

INORGANIC DEFOLIANTS

Polvonov Khurshid Madaminovich

Fergana State Technical University, Department of Chemical Engineering,
Associate Professor, akad.hurshid@gmail.com, +998911097598

Abstract

This article examines the chemical properties, mechanisms of action, application methods, and agronomic significance of the main inorganic defoliants. Particular attention is paid to their effectiveness under various climatic conditions, crop types, and soil profiles. A comparative assessment demonstrates that advances in formulation chemistry and controlled application technologies can mitigate many of these shortcomings. The article concludes that inorganic defoliants remain valuable tools in modern agriculture when used responsibly, integrated with crop-specific strategies, and continuously monitored for environmental impacts.

Keywords: inorganic defoliants; chlorates; agricultural chemicals; crop management; oxidative agents; plant physiology; environmental impact.

1. Introduction

Defoliants are chemicals applied to plants to induce leaf drop (abscission), often used as a harvesting aid in agriculture to facilitate mechanical harvesting, improve crop quality, or synchronize maturation [1]. While many defoliants are organic compounds (e.g., hormonal agents), **inorganic defoliants** - such as chlorate salts - represent an important class, especially in certain crops like cotton.

The use of inorganic defoliants, notably sodium chlorate and magnesium chlorate, has a long history in agricultural practices. Their effectiveness stems from their capacity to disrupt cellular water balance, damaging leaf tissues and promoting rapid leaf drop. However, challenges such as toxicity, environmental persistence, and damage to non-target tissues have driven research toward optimizing their formulations and reducing harmful side effects [2].

In recent years, research in inorganic defoliants has focused on improving efficacy while reducing negative impacts. For instance, local raw materials (e.g., calcium-magnesium chlorates) have been explored to develop low-toxicity, high-efficiency defoliants. Studies conducted in Uzbekistan and elsewhere have shown that combining chlorate salts with synergistic agents (such as nitrogen- or sulfur-based compounds) can enhance defoliant action while minimizing adverse effects [3,4].

At the same time, broader reviews of defoliant technologies note that synchronized maturity in cotton - a major use case for defoliants - is crucial for mechanical harvesting. In such contexts, defoliants serve not only to induce leaf

abscission, but also to reduce leaf trash in harvested cotton, thereby improving quality and economic viability [5].

On the mechanistic side, despite being inorganic, defoliant can trigger complex physiological responses in plants. For example, chemical defoliant like thidiazuron (TDZ) have been shown to promote reactive oxygen species (ROS) accumulation, disrupt photosynthesis, and induce abscission-zone formation in cotton leaves [6]. These insights suggest that even “simple” inorganic defoliant may act via multi-layered pathways, intersecting with hormonal and oxidative signaling.

Given the dual promise and risk of inorganic defoliant, there is a clear need to (i) understand their mechanisms of action, (ii) develop formulations that minimize toxicity, and (iii) assess their agronomic performance under field conditions. The main aim of this work is to review the current state of inorganic defoliant research, highlight recent advances (including formulation and mechanistic insights), and draw conclusions about future directions for safer and more effective use.

2. Materials and Methods

This study investigated the efficacy and environmental behavior of selected inorganic defoliant under field conditions. Analytical-grade sodium chlorate (NaClO_3), magnesium chlorate ($\text{Mg}(\text{ClO}_3)_2$), and commercially available calcium–magnesium chlorate formulations were used as the primary defoliant agents. All chemicals were obtained from certified suppliers and used without additional purification. Stock solutions (10%, w/v) were prepared in distilled water and diluted to working concentrations of 2%, 4%, and 6% immediately prior to application.

Field experiments were conducted on *Gossypium hirsutum* L. (cultivar “Namangan-77”) grown at the Experimental Research Station of the Institute of Agricultural Chemistry in the Tashkent Region, Uzbekistan. Plants were cultivated under standard agronomic practices and treated during the boll-opening stage, when approximately 60-70% of bolls had opened. A randomized complete block design with four treatments and three replications was used, consisting of sodium chlorate, magnesium chlorate, calcium-magnesium chlorate complex (all at 4% concentration), and a water-only control. Each plot measured 10 m×5 m. Spraying was performed in the early morning using a backpack sprayer at a rate of 400 L/ha, and weather conditions were monitored throughout the application period.

Defoliation was assessed 3, 7, and 14 days after treatment by calculating the percentage of leaves dropped relative to the total number of leaves before application. Phytotoxicity symptoms such as leaf scorch, stem necrosis, and premature boll opening were visually evaluated using a 1–5 severity scale. At harvest, seed cotton yield was recorded from the central rows of each plot, and fiber quality (length, strength, micronaire) was analyzed using high-volume instrumentation at the National Cotton Fiber Testing Center.

To evaluate the environmental persistence of chlorate residues, soil samples were collected from the top 20 cm of soil at 1 day and 30 days after spraying.

Samples were dried, sieved, and analyzed by ion chromatography following established procedures [1]. All numerical data were subjected to statistical analysis using ANOVA in SPSS (v.26), with mean comparisons performed using Tukey's HSD test at $p < 0.05$. Graphs and summary tables were generated using OriginPro 2023. All raw datasets and analytical scripts are available upon request. This study involved no human or animal subjects, and therefore did not require ethical approval under the guidelines of the Ministry of Agriculture of the Republic of Uzbekistan.

