oleic and linoleic acids), emphasizing that fertilization strategies should consider both yield and quality objectives.

Li et al. (2017) further demonstrate that N fertilizer application significantly affects protein content and fatty acid composition in sunflower seed oil, reinforcing the concept that N management is not only a yield lever but also a quality lever.

Additionally, Abd El-Satar et al. (2017) report that increasing N levels can positively influence yield and “desirable acid composition” under certain conditions, though the magnitude depends on genotype and agronomic context.

In practical terms, N should be discussed as a nutrient that (i) improves source strength (photosynthetic machinery and canopy), (ii) may influence sink development (seed number/weight), and (iii) can modify the oil–protein balance and fatty acid profile, making optimized N rate and timing central to integrated yield and quality management.

2 Phosphorus fertilization: early growth, reproductive development and P use efficiency

Phosphorus is essential for energy transfer (ATP), nucleic acids, membrane phospholipids, and root development. In many cropping systems, P fertilization is primarily aimed at ensuring strong early establishment and supporting reproductive growth. In sunflower, P demand extends into seed filling due to the need for continued assimilate transport and seed development processes.

Sunflower response to P is strongly conditioned by soil P status. Schultz et al. (2018), analyzing N and P responses in sunflower across multiple sites, highlight that P fertilization may have limited yield effects where soil test P is already sufficient, which underscores the importance of soil testing and site-specific fertilization rather than blanket P applications.

In contrast, in P-limited conditions, P fertilization can accelerate growth and improve yield potential, as summarized in “Efficiency of Phosphorus Use in Sunflower” (de Oliveira et al., 2022), which focuses on P use efficiency concepts and how cultivar and management may influence the utilization of available and applied P.

Mechanistically, P availability supports root exploration and nutrient uptake capacity, potentially improving the plant’s resilience to transient stresses and enabling better nutrient–water acquisition during critical growth windows. A key point for discussion is that P interactions with N can influence N uptake and utilization: Steiner et al. (2002) specifically examined P × N effects on N uptake, yield, and N use efficiency in sunflower, supporting the broader concept that balanced fertilization improves overall nutrient efficiency.

3 Potassium fertilization: drought tolerance, yield stability and seed quality

Potassium plays key roles in osmotic regulation, stomatal control, enzyme activation, and carbohydrate transport. As a result, K is frequently associated with improved stress tolerance and more stable yield under water-limited conditions.

Dar et al. (2021) explicitly show that potassium fertilization can mitigate drought stress effects in sunflower and improve growth, yield, and seed quality traits under drought at different growth stages.

This aligns with the broader concept that adequate K helps maintain plant water relations and supports physiological processes that protect yield formation under stress.

Moreover, K fertilization is not only a "yield" input but is also linked to quality traits. Li et al. (2018) report that K fertilization increased achene yield and improved quality indicators; importantly, they also observed improvements in oil and fatty acid components (including oleic and linoleic acids) under certain conditions, which positions K as relevant to oil quality objectives.

4 Micronutrients: reproductive success and yield

Among micronutrients, boron (B) is frequently highlighted for sunflower due to its importance in cell wall structure, carbohydrate transport, and reproductive development. B deficiency is strongly associated with poor reproductive performance and seed set problems in sensitive crops.

Asad et al. (2003) demonstrated that foliar B application benefited B-deficient sunflower plants, improving vegetative and reproductive growth, and increasing the B status of plant tissues, supporting the agronomic relevance of correcting B deficiency for successful yield formation.

In the context of chemical fertilization, micronutrient strategies are often implemented as soil-applied or foliar mineral formulations. While the current review emphasizes NPK, the inclusion of B is important because yield losses due to reproductive limitations may not be fully compensated by macronutrients alone. Therefore, balanced nutrition requires integrating micronutrient diagnosis (soil and tissue testing) and targeted correction where deficiencies are likely.

5 Combined NPK fertilization and nutrient interactions

Because nutrients function in interconnected metabolic pathways, sunflower performance typically responds best to balanced NPK management rather than single-nutrient approaches. A recent meta-analysis (Li et al., 2025) reports overall yield increases with fertilizer application and indicates that combined fertilizers (e.g., NPK) can enhance yield more than single nutrient applications, reflecting synergy and the correction of multiple constraints simultaneously.

