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Agronomic Value of Carnallite-Derived Potassium and Magnesium Fertilizers: Nutrient Availability, Soil Interactions, and Crop Performance

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Abstract

Carnallite is a hydrated potassium–magnesium chloride mineral that can supply K and Mg, but its agronomic value cannot be inferred from stoichiometry or dissolution alone. This critical narrative review examines processing-dependent nutrient inventories, product quality, soil exchanges, K–Mg nutrition, chloride exposure, and crop-response evidence. We evaluated the supplied 2010–2026 candidate bibliography thematically; we cannot reconstruct its retrieval and screening history. We distinguished direct carnallite-processing studies, agronomic analogies, mechanistic research, and untested hypotheses by their relationship to the question, not by automatic methodological quality grades. Evidence from polyhalite or independent nutrient supplementation does not validate carnallite-derived products. A proposed evaluation framework specifies product-specific K and Mg dose matching, independent nutrient-response controls, defined chloride and salinity contrasts, and separate assessment of agronomic efficiency and source comparisons. Consider field use or commercialization only after chemical and physical product characterization and replicated trials confirm efficacy and acceptable environmental performance in relevant soil–crop systems.

Keywords: carnallite; potassium fertilizer; magnesium nutrition; chloride salinity; cation antagonism; agronomic efficiency

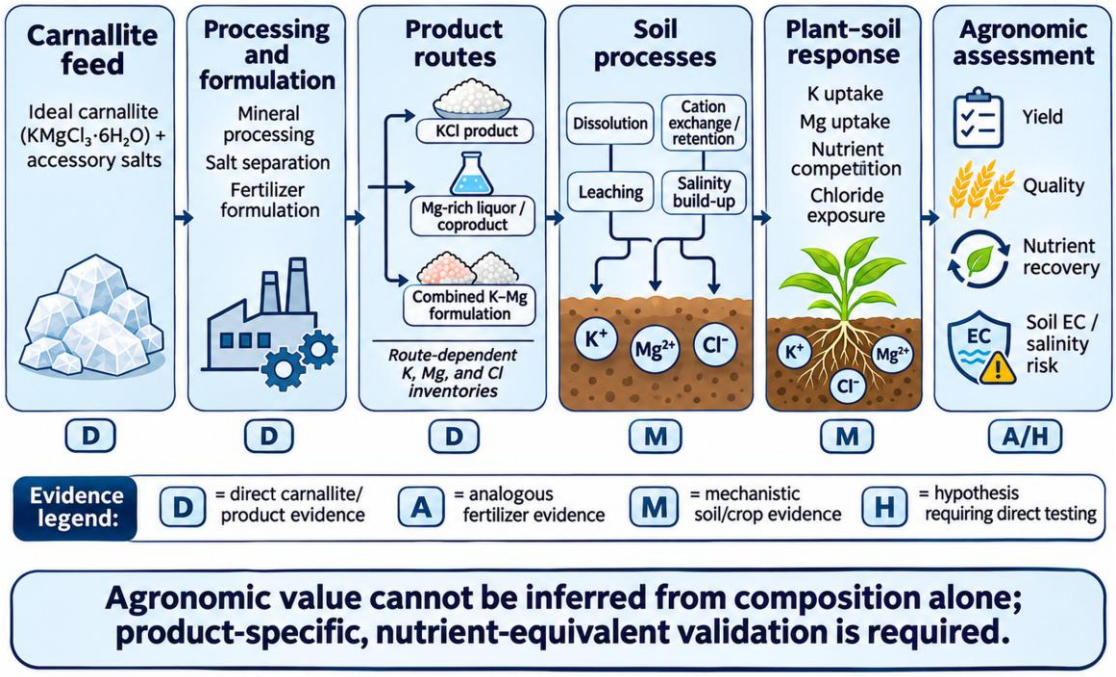
Highlights

- Carnallite composition alone does not establish agronomic superiority.
- Potassium–magnesium balance is conditional on soil and crop demand.
- Chloride and osmotic loading must be assessed alongside nutrient supply.
- Equivalent-rate field trials are essential for validating derived products.

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Graphical Abstract



1. Introduction

Potassium (K) and magnesium (Mg) are necessary for productive cropping. However, their economic and agronomic importance depends on crop uptake requirements, the soil's reserve and buffering capacity, and fertilizer chemistry rather than on the number of nutrients present in a mineral. K supports osmotic adjustment and many physiological processes, whereas Mg is essential for chlorophyll function, enzyme activation, and carbohydrate partitioning. The relevant comparative question is therefore whether a carnallite-derived formulation improves crop outcomes at equal nutrient doses rather than whether it contains both K and Mg. (Cakmak, 2010; Gransee & Führs, 2013; Rietra et al., 2017; Wang et al., 2020; Xie et al., 2021; Zörb et al., 2014)

This review examines the mineral-to-product chain illustrated in Figure 1 and the plant–soil processes summarized in Figure 2. Table 2 differentiates nutrient sources and chloride exposure; Table 3 specifies quality-control indicators; Table 4 organizes nutrient availability

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tests; Table 5 summarizes crop-response evidence; and Table 6 presents the minimum experimental comparison needed for defensible agronomic claims. Figure 3 integrates those measurements into a validation sequence. These tables and figures are analytical syntheses, not a claim that all listed pathways have already been validated for carnallite.

The available literature is asymmetrical: carnallite processing studies address mineral separation, whereas agronomic evidence mainly concerns other K or Mg sources, polyhalite, and soil–plant interactions. The designations D (direct carnallite or derived-product evidence), A (analogous fertilizer evidence), M (soil or plant mechanism), and H (untested proposition) specify relevance and transferability, not strength, certainty, or risk of bias. Primary experiments and syntheses are distinguished to avoid counting the same underlying trials as independent confirmations (Cheng et al., 2020; Dal Molin et al., 2020; Mann et al., 2025; Rietra et al., 2017).

1.1 Review design, evidence classification, and limitations

This article is a critical narrative review based on a previously supplied compilation of 121 candidate bibliographic items dated 2010–2026, organized around carnallite processing and product composition; K and Mg physiology; fertilizer dissolution; soil exchange and antagonism; crop response; formulation; and salinity. The original compilation source, exact search strings, database query dates, and search cutoff are not documented sufficiently to reproduce the retrieval. No retrospective retrieval counts, eligibility flow, quality scores, or search dates are inferred. The cited studies were selected thematically for their direct bearing on an argument or their illustrative mechanistic or analogous relevance; the cited subset is not equivalent to the 121 candidate items. This is neither a systematic review nor a meta-analysis.

We evaluated evidence relationships narratively by considering study format (primary experiment, process investigation, or synthesis), material tested, experimental comparator, soil/crop or process context, and limits of transfer. D/A/M/H categories are not quality rankings: a direct but poorly controlled study may support a weaker inference than a robust

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indirect trial. Process studies cannot establish crop yields, sulfate-based fertilizer trials do not test chloride-rich carnallite, and physiological observations cannot validate a commercial formulation. A synthesis may summarize trials already discussed and is not a separate replication (Cheng et al., 2020; Dal Molin et al., 2020; Mann et al., 2025; Rietra et al., 2017).

The 121-item bibliography is a candidate compilation, rather than a verified set of 121 independent studies. The evidence matrix below identifies representative cited sources and the specific type of inference used in this review; it is not an exhaustive study-level systematic extraction. Missing historical screening records and unverified full-text details limit assessment of completeness and source robustness. The absence of an identified direct field comparison in this compilation should not be interpreted as evidence that no such trial exists.

Table 1. Illustrative source-level evidence and transferability matrix (D/A/M/H denote relevance, not methodological quality). Design and comparator details not explicit in available bibliographic metadata are qualified rather than reconstructed.

Cited evidence	Study format	Product/system	Comparator/design	Inference used	Class	Transfer limit
Cheng et al. (2020).	Primary process study	Carnallite ore/flotation	Processing conditions, not crop controls	Carnallite separation is technically investigated	D	No direct evidence of crop response, moisture shelf-life, or a specific fertilizer batch
Tan et al. (2022).	Primary agronomic study	Polyhalite/peanut and soil	Conventional fertilizer comparison (see source)	Analogous multinutrient crop and soil outcomes	A	No evidence of carnallite processing or ore impurities
Albadarin et al. (2017).	Primary materials study	Granulated polyhalite/caking	Material storage tests (details require source verification)	Physical stability is a qualification issue for an analogous salt	A	Not a direct test of carnallite-derived granules

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Cited evidence	Study format	Product/system	Comparator/design	Inference used	Class	Transfer limit
Pavinato et al. (2020).	Primary field study	Polyhalite/sugarcane, Brazilian Oxisols	Field fertilizer treatments (exact contrasts require source verification)	Crop response to a sulfate-based multinutrient product	A	Soil/crop- and product-specific; sulfate differs from chloride
Gopinath et al. (2024).	Primary agronomic study	POLY4 / peanut, Southern India	Agronomic fertilizer treatments	Crop productivity, quality and soil properties	A	No evidence for storage caking of carnallite
Keren-Keiserman et al. (2019).	Primary agronomic study	Polyhalite/potato tuber skin	Fertilization comparison	A crop-quality endpoint relevant to product assessment	A	Not a physical storage or handling study
Rietra et al. (2017).	Scientific synthesis	Nutrient antagonism and synergy	Synthesis of nutrient interaction literature	Mechanistic rationale for K–Mg controls	M	Not an independent carnallite field trial
Mann et al. (2025).	Meta-analysis	Polyhalite / multiple crops and soils	Aggregated trials, heterogeneous contexts	Distribution of agronomic responses in analogous materials	A	Included primary trials may overlap with cited studies; not independent confirmation
Carnallite-derived field formulation	Unverified evidence gap	Specified K–Mg–Cl batch/field	Matched K and Mg comparator required	Direct yield or uptake advantage remains to be established	H	No identified direct matched trial in supplied bibliography

Note. Entries identify cited material and the type of inference used, without purporting to be a systematic evidence inventory. Primary studies and syntheses may overlap. Detailed comparator descriptions and study quality require verification against full texts.

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2. Carnallite as a Potassium–Magnesium Resource

2.1 Mineralogical composition and resource variability

Carnallite is conventionally represented as $KMgCl_3 \cdot 6H_2O$, equivalently $KCl \cdot MgCl_2 \cdot 6H_2O$. Its theoretical molar composition contains one K atom, one Mg atom, and three chloride ions per formula unit. Natural or processed materials may include accessory salts, insoluble constituents, and residual process liquor. These are potential sources of compositional variability requiring batch assays rather than assumptions about any given deposit. The carnallite-flotation study of Cheng et al. (2020) pertains to processing, while Tan et al. (2022) addresses a polyhalite fertilization trial and provides no support for claims about carnallite ore variability (Cheng et al., 2020).

2.2 Processing routes and agronomic consequences

Carnallite processing often exploits the different phase-equilibrium behavior of KCl and $MgCl_2$ in saline aqueous systems. A route optimized for KCl recovery may direct much of the magnesium into a liquor, whereas a dual-nutrient route must retain or reintroduce recoverable Mg in a controlled product. Thus, a high mineral recovery is not synonymous with a balanced K–Mg fertilizer; crop-relevant performance also depends on chloride, hygroscopicity, storage stability, and impurity enrichment. (Cheng et al., 2020; Dal Molin et al., 2020) This distinction between salt decomposition, selective KCl recovery, and retention of magnesium for a dual-nutrient product is also central to the carnallite-specific process review by Pereira (2026b); that source is used here for process framing, not as evidence of field performance.