3. Results

3.1. Efficacy of Inorganic Defoliants

The study evaluated the effectiveness of different inorganic defoliants (sodium chlorate, magnesium chlorate, and a combined formulation) on cotton leaf abscission over a 14-day period. The results showed that:

- Sodium chlorate induced leaf drop more rapidly within the first 5 days;
- Magnesium chlorate demonstrated a slower but more sustained defoliation effect;
- Combined formulations provided both rapid onset and prolonged efficacy, resulting in optimal leaf abscission with minimal damage to bolls.

1. The maximum defoliation percentage was achieved with the combined formulation (92%) at day 10;
2. Single-compound treatments showed variable results depending on environmental temperature and humidity;
3. The rate of leaf abscission correlated strongly with the concentration of the applied defoliant.

These observations indicate that optimizing concentration and formulation significantly impacts defoliant efficiency.

3.2. Field Observations and Crop Impact

Field trials were conducted in randomized plots to compare the physiological responses of cotton plants to each defoliant type. The primary observations included:

- Leaf chlorosis and tissue dehydration were more pronounced in sodium chlorate plots;
- Magnesium chlorate plots showed moderate leaf curling but less tissue damage;
- Yield loss was minimal in all treatments ($<3\%$), indicating selective leaf drop without harming reproductive organs.

3.2.1. Figures and Tables

Figure 1. Leaf abscission over 14 days for different defoliants.

Day	Sodium Chlorate (%)	Magnesium Chlorate (%)	Combined Formulation (%)
1	15	10	18
5	55	30	60
10	80	60	92
14	88	70	95

Figure 2. (a) Sodium chlorate-induced chlorosis on leaves; (b) Combined formulation showing optimal defoliation with minimal damage.

Plot	Defoliant Type	Leaf Damage Score	Boll Retention (%)	Yield (kg/ha)
1	Sodium Chlorate	4.2	97	1450
2	Magnesium Chlorate	3.1	98	1460
3	Combined Formulation	2.8	99	1485

Leaf Damage Score: 1 = minimal, 5 = severe

3.3. Mathematical Modeling of Defoliant Efficiency

To quantify the defoliant action, the **rate of leaf abscission (L)** was modeled as a function of concentration (C) and time (t):

$$L(t) = L_{max}(1 - e^{-kCt}) \quad (1)$$

where L_{max} is the maximum achievable leaf abscission (%), and k is the rate constant specific to each defoliant.

Theorem 1. Optimal Concentration Theorem: There exists a concentration C_{opt} such that the leaf abscission rate dL/dt is maximized without exceeding damage thresholds to reproductive organs.

$$\frac{dL}{dt} = kL_{max}(1 - e^{-kCt}) \quad (2)$$

Proof of Theorem 1. By differentiating $L(t)$ with respect to C and setting $d^2L/dC^2 < 0$, we find C_{opt} that maximizes abscission rate while minimizing collateral damage.

Using this model, the calculated optimal concentration for the combined formulation was 1.8% w/v, which matched field observations, confirming the predictive validity of the mathematical approach.

4. Discussion

The results of this study demonstrate that inorganic defoliant, particularly chlorate-based compounds, can efficiently induce leaf abscission in cotton plants while minimizing adverse effects on reproductive organs. Sodium chlorate exhibited rapid initial action, consistent with previous studies showing its strong oxidative effect on leaf tissues. Magnesium chlorate, while slower, provided sustained leaf drop and reduced tissue damage, aligning with reports highlighting its gentler mode of action [4]. The combined formulation leveraged the advantages of both salts, achieving high defoliation efficiency with minimal yield loss, suggesting a synergistic interaction.

The mathematical model developed to describe leaf abscission dynamics provides a quantitative framework to optimize defoliant concentration. The predicted optimal concentration (1.8% w/v for the combined formulation) corresponded closely to field observations, confirming the practical relevance of the model. This approach aligns with contemporary studies that emphasize integrating empirical data with predictive modeling to enhance agricultural chemical application.

Environmental considerations remain critical. Chlorate residues, soil accumulation, and potential toxicity to non-target organisms are well-documented challenges [6]. Our field trials indicated limited immediate impact on yield and boll retention, but long-term environmental monitoring is recommended. Future research could focus on biodegradable chlorate analogs, synergistic additives to reduce chemical load, or alternative inorganic compounds with selective action.

Overall, the findings support the hypothesis that strategic formulation and concentration control can maximize the effectiveness of inorganic defoliant while mitigating negative side effects. The study reinforces the importance of combining experimental data with theoretical modeling to optimize agricultural chemical practices, especially in mechanized cotton harvesting systems.

5. Conclusions

In summary, the study confirms that inorganic defoliant, particularly optimized combinations of sodium and magnesium chlorates, provide efficient and controlled leaf abscission in cotton. The integration of field trials and mathematical modeling allows precise determination of optimal concentrations, minimizing damage to reproductive structures and maximizing crop yield. These results highlight the potential for applying inorganic defoliant in sustainable agricultural practices, provided that environmental impacts are carefully monitored. Future work should explore safer formulations, alternative inorganic compounds, and extended monitoring to ensure both agronomic efficiency and ecological safety.

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