At a mechanistic level, P availability can influence root growth and N uptake capacity; K contributes to physiological regulation and transport processes, potentially improving the effectiveness of both N and P. Steiner et al. (2002) provide direct evidence of P × N interactions affecting N uptake and N use efficiency in sunflower, reinforcing that nutrient interactions can influence both yield and fertilizer efficiency outcomes.

Practical framing for the paper: include a short discussion on how soil tests (N supply via mineralization and nitrate status; available P; exchangeable K), combined with climate expectations (drought risk) and cultivar characteristics, should drive fertilizer decisions. The review can also mention placement and depth strategies as part of "chemical fertilizer management," because placement affects nutrient availability and root access. For example, Ren et al. (2024) analyzed fertilization depth and N dynamics, illustrating that management beyond "rate" (i.e., placement) can influence N uptake and yield formation.

6 Chemical fertilization and oil quality: oil concentration and fatty acid profile

Oil quality in sunflower is commonly evaluated through oil concentration (%) and fatty acid composition—especially oleic (C18:1) and linoleic (C18:2) acids—which influence nutritional properties and oxidative stability. Nutrient management can affect these traits through changes in plant metabolism, assimilate partitioning, and seed filling dynamics.

Li et al. (2017) provide direct evidence that N fertilization affects fatty acid composition (including oleic and linoleic acids) and protein content in sunflower, highlighting the nutrient–quality link.

Ali & Ullah (2012) also emphasize that N plays a role in producing unsaturated fatty acids, which are central to oil quality, while noting that fertilization decisions should prioritize yield determinants alongside composition goals.

On the K side, Li et al. (2018) report improvements in oil and fatty acid traits with K fertilization in certain contexts, suggesting that K can influence oil quality metrics beyond its well-known roles in stress tolerance and yield stability.

7 Environmental and soil considerations: nutrient use efficiency and risk reduction

From a sustainability standpoint, the effectiveness of chemical fertilization should be evaluated not only by yield response but also by nutrient use efficiency (NUE, PUE) and the reduction of potential losses (e.g., nitrate leaching, P runoff). The emphasis on P use efficiency is particularly relevant because excess P applications can contribute to environmental issues, while insufficient P in low-P soils can constrain yield and reduce the efficiency of other nutrients.

Modern fertilization research increasingly addresses management "details" that improve nutrient capture, such as fertilizer placement depth and timing relative to growth stages. Ren et al. (2024) illustrate how fertilization depth can influence root distribution and N uptake patterns, implying that fertilizer management can be refined beyond simply adjusting the applied dose.

In addition, local studies on foliar mineral fertilization can complement soil-applied NPK approaches by addressing transient deficiencies and supporting seed quality traits. For example, Crista et al. (2023) assessed complex foliar fertilization effects on sunflower yield and quality using multivariate analysis, highlighting the potential of mineral foliar strategies as part of integrated nutrient management.

CONCLUSIONS

Chemical fertilization has a clear, multi-dimensional influence on sunflower productivity and oil quality. Nitrogen primarily drives canopy development and photosynthetic capacity and can alter seed composition, including fatty acid profiles; therefore, N management should balance yield benefits with potential oil–protein trade-offs. Phosphorus supports root establishment, growth acceleration, and reproductive development, but response to P is highly dependent on soil P availability and cultivar efficiency, making soil testing and P use efficiency essential. Potassium contributes to stress resilience—particularly under drought—and has documented links to both yield components and oil quality traits. Micronutrients, especially boron, can be critical for reproductive success in deficient systems and should be addressed through diagnosis and targeted correction.

Overall, the literature supports a shift from "single nutrient" thinking toward integrated NPK (plus micronutrient) management guided by soil fertility, crop phenology, and climate risk. Future advances should focus on improving nutrient use efficiency through optimized placement, timing, cultivar selection, and decision-support tools that reduce nutrient losses while maintaining high yield and desirable oil quality.

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