The impact of water addition, salt equilibria, and mother-liquor entrainment on a specified carnallite separation flowsheet should be established experimentally by recording phase composition, material recovery, K and Mg partitioning, and moisture on a consistent mass-balance basis. Incomplete decomposition under a particular low-water condition is a process hypothesis or operating risk to test, not an experimentally established result of Tan et

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al. (2022), which investigates polyhalite fertilization of peanuts. Results from one process configuration should not be generalized to other ores or products without measurements (Cheng et al., 2020).

Assess the decision between separate KCl and Mg coproducts, blended chloride fertilizers, and chemically modified products against regional chloride sensitivity and the cost of purification or sulfate conversion. Any proposed conversion changes the salt inventory and may generate brines that require treatment; claims of environmental advantage require a defined mass balance, not a nominal nutrient count.

Figure 1 contrasts fertilizer product routes that begin from the same carnallite mineral but do not retain the same nutrient inventories. A process optimized for KCl recovery cannot be presumed to yield a marketable dual-nutrient fertilizer.

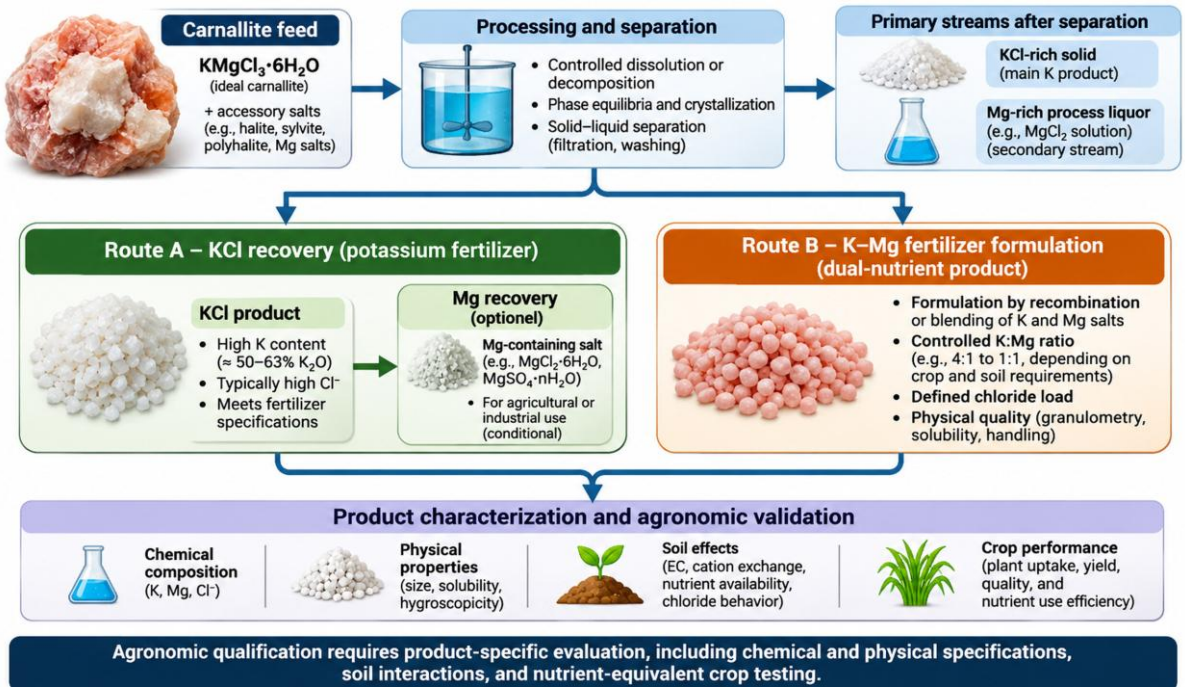


Figure 1. Product pathways and changing K–Mg–chloride inventories during carnallite valorization.
Note. Conceptual diagram prepared for this review; arrows depict processing choices, not quantified recoveries.

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Figure 1 highlights the mass-balance discontinuity between KCl-focused separation and a combined K–Mg formulation. Each route requires its own feed assay, chloride balance, grade specification, and agronomic control before a meaningful product-level comparison.

3. Chemical Composition and Fertilizer Product Specifications

Table 2 provides a basic compositional comparison. The percentage estimates for ideal carnallite are theoretical stoichiometric values, not measured ore grades; commercial fertilizer specifications vary by product and jurisdiction. Analytically, both elemental K/Mg and the reporting conventions K_2O/MgO should be stated to avoid misleading comparisons. Product evaluation should be expressed on dry and as-delivered bases, including chloride mass per unit of applied K. (Albadarin et al., 2017; Dal Molin et al., 2020; Lillywhite et al., 2020)

Table 2. Nutrient identity and relevant limitations of selected potassium–magnesium fertilizer sources

Source	Principal nutrient profile	Agronomic qualification
Ideal carnallite	K 14.1%; Mg 8.7%; Cl 38.3%	Strong chloride loading; theoretical composition only
Potassium chloride (KCl)	K; chloride	No Mg unless separately supplemented
Magnesium sulfate	Mg; sulfur	No K; sulfate counter-ion
Polyhalite	K, Mg, Ca, S	Sulfate mineral; not a chemical proxy for carnallite
KCl + Mg salt blend	Adjustable K and Mg	Counter-ions and physical quality depend on blending

Note. Theoretical mass fractions computed from the ideal formula $KMgCl_3 \cdot 6H_2O$ (M = 277.85 g mol^{-1}): K ≈ 14.1%, Mg ≈ 8.7%, Cl ≈ 38.3%, K_2O equivalent ≈ 17.0%, and MgO equivalent ≈ 14.5%. Values are not measured ore grades. Product comparisons are an original synthesis; published product-specific assays must be used for procurement and registration.

Table 2 demonstrates that simultaneous nutrient supply is coupled to a substantial chloride inventory in pure carnallite. At constant K dose, a salt's accompanying ions differ markedly; at constant total product dose, the K dose differs. Valid comparisons therefore require separate nutrient equivalence and salt-equivalence analyses. A product with a lower K concentration may require a higher application mass and transport burden.

Table 3 identifies the analytical thresholds to specify before agronomic trials. A rigorous product dossier distinguishes batch variability, soluble fractions, trace elements,

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physical stability, and potential caking. A chemically attractive composition that segregates in bulk blends or deliquesces during storage may not be practical in field application. (Albadarin et al., 2017; Cheng et al., 2020; Keren-Keiserman et al., 2019)

Table 3. Minimum quality dossier for carnallite-derived fertilizer qualification

Attribute	Measurement	Decision relevance
Guaranteed nutrients	Total and water-soluble K, Mg; K_2O and MgO equivalents	Dose calculations and label conformity
Counter-ions	Cl^-, SO_4^{2-}, Na^+, Ca^{2+}	Salinity and stoichiometric balance
Impurity profile	Trace metals and insolubles	Regulatory and soil accumulation risks
Physical quality	Moisture, size, density, hygroscopicity, caking	Handling, mixing, application
Dissolution	Time-resolved release at representative ionic strength	Short-term nutrient and osmotic pulse
Reproducibility	Batch-to-batch assay with uncertainty	Commercial specifications

Note. Proposed analytical decision matrix (original synthesis). No regulatory limits are assumed; limits must follow the target jurisdiction.

Quality control should also report confidence intervals and sampling procedures. A single assay is insufficient for heterogeneous carnallite feed, especially when processing introduces soluble mother liquor carryover or selective K/Mg separation.

4. Potassium Nutrition and Plant Physiological Functions

4.1 Root acquisition and metabolic roles

Potassium supports membrane potential regulation, enzyme activation, stomatal function, phloem transport, and adaptation to water stress. Its presence in solution does not guarantee efficient uptake: soil exchange equilibria, diffusion to roots, competing ions, and plant developmental demand modulate availability. When K is already sufficient, applying additional K can have diminishing yield benefits and may increase competition with Mg. (Cakmak, 2010; Grzebisz et al., 2013; Ragel et al., 2019; Sardans & Peñuelas, 2021; Zörb et al., 2014)

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4.2 Plant demand and response diagnostics

Justify potassium fertilization using soil testing, tissue analysis, expected yield removal, and local calibration. Plants differ in K demand and recovery efficiency; gross fertilizer recovery must not be inferred from a single post-harvest soil concentration. Long-term budget analyses indicate that sustained crop removal and soil fixation can diverge, making both immediate and residual effects important. (Das et al., 2022; Firmano et al., 2020; Schut & Reymann, 2023)

Long-term nutrient accounting makes the application problem more complex than a single-season fertilizer comparison. Potassium budgets and availability tests in irrigated and intensively cropped systems address reserves, fixed pools, and temporal nutrient depletion rather than dissolution of the added product alone (Buresh et al., 2010; Bilias & Barbayiannis, 2017, 2019a, 2019b, 2020; Das et al., 2018, 2019, 2021, 2022). Taken together, these findings suggest not a single soil threshold, but the need to interpret fertilizer response in relation to initial K reserves and crop removal.

Soil tests are also regionally calibrated. Studies addressing southern Brazilian soils and tropical clay mineralogy show why fixed K pools, texture, and extraction chemistry affect interpretation (Bortolon et al., 2010, 2011; Bortoluzzi et al., 2013; Firmano et al., 2020). These mechanistic observations justify documenting soil mineralogy and extraction methods when comparing a chloride-rich fertilizer with conventional KCl.

5. Magnesium Nutrition and Plant Physiological Functions

5.1 Photosynthesis and carbon allocation

Magnesium forms the central atom in chlorophyll and contributes to enzyme complexes, ribosome stability, and photoassimilate transport. Mg deficiency can impair growth and carbon allocation before yield losses become obvious. Increased Mg supply can improve productivity on deficient soils, but the response depends on crop species, nitrogen status, seasonal moisture, and existing Mg reserves. (Ahmed et al., 2023; Gerendás & Führs, 2013;

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Guo et al., 2016; Hauer-Jákli & Tränkner, 2019; Ishfaq et al., 2022; Senbayram et al., 2015; Wang et al., 2020)

5.2 Tissue thresholds and crop-specific response

Critical leaf Mg concentrations are not universal. Phenological timing, leaf sampling position, and the K supply environment alter diagnostic interpretation. Data for crop-specific Mg fertilization provide a stronger physiological basis than general claims that Mg content necessarily improves quality. Foliar application may rescue late-season deficiency but does not replace a soil K–Mg mass balance. (Geng et al., 2024; Guan et al., 2020; He et al., 2024)

Field studies on peanut, rapeseed, winter wheat, and crop-specific nutrient thresholds demonstrate that Mg response interacts with nitrogen, baseline soil supply, and phenological timing; they should not be collapsed into a universal Mg benefit (Gao et al., 2024; Geng et al., 2024; Grzebisz, 2013; Grzebisz & Potarzycki, 2022). Nutrient interaction trials should therefore collect both leaf concentrations and yield components rather than using harvested mass as a sole diagnostic.

6. Nutrient Release and Dissolution Behavior

For readily soluble chloride salts, release should normally be conceptualized as dissolution and transport rather than controlled nutrient release. Product dissolution may be rapid under sufficient water. Nevertheless, local saturation, particle size, ionic strength, and preferential dissolution of mixed salts can alter the short-term K: Mg ratio around granules. By contrast, sulfate mineral dissolution and nutrient delivery are not kinetically equivalent. (Dal Molin et al., 2020; Das et al., 2026)

Table 4 proposes a linked sequence of chemical and agronomic tests. In vitro dissolution alone cannot establish plant availability because ions may be exchanged, fixed, leached, or absorbed after entering the porewater. A release curve should therefore be coupled with electrical conductivity, ionic balance, soil column transport, and crop recovery. (Bilias & Barbayiannis, 2019a; Bilias & Barbayiannis, 2020; Schut & Reymann, 2023)

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Table 4. Hierarchical assays linking dissolution to nutrient availability

Scale	Recommended endpoint	Interpretive constraint
Water dissolution	Time-resolved K, Mg, Cl, EC and pH	Chemical liberation only
Batch soil contact	Solution K/Mg, exchangeable pools, EC	Sorption and ion exchange may dominate
Soil column	Leachate K, Mg, Cl; water flux	Texture and irrigation-dependent
Controlled pot	Tissue K/Mg and biomass; salinity signs	Restricted root volume may bias outcomes
Replicated field	Harvested K/Mg, yield, quality, residual salt	Season, soil, and cultivar dependence

Note. Original test hierarchy synthesizing soil K dynamics and multinutrient-fertilizer evidence (Bilias & Barbayiannis, 2019a; Dal Molin et al., 2020; Schut & Reymann, 2023).

A rigorous kinetic comparison also separates concentration from cumulative mass released and accounts for the background K and Mg contributed by soil or irrigation. A low concentration does not prove slow release if rapid leaching has removed the dissolved nutrients.

7. Soil–Fertilizer Interactions

7.1 Exchange, fixation, and mobility

Soil cation exchange capacity (CEC), clay mineralogy, organic matter, and water regime influence how applied K and Mg distribute between porewater and exchange sites. Potassium can be retained in interlayer positions of selected clay minerals; magnesium mobility and plant supply depend strongly on soil properties. In sandy media, rapid dissolution may be followed by significant losses under excess drainage, whereas clay-rich soils may buffer an acute salt pulse but retain K unevenly. (Bilias & Barbayiannis, 2019a; Bilias & Barbayiannis, 2020; Bortolon et al., 2010; Bortolon et al., 2011; Das et al., 2021; Firmano et al., 2020; Gransee & Führs, 2013; Schut & Reymann, 2023)

7.2 Chloride and ionic strength

Chloride is an essential micronutrient for plants, but chloride-rich fertilizer can contribute to electrical conductivity (EC), osmotic stress, and crop-specific chloride accumulation when applied at high rates. Its effects must be evaluated in relation to irrigation-

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water quality, leaching fraction, climate, soil permeability, and the target crop's tolerances. Applying salt-sensitive-crop conclusions to all crops would be inappropriate. (Banerjee et al., 2018; Peinado-Torrubia et al., 2026)

The conceptual interactions in Figure 2 show why a favorable fertilizer assay may not translate into proportional uptake. A chemical comparison must accompany agronomic testing across at least two contrasting exchange/salinity environments.

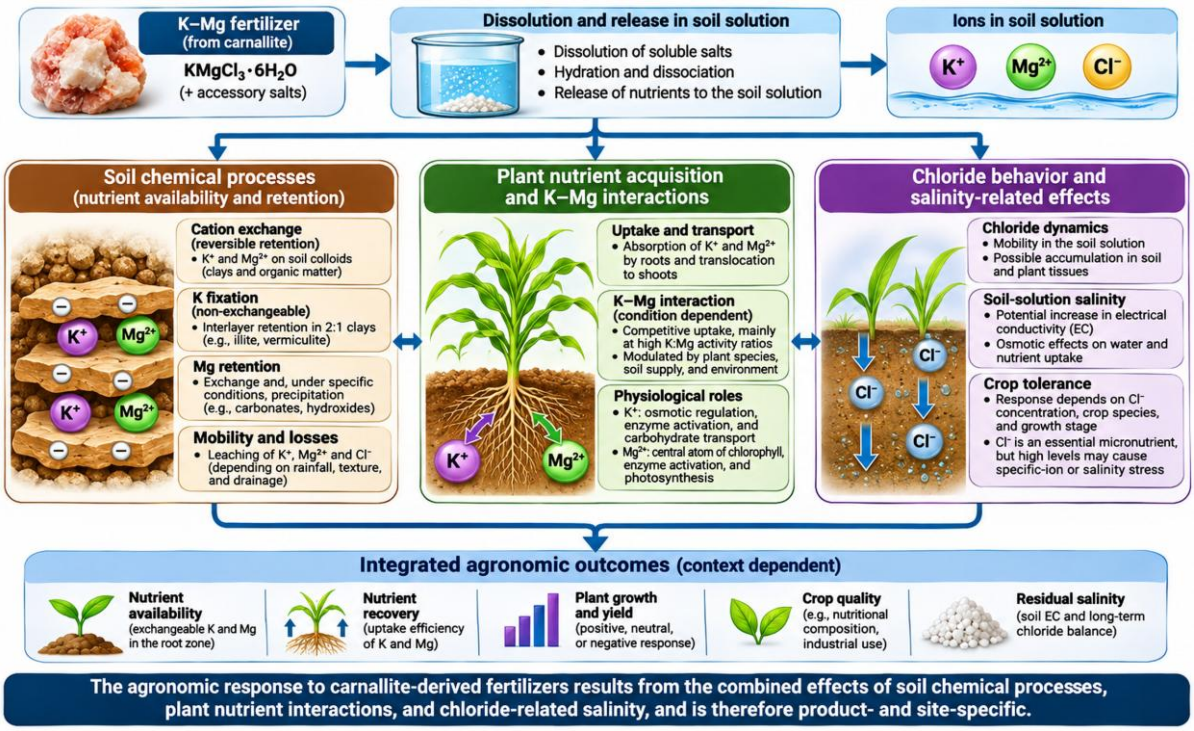


Figure 2. Coupled mechanisms controlling K and Mg availability after chloride-rich fertilizer application.

Note. Conceptual schematic prepared for this manuscript based on the soil exchange and nutrient-antagonism literature (Gransee & Führs, 2013; Rietra et al., 2017; Xie et al., 2021). The arrow sequence does not imply linear causality in all soils.

Figure 2 highlights three independent response domains: soil chemical buffering, plant nutrient acquisition, and salt exposure. A trial that measures only yield cannot identify which domain explains a positive or negative outcome.

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8. Potassium–Magnesium Nutrient Competition

8.1 Competition and conditional synergy

Excess K supply can decrease Mg uptake or translocation in some systems, although the intensity of antagonism varies with species, K/Mg ratio, soil Mg sufficiency, and environmental conditions. Balanced supply can improve nutrition where one element is limiting; however, adding the nutrients together does not ensure a balanced ratio in soil solution or tissues. There is therefore no universal optimal fertilizer K/Mg ratio transferable across crops and soils. (Chen et al., 2025; Dölger, Henningsen, et al., 2024; Dölger, Pitann, et al., 2024; Guan et al., 2020; Khokhar et al., 2022; Prabowo et al., 2023; Rhodes et al., 2018; Rietra et al., 2017; Xie et al., 2021; Xue et al., 2020)

8.2 A diagnostic approach to antagonism

Key diagnostic variables include absolute and relative ion activities, exchangeable K and Mg, leaf concentrations, and responses to independent rates. A factorial K × Mg design allows estimation of main effects and interactions, whereas a single combined formulation cannot distinguish nutrient synergy from simply correcting two independent deficiencies. The same design should identify whether chloride counter-ions influence nutrient uptake. (Dölger, Henningsen, et al., 2024; Khokhar et al., 2022; Prabowo et al., 2023; Rhodes et al., 2018; Xie et al., 2021)

9. Crop Response and Agronomic Efficiency

9.1 Available crop evidence and its transferability

Studies of polyhalite and independent K/Mg nutrition span cereal, sugarcane, potato, tomato, coffee, oilseed, and other crop systems; such results support the agronomic relevance of multiple macronutrient delivery, but not equivalence between sulfate-rich and chloride-rich fertilizer chemistries. Table 5 organizes representative evidence by its appropriate inference level. A critical gap within the supplied evidence base is the lack of clearly identified product-

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specific, nutrient-equivalent field comparisons for carnallite formulations in the supplied bibliography. (Andrzejewska et al., 2025; Arunachalam et al., 2025; Barłóg & Grzebisz, 2025; Bhatt et al., 2021; Gao et al., 2024; Geng et al., 2024; González-Osorio et al., 2023; He et al., 2024; Khokhar et al., 2022; Kile et al., 2025; Lillywhite et al., 2020; Mann et al., 2025; Mello, Pierce, et al., 2018; Mello, Tonhati, et al., 2018; Oliveira et al., 2026; Pavinato et al., 2020; Prabowo et al., 2023; Wang et al., 2020; Yakimenko & Naumova, 2021)

Table 5. Representative agronomic evidence and limits of transfer to carnallite-derived products

Evidence family	Crop/system examples	Transferability
Direct K + Mg studies	Maize; wheat; oil palm; potato	Mechanisms and ratio effects; counter-ion caution
Polyhalite field experiments	Sugarcane; potato; tomato; wheat; coffee	Demonstrate multi-nutrient feasibility, not carnallite equivalence
Mg supplementation	Rice; rapeseed; peanut	Shows Mg response on responsive soils
Meta-analyses	Mg fertilizers; polyhalite	Broader patterns; formulation-specific uncertainty
Direct carnallite field performance	Not established in the supplied references	Research gap; no direct yield claim justified

Note. Classification derived from studies and meta-analyses (Khokhar et al., 2022; Mann et al., 2025; Mello, Pierce, et al., 2018; Pavinato et al., 2020; Prabowo et al., 2023; Wang et al., 2020). Evidence that families are not pooled as statistically interchangeable.

Table 5 illustrates the risk of conflating "multinutrient fertilizer" with a single product class. Polyhalite contributes Ca and S with sulfate-based chemistry; carnallite contributes substantial chloride. Even if two products supply nominally equal K and Mg, differences in counter-ions, mass applied, dissolution, and osmotic potential can change the response.

9.2 Metrics that separate efficiency from apparent gain

Let Y_t and Y_0 be harvested yield (kg ha^{-1}) in treatment t and the zero-K/zero-Mg baseline, respectively; $F_{n,t}$ be the applied rate of nutrient n (kg n ha^{-1}, n = K or Mg), and $U_{n,t}$ and $U_{n,0}$ be total measured plant uptake of nutrient n (kg n ha^{-1}; explicitly state whether shoots or whole plants and use the same fraction throughout). For $F_{n,t} > 0$, apparent agronomic efficiency $AE_{n,t} = (Y_t - Y_0)/F_{n,t}$ (kg harvested product per kg nutrient applied), and apparent recovery efficiency $RE_{n,t} = 100 \times (U_{n,t} - U_{n,0})/F_{n,t}$ (%). The reference in both equations is the

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unfertilized baseline, not a nutrient-equivalent source. For combined K–Mg treatments, the same yield change may enter AE_K and AE_Mg denominators, but neither value isolates the causal contribution of that nutrient. Source performance at matched K and Mg rates is separately compared using $\Delta Y_source = Y_carnallite - Y_blend$ (kg ha^{-1}) and $\Delta U_n,source = U_n,carnallite - U_n,blend$ (kg n ha^{-1}), with uncertainty intervals. Nutrient-specific marginal and K × Mg interaction effects require independent K and Mg rate variation with appropriate controls, and cannot be estimated solely from a fixed-ratio combined-product contrast.

A full factorial arrangement of K rate × Mg rate, optionally crossed with defined chloride or salt exposures, can estimate nutrient main effects and interactions only if those factors are varied independently and relevant counterions are balanced or explicitly modeled. A single fixed-ratio carnallite product is not itself a full factorial treatment. A staged experimental design is therefore proposed: characterize a defined product batch and establish its application rates, determine crop-relevant response ranges in controlled studies, then compare nutrient-equivalent sources in randomized replicated field trials. Separate diagnostic comparisons may examine added chloride and overall salt exposure, but they do not provide an exclusive causal estimate where ionic matrices differ.

Quality endpoints should be crop-specific—for example, sugar content, tuber defects, or storage properties—and predeclared, not selected after treatment outcomes are known. Where products supply multiple nutrients, factorial designs and equivalent-rate controls are necessary to attribute yield gains. (González-Osorio et al., 2023; Kile et al., 2025; Mann et al., 2025; Mello, Pierce, et al., 2018; Mello, Tonhati, et al., 2018; Pavinato et al., 2020)

10. Comparison with Conventional K and Mg Fertilizers

Conventional KCl supplies K efficiently but no Mg; separate Mg salts permit rate adjustment. A combined carnallite-derived product could reduce handling complexity in locations with simultaneous deficiencies, whereas independent sources provide flexibility where soil K and Mg statuses diverge. Polyhalite is an important agronomic comparator but

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differs markedly in co-nutrient and chloride balance. (Arunachalam et al., 2025; Dal Molin et al., 2020; Das et al., 2026; Kile et al., 2025; Lillywhite et al., 2020; Mann et al., 2025)

Across published studies, polyhalite was evaluated in different crops, soils, and combinations with conventional nutrient sources, including sugarcane, potato, tomato, coffee, peanut, onion, garlic, and cereals (Bhatt et al., 2021; González-Osorio et al., 2023; Gopinath et al., 2024; Arunachalam et al., 2025; Mello, Pierce, et al., 2018; Mello, Tonhati, et al., 2018; Mello et al., 2020; Pavinato et al., 2020). Variation in crop and soil context makes cross-trial ranking unreliable, while the sulfur and calcium fractions prevent treating polyhalite as compositionally interchangeable with carnallite. Non-evaporitic potassium feedstocks, including feldspar, require their own extraction and agronomic evidence and should not be assumed equivalent to readily soluble K–Mg chlorides (Pereira, 2025).

The economically meaningful denominator is delivered and crop-utilized nutrient, not tonnes of saleable product. Cost comparisons should include processing recovery, moisture management, granulation, storage, freight, chloride-related restrictions, and possible brine disposal. Benefits are site-specific, and product pricing alone cannot establish agronomic value. (Albadarin et al., 2017; Keren-Keiserman et al., 2019; Mello, Pierce, et al., 2018; Pavinato et al., 2020)

11. Fertilizer Formulation and Quality Control

Carnallite-containing formulations should be evaluated for moisture uptake, particle integrity, segregation, and caking under the relevant production, storage, and application conditions. The physical risks are plausible qualification questions, not demonstrated failure modes of the particular carnallite-derived product reviewed here. Albadarin et al. (2017) address granulated polyhalite caking as an analogous material; Cheng et al. (2020) concern carnallite separation, not fertilizer shelf-life. Gopinath et al. (2024) and Keren-Keiserman et al. (2019) report agronomic or potato-quality outcomes, not dedicated storage or caking tests, and do not support physical-stability claims.

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Proposed product-specific physical testing includes controlled relative-humidity conditioning, moisture sorption, repeated wet–dry exposure, particle or granule strength, size segregation, and caking assessment before and after storage. The test protocol should record temperature, humidity, packaging, time, and batch composition; absent these data, the discussion makes no claim about commercial shelf-life. Dissolution and nutrient recovery remain separate agronomic endpoints.

12. Agronomic Limitations and Research Priorities

12.1 Evidence gaps and the minimum validation protocol

A principal research gap within the supplied evidence base is the lack of clearly identified, directly comparable field trials of a characterized carnallite-derived K–Mg formulation. Table 6 specifies a proposed, not validated, experimental structure. First assay the candidate product on a dry and as-applied basis: if its measured elemental K and Mg mass fractions are wK and wMg, an application mass m (kg product ha^{-1}) supplies FK = m × wK and FMg = m × wMg. A comparator blend of separately assayed K and Mg sources must deliver FK and FMg at those same values; alternative supplementation must report the additional product, nutrients, and counterions. One fixed composition cannot independently set arbitrary K and Mg doses. Rates should be selected for relevant soil tests and crop requirements, not inferred solely from ideal carnallite stoichiometry.

Table 6. Recommended treatment matrix for nutrient-equivalent agronomic evaluation

Treatment	Purpose	Essential control
Untreated baseline	Estimate background response and baseline uptake	No added K or Mg; record background nutrient and salt inputs
K-only response series	Estimate K response over defined rates	Mg kept at background; all counterions recorded
Mg-only response series	Estimate Mg response over defined rates	K kept at background; all counterions recorded
Nutrient-matched KCl + Mg-source blend	Source benchmark with independent components	K and Mg rates set equal to assayed candidate; account for all co-ions

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Treatment	Purpose	Essential control
Characterized carnallite-derived formulation	Test actual candidate at its fixed measured K:Mg ratio	Set m and calculate K=m×wK; Mg=m×wMg; measure Cl
Separate Cl-/salinity diagnostic contrasts	Describe salt-associated treatment differences	Distinguish Cl-matched versus EC-matched; report added ions and confounding

Note. Proposed (not validated) design. Define the candidate batch and its measured K/Mg mass fractions before selecting doses; use a nutrient-matched KCl + Mg-source blend for source comparison and independent K and Mg series for marginal-response analysis. Apply the same N, P, irrigation, and other agronomic management across plots. Chloride-equivalent and conductivity-equivalent contrasts are different and may change other ions. Report all introduced cations/anions, EC, pH, ionic strength or osmotic proxy, and residual confounding. The matrix is not automatically a full factorial design; determine replication and effect size prospectively.

For the chloride-exposure contrast, compare treatments at the same measured K and Mg rates while recording and, where chemically feasible, matching Cl^- supplied by all fertilizers and supplements. For the total-salinity contrast, compare treatments targeting similar initial solution EC or osmotic potential while reporting full ionic composition and time dependence; equal EC does not establish chloride equivalence. Additions used to match Cl^- (for example, a chloride salt) introduce counterions; additions used to match EC introduce their own chemical effects. These contrasts therefore identify responses to defined treatment packages, not necessarily isolated chloride toxicity or a pure osmotic effect. K-only, Mg-only, and unfertilized controls are necessary to estimate nutrient-response components, while a nutrient-matched blend assesses differences between sources.

The decision logic in Figure 3 begins with source characterization and ends with a multivariate agronomic interpretation. Randomized replicated field trials should span at least contrasting low- and adequate-Mg soils; a trial limited to a single soil can establish only local performance.

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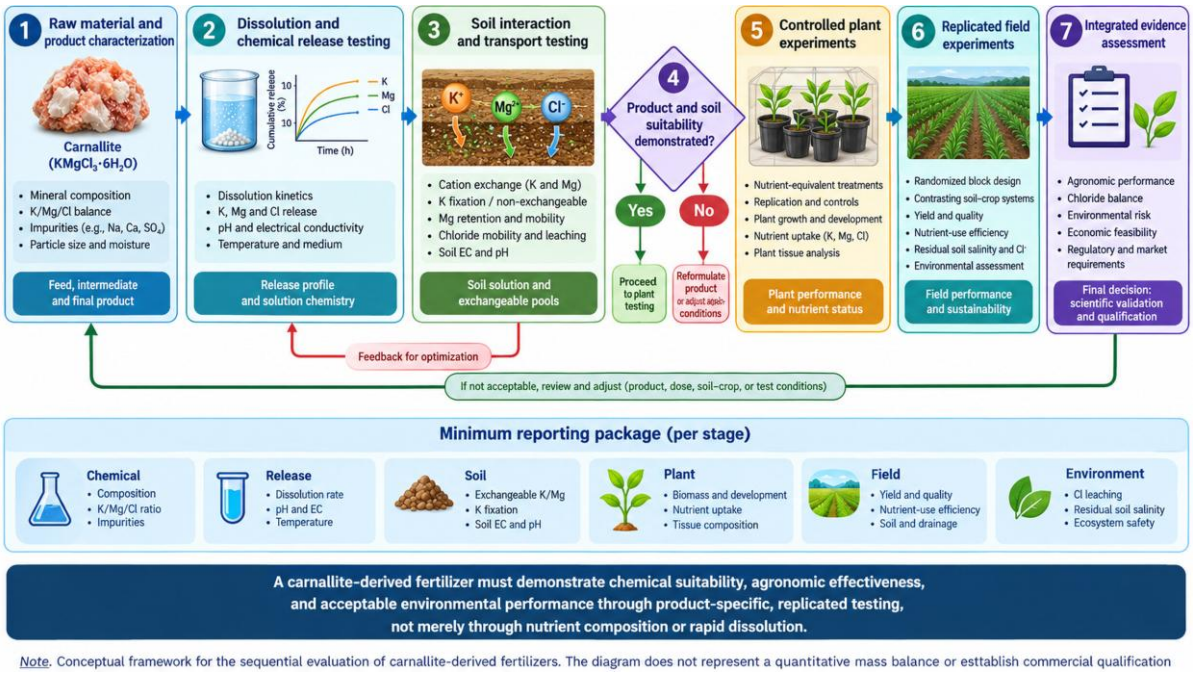


Figure 3. Sequential evaluation framework for a defensible carnallite-derived fertilizer claim.
Note. Conceptual figure prepared for this review using nutrient-equivalent comparisons and mechanistic soil diagnostics; no numerical performance benefits are asserted.

Figure 4 outlines hypothetical strata for selecting environments in which a defined product could be tested; joint K–Mg deficiency and acceptable chloride exposure identify study priorities, not validated categories for general field deployment.

Figure 4 translates the evidence hierarchy into conditional recommendations. It emphasizes that the prospective value of a combined K–Mg source is greatest when nutrient co-deficiency coincides with manageable chloride exposure.

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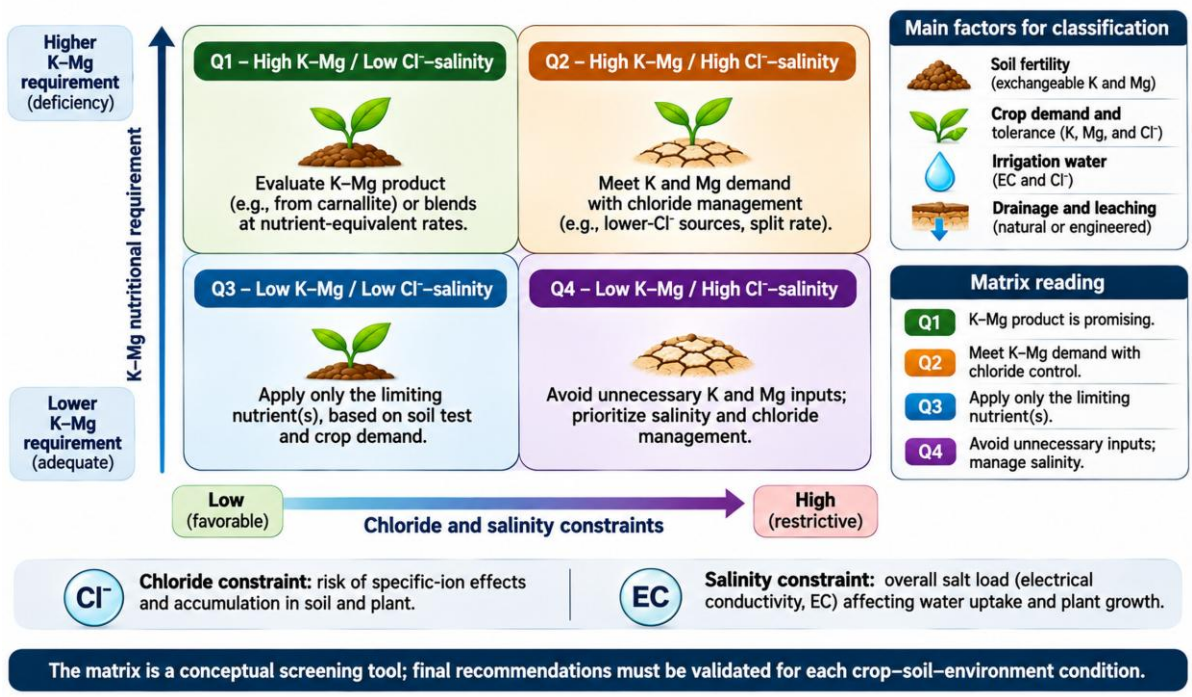


Figure 4. Conceptual decision matrix for matching dual-nutrient demand to chloride and salinity constraints.

The conditions in Figure 4 are trial-stratification hypotheses, not product prescriptions or verified safety thresholds. Assess crop-specific chloride tolerance, irrigation water composition, soil conductivity, and diagnostic K and Mg sufficiency before selecting trials. Practical recommendations require a characterized product and local replicated validation.

The four conditions in Figure 4 should be treated as strata for testing, not as prescription categories. Measure crop-specific chloride tolerance, irrigation water, soil conductivity, and nutrient diagnostics before assigning a field to any category.

12.2 Environmental and operational considerations

Risks include salt accumulation under insufficient leaching, chloride-sensitive crop damage, leaching of soluble Mg, and processing brines that shift pollution from fields to production sites. Sustainable use requires integrated water–salt–nutrient accounting and compliance with local regulations. Conditional benefits may be strongest where both K and

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Mg are deficient and salinity constraints are moderate; blanket recommendations are not defensible. (Banerjee et al., 2018; Chen et al., 2025; Rhodes et al., 2018; Rietra et al., 2017; Yakimenko & Naumova, 2021)

A practical environmental comparison should define two functional units: one tonne of marketable product and one kilogram of crop-recovered K or Mg. The first captures processing yield and distribution burden; the second accounts for the fact that nominal fertilizer grade and in-field recovery may diverge. Both need inventories of brine management, water demand, granulation, transport, and chloride leaching. Without primary production data, a quantified lifecycle ranking would be speculative. A performance-based assessment of fertilizer and soil-amendment products also supports evaluating safety, processing, and agricultural function jointly rather than relying on product origin alone (Pereira, 2026c).

A technology readiness level (TRL) classification would be useful only once a specific commercial formulation, manufacturing route, and validation environment are defined. Mineral availability alone does not imply maturity of a novel fertilizer. At the current evidence level, process readiness and agronomic readiness should remain separate assessments.

13. Conclusion

Carnallite is a credible mineral feedstock for potassium and magnesium products, but its intrinsic dual-nutrient composition does not prove superior agronomic performance. Product value depends on recoverable nutrient grade, chloride and impurity burden, formulation stability, soil buffering, nutrient competition, and crop-specific demand. The available evidence supports the importance of balanced K and Mg nutrition and the feasibility of multinutrient fertilizers, while providing insufficient direct support for generalized yield advantages from carnallite-derived formulations. The priority is to validate defined products using nutrient-equivalent and salt-aware comparisons, replicated soil–crop trials, and transparent mass balances. The appropriate recommendation is conditional deployment where K and Mg are jointly limiting and chloride exposure is agronomically acceptable.

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Conflict of Interest

The author declares no conflict of interest.

Data Availability

No new experimental datasets were generated. All quantitative values discussed in the review are traceable to the cited literature.

Author Contributions

The author performed conceptualization, critical analysis, literature synthesis, visualization, and manuscript preparation.

References

Ahmed, N., Zhang, B., Bozdar, B., Chachar, S., Rai, M., Li, J., Li, Y., Hayat, F., Chachar, Z., & Tu, P. (2023). The power of magnesium: Unlocking the potential for increased yield, quality, and stress tolerance of horticultural crops. Frontiers in Plant Science, 14, 1285512. https://doi.org/10.3389/fpls.2023.1285512

Albadarin, A. B., Lewis, T. D., & Walker, G. M. (2017). Granulated polyhalite fertilizer caking propensity. Powder Technology, 308, 193–199. https://doi.org/10.1016/j.powtec.2016.12.004

Andrzejewska, A., Przygocka-Cyna, K., & Grzebisz, W. (2025). Balanced fertilization of winter wheat with potassium and magnesium—An effective way to manage fertilizer nitrogen sustainably. Sustainability, 17(15), 6705. https://doi.org/10.3390/su17156705

Appiah, E. A., Balla-Kovács, A., Ocwa, A., Csajbók, J., & Kutasy, E. (2024). Enhancing alfalfa (Medicago sativa L.) productivity: Exploring the significance of potassium nutrition. Agronomy, 14(8), 1806. https://doi.org/10.3390/agronomy14081806

Arunachalam, T., Gade, K., Mahadule, P. A., Khalate, A., Awasti, N. K., Mishra, V., & Mahajan, V. B. (2025). Polyhalite as an alternate nutrient source for improving growth, yield, and nutrient use efficiency in onion and garlic. Scientific Reports, 15, Article 26623. https://doi.org/10.1038/s41598-025-10889-z

Aziz, M. A., Wattoo, F. M., Khan, F., Hassan, Z., Mahmood, I., Anwar, A., Karim, M. F., Akram, M. T., Manzoor, R., Khan, K. S., & Majrashi, M. A. (2023). Biochar and polyhalite fertilizers improve soil's biochemical characteristics and sunflower

Nexus Science Review
INTERNATIONAL JOURNAL OF INTERDISCIPLINARY RESEARCH

Received: 18/09/2026 - **Accepted:** 04/11/2026
Vol: 01.06
DOI: 10.66104/g2e14853
Pages: 1-35

(Helianthus annuus L.) yield. Agronomy, 13(2), 483. https://doi.org/10.3390/agronomy13020483

Banerjee, H., Ray, K., Dutta, S. K., Majumdar, K., Satyanarayana, T., & Timsina, J. (2018). Optimizing potassium application for hybrid rice (Oryza sativa L.) in coastal saline soils of West Bengal, India. Agronomy, 8(12), 292. https://doi.org/10.3390/agronomy8120292

Barłóg, P., & Grzebisz, W. (2025). Potassium and magnesium balance the effect of nitrogen on the yield and quality of sugar beet. Agronomy, 15(9), 2075. https://doi.org/10.3390/agronomy15092075

Basak, B. B., & Biswas, D. R. (2010). Co-inoculation of potassium-solubilizing and nitrogen-fixing bacteria on solubilization of waste mica and their effect on growth promotion and nutrient acquisition by a forage crop. Biology and Fertility of Soils, 46, 641–648. https://doi.org/10.1007/s00374-010-0456-x

Bhatt, R., Singh, P., Ali, O. M., Abdel Latef, A. A. H., Laing, A. M., & Hossain, A. (2021). Polyhalite positively influences the growth, yield, and quality of sugarcane (Saccharum officinarum L.) in potassium- and calcium-deficient soils in the semi-arid tropics. Sustainability, 13(19), 10689. https://doi.org/10.3390/su131910689

Bilias, F., & Barbayiannis, N. (2017). Evaluation of sodium tetraphenylboron (NaBPh4) as a soil test of potassium availability. Archives of Agronomy and Soil Science, 63, 468–476. https://doi.org/10.1080/03650340.2016.1218479

Bilias, F., & Barbayiannis, N. (2019a). Potassium availability: An approach using thermodynamic parameters derived from quantity–intensity relationships. Geoderma, 338, 355–364. https://doi.org/10.1016/j.geoderma.2018.12.026

Bilias, F., & Barbayiannis, N. (2019b). Potassium-fixing clay minerals as parameters that define K availability of K-deficient soils assessed with a modified Mitscherlich equation model. Journal of Soil Science and Plant Nutrition, 19, 830–840. https://doi.org/10.1007/s42729-019-00082-3

Bilias, F., & Barbayiannis, N. (2020). Towards a single-point approach for estimating potassium quantity–intensity parameters in soils at different K saturation ratios. Journal of Soil Science and Plant Nutrition, 20, 1679–1685. https://doi.org/10.1007/s42729-020-00238-6

Bilias, F., Tsigili, S., & Barbayiannis, N. (2021). A preliminary evaluation of cation exchange resins as a soil test of potassium availability in soils of northern Greece with different K loadings. Journal of Soil Science and Plant Nutrition, 21, 1004–1012. https://doi.org/10.1007/s42729-021-00417-z

Bortolon, L., Gianello, C., & Schlindwein, J. A. (2010). Disponibilidade de potássio para as plantas em solos do sul do Brasil (Potassium availability to plants in soils of southern

Nexus Science Review
INTERNATIONAL JOURNAL OF INTERDISCIPLINARY RESEARCH

Received: 18/09/2026 - **Accepted:** 04/11/2026
Vol: 01.06
DOI: 10.66104/g2e14853
Pages: 1-35

Brazil). Revista Brasileira de Ciência do Solo, 34, 497–506. https://doi.org/10.1590/S0100-06832010000200026

Bortolon, L., Gianello, C., Welter, S., Almeida, R. G. O., & Giasson, E. (2011). Simultaneous extraction of phosphorus, potassium, calcium, and magnesium from soils and potassium recommendations for crops in southern Brazil. Pedosphere, 21(3), 365–372. https://doi.org/10.1016/S1002-0160(11)60137-9

Bortoluzzi, E. C., Rheinheimer, D. S., Santanna, M. A., & Caner, L. (2013). Mineralogy and nutrient desorption of suspended sediments during a storm event. Journal of Soils and Sediments, 13, 1093–1105. https://doi.org/10.1007/s11368-013-0692-4

Brunetto, G., Ventura, M., Scandellari, F., Ceretta, C. A., Kaminski, J., de Melo, G. W., & Tagliavini, M. (2011). Nutrient release during the decomposition of mowed perennial ryegrass and white clover and its contribution to nitrogen nutrition of grapevine. Nutrient Cycling in Agroecosystems, 90, 299–308. https://doi.org/10.1007/s10705-011-9430-8

Buresh, R. J., Pampolino, M. F., & Witt, C. (2010). Field-specific potassium and phosphorus balances and fertilizer requirements for irrigated rice-based cropping systems. Plant and Soil, 335, 35–64. https://doi.org/10.1007/s11104-010-0441-z

Cakmak, I. (2010). Potassium for better crop production and quality. Plant and Soil, 335, 1–2. https://doi.org/10.1007/s11104-010-0534-8

Chen, W., Hu, Z., & Liu, D. (2025). Compared to MgSO4, magnesium nanofertilizer alleviates potassium-magnesium antagonism in tomato roots. Agriculture, 15(4), 368. https://doi.org/10.3390/agriculture15040368

Cheng, C., Huang, Z., Zhang, R., Zhou, J., Liu, Z., Zhong, H., Wang, H., Kang, Z., He, G., Yu, X., Ren, Z., Qiu, T., Hu, Y., & Fu, W. (2020). Synthesis of an emerging morpholine-typed Gemini surfactant and its application in reverse flotation of carnallite ore for production of potash fertilizer at low temperature. Journal of Cleaner Production, 261, 121121. https://doi.org/10.1016/j.jclepro.2020.121121

Chuan, L., He, P., Jin, J., Li, S., Grant, C., Xu, X., Qiu, S., Zhao, S., & Zhou, W. (2013). Estimating nutrient uptake requirements for wheat in China. Field Crops Research, 146, 96–104. https://doi.org/10.1016/j.fcr.2013.02.015

Dal Molin, S. J., Nascimento, C. O., Teixeira, P. C., & Benites, V. M. (2020). Polyhalite as a potassium and multinutrient source for plant nutrition. Archives of Agronomy and Soil Science, 66(5), 667–678. https://doi.org/10.1080/03650340.2019.1631451

Das, D., Dwivedi, B. S., Datta, S. P., Datta, S. C., Meena, M. C., Agarwal, B. K., Shahi, D. K., Singh, M., Chakraborty, D., & Jaggi, S. (2019). Potassium supplying capacity of a red soil from eastern India after forty-two years of continuous cropping and fertilization. Geoderma, 341, 76–92. https://doi.org/10.1016/j.geoderma.2019.01.041

Nexus Science Review
INTERNATIONAL JOURNAL OF INTERDISCIPLINARY RESEARCH

Received: 18/09/2026 - **Accepted:** 04/11/2026
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DOI: 10.66104/g2e14853
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Das, D., Dwivedi, B. S., Datta, S. P., Datta, S. C., Meena, M. C., Dwivedi, A. K., Singh, M., Chakraborty, D., & Jaggi, S. (2021). Long-term differences in nutrient management under intensive cultivation alter potassium-supplying ability of soils. Geoderma, 393, 114983. https://doi.org/10.1016/j.geoderma.2021.114983

Das, D., Nayak, A. K., Thilagam, V. K., Chatterjee, D., Shahid, M., Tripathi, R., Mohanty, S., Kumar, A., Lal, B., Gautam, P., Panda, B. B., & Biswas, S. S. (2018). Measuring potassium fractions is not sufficient to assess the long-term impact of fertilization and manuring on soil's potassium supplying capacity. Journal of Soils and Sediments, 18, 1806–1820. https://doi.org/10.1007/s11368-018-1922-6

Das, D., Sahoo, J., Raza, M. B., Barman, M., & Das, R. (2022). Ongoing soil potassium depletion under intensive cropping in India and probable mitigation strategies: A review. Agronomy for Sustainable Development, 42, 4. https://doi.org/10.1007/s13593-021-00728-6

Das, S., Bera, S., Kalindi, D., & Ghosh, R. (2026). Polyhalite nutrients driving balanced crop nutrition and sustainable agricultural productivity. Discover Soil, 3, Article 21. https://doi.org/10.1007/s44378-026-00179-z

Dölger, J. L., Henningsen, J. N., & Mühling, K. H. (2024). Antagonistic K/Mg ratios: Is foliar application of MgSO4 a superior alternative to root resupply?. Plant and Soil, 505, 747–761. https://doi.org/10.1007/s11104-024-06708-5

Dölger, J. L., Pitann, B., & Mühling, K. H. (2024). Potassium-induced suppression of magnesium uptake and translocation is limited in oat (Avena sativa L.). Journal of Plant Nutrition and Soil Science, 187(4), 454–458. https://doi.org/10.1002/jpln.202400151

Etesami, H., Emami, S., & Alikhani, H. A. (2017). Potassium-solubilizing bacteria (KSB): Mechanisms, promotion of plant growth, and prospects—A review. Journal of Soil Science and Plant Nutrition, 17, 897–911. https://doi.org/10.4067/S0718-95162017000400005

Firmano, R. F., Melo, V. F., Montes, C. R., Junior, A. O., Castro, C., & Alleoni, L. R. F. (2020). Potassium reserves in the clay fraction of a tropical soil fertilized for three decades. Clays and Clay Minerals, 68, 237–249. https://doi.org/10.1007/s42860-020-00078-6

Fornari, A. J., Caires, E. F., Bini, A. R., Haliski, A., Tzaskos, L., & Joris, H. A. W. (2020). Nitrogen fertilization and potassium requirement for cereal crops under a continuous no-till system. Pedosphere, 30(6), 747–758. https://doi.org/10.1016/S1002-0160(20)60035-2

Gao, Y., Zeng, R., Yao, S., Wang, Y., Wang, J., Wan, S., Hu, W., Chen, T., & Zhang, L. (2024). Magnesium fertilizer application increases peanut growth and pod yield under

Nexus Science Review
INTERNATIONAL JOURNAL OF INTERDISCIPLINARY RESEARCH

Received: 18/09/2026 - **Accepted:** 04/11/2026
Vol: 01.06
DOI: 10.66104/g2e14853
Pages: 1-35

reduced nitrogen application in southern China. The Crop Journal, 12(3), 915–926. https://doi.org/10.1016/j.cj.2024.03.008

Geng, G., Ye, X., Ren, T., Zhang, Y., Li, X., Cong, R., Cakmak, I., Lu, Z., & Lu, J. (2024). Optimal magnesium management for better seed yield and quality of rapeseed based on native soil magnesium supply. European Journal of Agronomy, 161, 127364. https://doi.org/10.1016/j.eja.2024.127364

Gerendás, J., & Führs, H. (2013). The significance of magnesium for crop quality. Plant and Soil, 368, 101–128. https://doi.org/10.1007/s11104-012-1555-2

González-Osorio, H., Sadeghian, S., Medina, R., & Furia, L. (2023). Response of granulated polyhalite on yield and quality of coffee (Coffea arabica). Communications in Soil Science and Plant Analysis, 54(11), 1525–1536. https://doi.org/10.1080/00103624.2023.2171051

Gopinath, K. A., Rajanna, G. A., Visha Kumari, V., Singh, V. K., Ajay, B. C., Awasthi, N. K., Mishra, V., Sukumaran, S., Venkatesh, G., & Rajkumar, B. (2024). Exploring the use of POLY4 for the improvement of productivity, peanut quality, and soil properties in Southern India. Frontiers in Plant Science, 15, 1448909. https://doi.org/10.3389/fpls.2024.1448909

Gransee, A., & Führs, H. (2013). Magnesium mobility in soils as a challenge for soil and plant analysis, magnesium fertilization and root uptake under adverse growth conditions. Plant and Soil, 368, 5–21. https://doi.org/10.1007/s11104-012-1567-y

Grzebisz, W. (2013). Crop response to magnesium fertilization as affected by nitrogen supply. Plant and Soil, 368, 23–39. https://doi.org/10.1007/s11104-012-1574-z

Grzebisz, W., & Potarzycki, J. (2022). Effect of magnesium fertilization systems on grain yield formation by winter wheat (Triticum aestivum L.) during the grain-filling period. Agronomy, 12(1), 12. https://doi.org/10.3390/agronomy12010012

Grzebisz, W., Gransee, A., Szczepaniak, W., & Diatta, J. (2013). The effects of potassium fertilization on water-use efficiency in crop plants. Journal of Plant Nutrition and Soil Science, 176(3), 355–374. https://doi.org/10.1002/jpln.201200287

Guan, X., Liu, D., Liu, B., Wu, C., Liu, C., Wang, X., Zou, C., & Chen, X. (2020). Critical leaf magnesium concentrations for adequate photosynthate production of soilless cultured cherry tomato—Interaction with potassium. Agronomy, 10(12), 1863. https://doi.org/10.3390/agronomy10121863

Guo, W., Nazim, H., Liang, Z., & Yang, D. (2016). Magnesium deficiency in plants: An urgent problem. The Crop Journal, 4(2), 83–91. https://doi.org/10.1016/j.cj.2015.11.003

Nexus Science Review
INTERNATIONAL JOURNAL OF INTERDISCIPLINARY RESEARCH

Received: 18/09/2026 - **Accepted:** 04/11/2026
Vol: 01.06
DOI: 10.66104/g2e14853
Pages: 1-35

Hauer-Jákli, M., & Tränkner, M. (2019). Critical leaf magnesium thresholds and the impact of magnesium on plant growth and photo-oxidative defense: A systematic review and meta-analysis from 70 years of research. Frontiers in Plant Science, 10, 766. https://doi.org/10.3389/fpls.2019.00766

He, B., Xue, C., Sun, Z., Ji, Q., Wei, J., & Ma, W. (2022). Effect of different long-term potassium dosages on crop yield and potassium use efficiency in the maize–wheat rotation system. Agronomy, 12(10), 2565. https://doi.org/10.3390/agronomy12102565

He, Z., Wang, Z., Hao, J., Wu, Y., & Liu, H. (2024). The use of magnesium fertilizer can improve the nutrient uptake, yield, and quality of rice in Liaoning Province. Agronomy, 14(3), 639. https://doi.org/10.3390/agronomy14030639

Ichami, S. M., Shepherd, K. D., Sila, A. M., Stoorvogel, J. J., & Hoffland, E. (2019). Fertilizer response and nitrogen use efficiency in African smallholder maize farms. Nutrient Cycling in Agroecosystems, 113, 1–19. https://doi.org/10.1007/s10705-018-9958-y

Ishfaq, M., Wang, Y., Yan, M., Wang, Z., Wu, L., Li, C., & Li, X. (2022). Physiological essence of magnesium in plants and its widespread deficiency in the farming system of China. Frontiers in Plant Science, 13, 802274. https://doi.org/10.3389/fpls.2022.802274

Ishfaq, M., Zhong, Y., Wang, Y., & Li, X. (2021). Magnesium limitation leads to transcriptional down-tuning of auxin synthesis, transport, and signaling in the tomato root. Frontiers in Plant Science, 12, 802399. https://doi.org/10.3389/fpls.2021.802399

Jezek, M., Geilfus, C.-M., Bayer, A., & Mühling, K.-H. (2015). Photosynthetic capacity, nutrient status, and growth of maize (Zea mays L.) upon MgSO4 leaf application. Frontiers in Plant Science, 5, Article 781. https://doi.org/10.3389/fpls.2014.00781

Jin, S., Zhou, W., Meng, L., Chen, Q., & Li, J. (2022). Magnesium fertilizer application and soil warming increase tomato yield by increasing magnesium uptake under a PE-film-covered greenhouse. Agronomy, 12(4), 940. https://doi.org/10.3390/agronomy12040940

Johnson, R. M., Richard, K. A., & Read, Q. D. (2024). Effects of potassium fertilizer on sugarcane yields and plant and soil potassium levels in Louisiana. Agronomy, 14(12), 2761. https://doi.org/10.3390/agronomy14122761

Keren-Keiserman, A., Baghel, R. S., Fogelman, E., Faingold, I., Zig, U., Yermiyahu, U., & Ginzberg, I. (2019). Effects of polyhalite fertilization on skin quality of potato tuber. Frontiers in Plant Science, 10, Article 1379. https://doi.org/10.3389/fpls.2019.01379

Khokhar, A., Sharma, V., Singh, M. J., Yousuf, A., Sandhu, P. S., Kumar, V., & Bhat, M. A. (2022). Effect of potassium and magnesium application on growth, yield, and nutrient

Nexus Science Review
INTERNATIONAL JOURNAL OF INTERDISCIPLINARY RESEARCH

Received: 18/09/2026 - **Accepted:** 04/11/2026
Vol: 01.06
DOI: 10.66104/g2e14853
Pages: 1-35

uptake of rainfed maize in the sub-montane region of Punjab, India. Journal of Plant Nutrition, 45(14), 2202–2212. https://doi.org/10.1080/01904167.2022.2063732

Kibria, M. G., Barton, L., & Rengel, Z. (2021). Applying foliar magnesium enhances wheat growth in acidic soil by stimulating malate and citrate exudation. Plant and Soil, 464, 621–634. https://doi.org/10.1007/s11104-021-04984-z

Kihara, J., Sileshi, G. W., Nziguheba, G., Kinyua, M., Zingore, S., & Sommer, R. (2017). Application of secondary nutrients and micronutrients increases crop yields in sub-Saharan Africa. Agronomy for Sustainable Development, 37, 25. https://doi.org/10.1007/s13593-017-0431-0

Kile, L., Woodley, A., Gatiboni, L., & Suchoff, D. (2025). Polyhalite as an alternative potassium fertilizer for sweet potatoes. Agronomy Journal, 117, e70114. https://doi.org/10.1002/agj2.70114

Kpai, P. Y., Adaramola, O., Addo, P. W., MacPherson, S., & Lefsrud, M. (2024). Mineral nutrition for Cannabis sativa in the vegetative stage using response surface analysis. Frontiers in Plant Science, 15, 1501484. https://doi.org/10.3389/fpls.2024.1501484

Kumar, V., Shekhawat, K., Rathore, S. S., Upadhyay, P. K., Singh, R. K., Gairola, A., Sharma, D., Devi, K., Babu, S., Pandey, A., Sanketh, G. D., & Roy, S. (2025). Optimizing root physiology and soil nutrient balance in rice–wheat sequence using polyhalite for enhanced profitability in the Indo-Gangetic plains of India. Scientific Reports, 15, Article 33895. https://doi.org/10.1038/s41598-025-08132-w

Kumar, V., Shekhawat, K., Singh, R. K., Rathore, S. S., Upadhyay, P. K., & Kumar, S. (2023). Effect of polyhalite on growth and yield of wheat (Triticum aestivum) in India. The Indian Journal of Agricultural Sciences, 93(3), 325–327. https://doi.org/10.56093/ijas.v93i3.132909

Li, J., Muneer, M. A., Sun, A., Guo, Q., Wang, Y., Huang, Z., Li, W., & Zheng, C. (2023). Magnesium application improves the morphology, nutrient uptake, photosynthetic traits, and quality of tobacco (Nicotiana tabacum L.) under cold stress. Frontiers in Plant Science, 14, 1078128. https://doi.org/10.3389/fpls.2023.1078128

Lillywhite, R. D., Wiltshire, J. J. J., Webb, J., & Menadue, H. (2020). The response of winter barley (Hordeum vulgare) and forage maize (Zea mays) crops to polyhalite, a multi-nutrient fertilizer. The Journal of Agricultural Science, 158(4), 269–278. https://doi.org/10.1017/S002185962000060X

Liu, J., Xia, H., Gao, Y., Pan, D., Sun, J., Liu, M., Tang, Z., & Li, Z. (2022). Potassium deficiency causes more nitrate nitrogen to be stored in leaves in low-K-sensitive sweet potato genotypes. Frontiers in Plant Science, 13, 1069181. https://doi.org/10.3389/fpls.2022.1069181

Nexus Science Review
INTERNATIONAL JOURNAL OF INTERDISCIPLINARY RESEARCH

Received: 18/09/2026 - **Accepted:** 04/11/2026
Vol: 01.06
DOI: 10.66104/g2e14853
Pages: 1-35

Lv, H., Luan, J., Guo, Y., Liang, J., Li, X., Sun, X., Zhou, W., & Liang, B. (2024). Soil heating significantly increases leaf magnesium concentration and fruit yield in tomatoes produced in a plastic greenhouse during winter. Agronomy, 14(12), 2844. https://doi.org/10.3390/agronomy14122844

Mann, K. K., Fields, R., Welham, S., Storer, K. E., Roques, S. E., Berry, P., Wade, B. R., Kindred, D., & Pienaar, C. (2025). Meta-analysis of polyhalite's yield performance across diverse soil, crop, and environmental conditions. Agronomy Journal, 117, e70259. https://doi.org/10.1002/agj2.70259

Mello, S. da C., Pavuluri, K., & Pierce, F. J. (2020). Polyhalite as a sulfur source for fresh market tomato production in Brazil. Journal of Plant Nutrition, 43(1), 92–107. https://doi.org/10.1080/01904167.2019.1659325

Mello, S. da C., Pierce, F. J., Tonhati, R., Almeida, G. S., Dourado Neto, D., & Pavuluri, K. (2018). Potato response to polyhalite as a potassium source fertilizer in Brazil: Yield and quality. HortScience, 53(3), 373–379. https://doi.org/10.21273/HORTSCI12738-17

Mello, S. da C., Tonhati, R., Dourado Neto, D., Darapuneni, M., & Pavuluri, K. (2018). Response of tomato to polyhalite as a multi-nutrient fertilizer in southeast Brazil. Journal of Plant Nutrition, 41(16), 2126–2140. https://doi.org/10.1080/01904167.2018.1497178

Oliveira, S. M. P. de, Smaniotto, A. O., Prado, J. V. S. do, Borges, J. G. C. G., Rodrigues, C. R., & Castoldi, G. (2026). Polyhalite as a potassium source for fertilization of ratoon cane in a Cerrado Oxisol. Agronomy, 16(1), 1. https://doi.org/10.3390/agronomy16010001

Pavinato, P. S., Corá, J. E., Santos, A. C., Herrera, W. F. B., Pavuluri, K., & Pierce, F. J. (2020). Sugarcane response to polyhalite fertilizer in Brazilian Oxisols. Agronomy Journal, 112, 5264–5278. https://doi.org/10.1002/agj2.20452

Peinado-Torrubia, P., Pons-Perpinyà, J., Clemente-Moreno, M. J., Gago, J., Colmenero-Flores, J. M., & López-Serrano, L. (2026). The role of the "overlooked" elements magnesium and chloride in improving photosynthesis and crop water-use efficiency in plants. Plant and Soil, 524, 37–62. https://doi.org/10.1007/s11104-026-08384-z

Pereira, A. C. (2025). Potassium recovery from feldspar: Activation routes, dissolution kinetics, agronomic performance, and techno-economic considerations. IKR Journal of Engineering and Technology, 1, 1–21. https://doi.org/10.5281/zenodo.17542110

Pereira, A. C. (2026a). Beyond NPK: A performance-first critical review of secondary nutrients, micronutrients, and multinutrient slow-release fertilizers. Journal International Review of Research Studies, 1(11). https://doi.org/10.66104/638xw983

Nexus Science Review
INTERNATIONAL JOURNAL OF INTERDISCIPLINARY RESEARCH

Received: 18/09/2026 - **Accepted:** 04/11/2026
Vol: 01.06
DOI: 10.66104/g2e14853
Pages: 1-35

Pereira, A. C. (2026b). Controlled decomposition and selective dissolution of carnallite: Phase equilibria, reaction mechanisms, and potassium–magnesium separation—A critical review. Journal International Review of Research Studies, 1(2), 1–23. https://doi.org/10.66104/m074ze34

Pereira, A. C. (2026c). De resíduo a fertilizante ou corretivo de solo: Uma revisão crítica baseada no desempenho sobre eficácia agronômica, segurança, processamento e prontidão para a economia circular (From waste to fertilizer or soil amendment: A performance-based critical review of agronomic efficacy, safety, processing, and circular-economy readiness). Lumen et Virtus, 17(64), e14540. https://doi.org/10.56238/levv17n64-098

Pereira, A. C. (2026d). From release kinetics to field performance: A critical review of slow- and controlled-release fertilizers, nutrient-use efficiency, environmental benefits, and scale-up challenges. Nexus Science Review, 1(5), 1–64. https://doi.org/10.66104/jmfjme46

Pereira, A. C., & Fonseca, R. B. da C. (2025). Potassium solubilization in micas by thermal and acid processes: Advances and perspectives. Studies in Engineering and Exact Sciences, 6(2), e18466. https://doi.org/10.54021/seesv6n2-005

Pereira, A. C., & Gomes, M. R. S. (2021). Biotita e flogopita como fonte alternativa de potássio para fertilizante: Extração hidrometalúrgica (Biotite and phlogopite as alternative potassium sources for fertilizer: Hydrometallurgical extraction). Geociências, 40(3), 781–786. https://doi.org/10.5016/geociencias.v40i03.13764

Pereira, A. C., Becheleni, E. M. de A., Gomes, M. R. dos S., & Rocha, S. D. F. (2019a). Fluoride-aided potassium extraction from Verdete rock by thermal processing with ferrous sulfate heptahydrate. Brazilian Applied Science Review, 3(2), 1373–1384. https://doi.org/10.34115/basr.v3i2.1565

Pereira, A. C., Becheleni, E. M. de A., Gomes, M. R. dos S., & Rocha, S. D. F. (2019b). Slow-release fertilizer from a rock containing glauconite by thermal processing with additives. In H. C. da Silva (Ed.), Estudos (Inter) Multidisciplinares nas Engenharias 2 (pp. 179–190). https://doi.org/10.22533/at.ed.01719091017

Pereira, A. C., Carvalho, I. S. B., & Rocha, S. D. F. (2019). Glauconite-bearing rocks as an alternative potassium source for fertilizer by thermal processing with additives. Brazilian Applied Science Review, 3(2), 1455–1467. https://doi.org/10.34115/basrv3n2-050

Pereira, A. C., Fonseca, R. B. da C., & Santos, J. R. dos (2026). Muscovite mica as an alternative source of potassium: Advances, challenges, and future directions—A critical review. Minerals Engineering, 235(Part 2), 109873. https://doi.org/10.1016/j.mineng.2025.109873

Nexus Science Review
INTERNATIONAL JOURNAL OF INTERDISCIPLINARY RESEARCH

Received: 18/09/2026 - **Accepted:** 04/11/2026
Vol: 01.06
DOI: 10.66104/g2e14853
Pages: 1-35

Pereira, A. C., Gomes, M. R. S., & Rocha, S. D. F. (2019a). Glauconita como fonte alternativa de potássio para produção de fertilizante de liberação lenta (Glauconite as an alternative potassium source for slow-release fertilizer production). Geonomos, 27(1), 32–37. https://doi.org/10.18285/geonomos.v27i1.21851

Pereira, A. C., Gomes, M. R. dos S., & Rocha, S. D. F. (2019b). Rocha contendo biotita como fonte alternativa de potássio para fertilizante após processamento térmico com aditivos (Biotite-bearing rock as an alternative potassium source for fertilizer after thermal processing with additives). Holos Environment, 19(4), 502–514. https://doi.org/10.14295/holos.v19i4.12323

Pereira, A. C., Santos, J. R. dos, & Fonseca, R. B. da C. (2025). Alternative sources of potassium from potassium feldspars, from mining to cropping: A review. International Journal of Advanced Research, 13(8), 492–502. https://doi.org/10.21474/IJAR01/21540

Prabowo, N. E., Foster, H. L., & Nelson, P. N. (2023). Potassium and magnesium uptake and fertilizer use efficiency by oil palm at contrasting sites in Sumatra, Indonesia. Nutrient Cycling in Agroecosystems, 126, 263–278. https://doi.org/10.1007/s10705-023-10289-7

Pramanick, B., Mahapatra, B. S., Datta, D., Dey, P., Singh, S. P., Kumar, A., Paramanik, B., & Awasthi, N. (2023). An innovative approach to improve oil production and quality of mustard (Brassica juncea L.) with multi-nutrient-rich polyhalite. Heliyon, 9(3), e13997. https://doi.org/10.1016/j.heliyon.2023.e13997

Ragel, P., Raddatz, N., Leidi, E. O., Quintero, F. J., & Pardo, J. M. (2019). Regulation of K+ nutrition in plants. Frontiers in Plant Science, 10, 281. https://doi.org/10.3389/fpls.2019.00281

Raza, A., Din, W. U., Waleed, A., Jabbar, A., Alharby, H. F., Al-Solami, H. M., Alabdallah, N. M., & Rehman, H. U. (2023). Magnesium fertilization reduces high-temperature damage during anthesis in spring wheat (Triticum aestivum L.) by affecting pollen viability and seed weight. Environmental Science and Pollution Research, 30, 118280–118290. https://doi.org/10.1007/s11356-023-29911-w

Rhodes, R., Miles, N., & Hughes, J. C. (2018). Interactions between potassium, calcium, and magnesium in sugarcane grown on two contrasting soils in South Africa. Field Crops Research, 223, 1–11. https://doi.org/10.1016/j.fcr.2018.01.001

Rietra, R. P. J. J., Heinen, M., Dimkpa, C. O., & Bindraban, P. S. (2017). Effects of nutrient antagonism and synergism on yield and fertilizer use efficiency. Communications in Soil Science and Plant Analysis, 48(16), 1895–1920. https://doi.org/10.1080/00103624.2017.1407429

Nexus Science Review
INTERNATIONAL JOURNAL OF INTERDISCIPLINARY RESEARCH

Received: 18/09/2026 - **Accepted:** 04/11/2026
Vol: 01.06
DOI: 10.66104/g2e14853
Pages: 1-35

Römheld, V., & Kirkby, E. A. (2010). Research on potassium in agriculture: Needs and prospects. Plant and Soil, 335, 155–180. https://doi.org/10.1007/s11104-010-0520-1

Sardans, J., & Peñuelas, J. (2021). Potassium control of plant functions: Ecological and agricultural implications. Plants, 10(2), 419. https://doi.org/10.3390/plants10020419

Schut, A. G. T., & Reymann, W. (2023). Towards a better understanding of soil nutrient dynamics and P and K uptake. Plant and Soil, 492, 687–707. https://doi.org/10.1007/s11104-023-06209-x

Senbayram, M., Gransee, A., Wahle, V., & Thiel, H. (2015). Role of magnesium fertilizers in agriculture: Plant–soil continuum. Crop & Pasture Science, 66(12), 1219–1229. https://doi.org/10.1071/CP15104

Shao, Y., Li, S., Gao, L., Sun, C., Hu, J., Ullah, A., Gao, J., Li, X., Liu, S., Jiang, D., Cao, W., Tian, Z., & Dai, T. (2021). Magnesium application promotes Rubisco activation and contributes to high-temperature stress alleviation in wheat during grain filling. Frontiers in Plant Science, 12, 675582. https://doi.org/10.3389/fpls.2021.675582

Silva, D. M. da, Brandão, I. R., Alves, J. D., Santos, M. O. de, Souza, K. R. D. de, & Silveira, H. R. O. de. (2014). Physiological and biochemical impacts of magnesium deficiency in two cultivars of coffee. Plant and Soil, 382, 133–150. https://doi.org/10.1007/s11104-014-2150-5

Singh, S. K., & Reddy, V. R. (2017). Potassium starvation limits soybean growth more than the photosynthetic processes across CO2 levels. Frontiers in Plant Science, 8, 991. https://doi.org/10.3389/fpls.2017.00991

Singh, V. K., Shekhawat, K., Singh, R. K., Babu, S., Upadhyay, P. K., Rai, P. K., Kumar, A., Awasthi, N. K., & Rathore, S. S. (2023). Optimizing polyhalite (POLY-4) use in the maize-wheat system: A comparative case study from the upper and Trans Indo-Gangetic plains of India. Heliyon, 9(12), e22566. https://doi.org/10.1016/j.heliyon.2023.e22566

Tan, H., Cui, Y., Liu, C., Zeng, F., Han, C., Zhang, H., Fan, X., Mitchell, R., Yan, D., & Zhang, D. (2022). Toward the replacement of conventional fertilizer with polyhalite in eastern China to improve peanut growth and soil quality. Chemical and Biological Technologies in Agriculture, 9, 94. https://doi.org/10.1186/s40538-022-00363-7

Tang, L., Tang, J., Huang, K., & Huang, X. (2024). Potassium fertilizer promotes the thin-shelled Tartary buckwheat yield by delaying senescence and promoting grain filling. Frontiers in Plant Science, 15, 1385548. https://doi.org/10.3389/fpls.2024.1385548

Tanoi, K., & Kobayashi, N. I. (2015). Leaf senescence by magnesium deficiency. Plants, 4(4), 756–772. https://doi.org/10.3390/plants4040756

Nexus Science Review
INTERNATIONAL JOURNAL OF INTERDISCIPLINARY RESEARCH

Received: 18/09/2026 - **Accepted:** 04/11/2026
Vol: 01.06
DOI: 10.66104/g2e14853
Pages: 1-35

Tränkner, M., Jákli, B., Tavakol, E., Geilfus, C.-M., Cakmak, I., Dittert, K., & Senbayram, M. (2016). Magnesium deficiency decreases biomass water-use efficiency and increases leaf water-use efficiency and oxidative stress in barley plants. Plant and Soil, 406, 409–423. https://doi.org/10.1007/s11104-016-2886-1

Vašíček, J., Kulhánek, M., Šulcová, K., Hladík, J., Černý, J., & Balík, J. (2026). Addressing magnesium deficiency through crop biofortification: Plant–soil–human perspective—A review. Plants, 15(5), 801. https://doi.org/10.3390/plants15050801

Wang, J., Ding, Z., AL-Huqail, A. A., Hui, Y., He, Y., Reichman, S. M., Ghoneim, A. M., Eissa, M. A., & Abou-Zaid, E. A. A. (2022). Potassium source and biofertilizer influence K release and fruit yield of mango (Mangifera indica L.): A three-year field study in sandy soils. Sustainability, 14(15), 9766. https://doi.org/10.3390/su14159766

Wang, Z., Hassan, M. U., Nadeem, F., Wu, L., Zhang, F., & Li, X. (2020). Magnesium fertilization improves crop yield in most production systems: A meta-analysis. Frontiers in Plant Science, 10, 1727. https://doi.org/10.3389/fpls.2019.01727

Xie, K., Cakmak, I., Wang, S., Zhang, F., & Guo, S. (2021). Synergistic and antagonistic interactions between potassium and magnesium in higher plants. The Crop Journal, 9(2), 249–256. https://doi.org/10.1016/j.cj.2020.10.005

Xiong, W., Wang, Y., Guo, Y., Tang, W., Zhao, Y., Yang, G., Pei, Y., Chen, J., Song, X., & Sun, J. (2022). Transcriptional and metabolic responses of maize shoots to long-term potassium deficiency. Frontiers in Plant Science, 13, 922581. https://doi.org/10.3389/fpls.2022.922581

Xue, X.-X., Wei, Y.-X., Wang, W.-B., Luo, X.-H., Zhao, C.-M., Wang, D.-P., Zhang, Y.-F., & Wu, X.-P. (2020). Interaction of potassium and magnesium on the growth and nutrient absorption of Hevea brasiliensis seedlings. Journal of Plant Nutrition and Fertilizers, 26(10), 1870–1878. https://doi.org/10.11674/zwyf.20065

Yakimenko, V., & Naumova, N. (2021). Tuning potassium and magnesium fertilization of potato in the south of West Siberia. Agronomy, 11(9), 1877. https://doi.org/10.3390/agronomy11091877

Ye, D., Yu, Z., Chen, J., Wei, S., Zhang, Z., Huang, S., Su, D., Liu, T., & Muneer, M. A. (2025). Foliar magnesium application improves sweet corn yield: Boosting nutrient uptake and grain carbohydrate under dense planting conditions. Frontiers in Plant Science, 16, 1499391. https://doi.org/10.3389/fpls.2025.1499391

Zhang, Q., Tang, D., Yang, X., Geng, S., He, Y., Chen, Y., Yi, X., Ni, K., Liu, M., & Ruan, J. (2021). Plant availability of magnesium in typical tea plantation soils. Frontiers in Plant Science, 12, 641501. https://doi.org/10.3389/fpls.2021.641501

Zhang, W., Liu, Y., Muneer, M. A., Jin, D., Zhang, H., Cai, Y., Ma, C., Wang, C., Chen, X., Huang, C., Tang, Y., & Wu, L. (2022). Characterization of different magnesium

Nexus Science Review
INTERNATIONAL JOURNAL OF INTERDISCIPLINARY RESEARCH

Received: 18/09/2026 - **Accepted:** 04/11/2026
Vol: 01.06
DOI: 10.66104/g2e14853
Pages: 1-35

fertilizers and their effect on yield and quality of soybean and pomelo. Agronomy, 12(11), 2693. https://doi.org/10.3390/agronomy12112693

Zhang, Y., Zhang, Q., Wang, Y., Lin, S., Chen, M., Cheng, P., Du, M., Jia, X., Ye, J., & Wang, H. (2023). Study on the effect of magnesium on leaf metabolites, growth, and quality of tea tree. Frontiers in Plant Science, 14, 1192151. https://doi.org/10.3389/fpls.2023.1192151

Zhou, H., Huang, S., Zhang, Z., Li, T., Li, Y., Zhuang, G., Liu, G., Fu, B., & Kuang, X. (2024). Network and stoichiometry analysis revealed rapid magnesium and calcium deficiency in mulched Phyllostachys violascens. Frontiers in Plant Science, 15, 1492137. https://doi.org/10.3389/fpls.2024.1492137

Zhou, Z., Chen, K., Yu, H., Chen, Q., Wu, F., Zeng, X., Tu, S., Qin, Y., Meakin, R., & Fan, X. (2019). Changes in tea performance and soil properties after three years of polyhalite application. Agronomy Journal, 111(4), 1967–1976. https://doi.org/10.2134/agronj2018.06.0393

Zörb, C., Senbayram, M., & Peiter, E. (2014). Potassium in agriculture—Status and perspectives. Journal of Plant Physiology, 171(9), 656–669. https://doi.org/10.1016/j.jplph.2013.08.008