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The Role of Defoliants in Modern Cotton Farming: Facilitating Easy Mechanical Harvesting and Enhancing Cotton Quality

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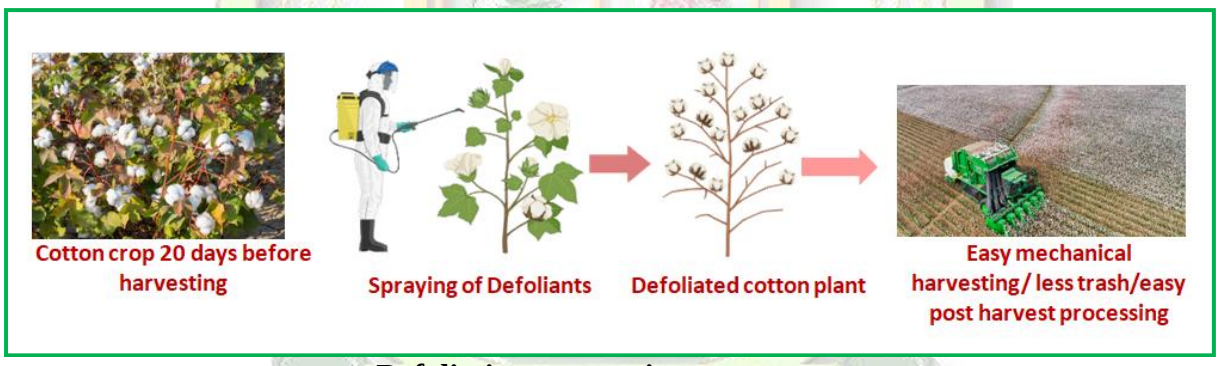
Uneven boll opening in cotton crops affects yield. Dense leaves obstruct boll opening, delay crop maturity, and create trash during harvesting. Natural leaf drop facilitates mechanical harvesting, but if this process doesn't occur on time, mechanical harvesting becomes challenging. To address this issue, farmers use chemical defoliants, which promote leaf drop and simplify the mechanical harvesting process. Chemical defoliants play an important role in promoting leaf drop and boll opening. The use of these chemicals improves boll maturity, enhances fiber quality, and increases harvesting efficiency. In different countries, defoliation in cotton crops is carried out through various techniques and methods. In developed countries, highly advanced techniques are used for defoliant spraying and monitoring, whereas in developing countries like India, these techniques are comparatively less advanced. Defoliation makes the cotton crop harvesting process more effective and smooth, and it also simplifies post-harvest processing activities.



Defoliation process in cotton crop

Introduction

One of the key constraints limiting the realization of cotton's potential yield is the poor and uneven opening of mature bolls. Excessive vegetative growth, resulting from the use of high nutrient levels and dense crop canopy, obstructs the opening of mature bolls. This not only delays crop maturity but also leads to increased trash during harvest and extends the duration of picking. Dense foliage also hinders the circulation of air and sunlight penetration. In cotton cultivation, defoliation occurs naturally as part of the plant's physiological cycle. However, when natural leaf loss happens too late or is insufficient, it can interfere with mechanical cotton harvesting. To address this, farmers often induce defoliation by applying chemical defoliants, which helps streamline the mechanical harvest process.

Defoliation is the process of leaves being shed through natural events or human intervention. Effective cotton defoliation is crucial because it impacts the efficiency of

mechanical harvesting, the quality of the fiber, and the overall costs of growing cotton. Additionally, promoting the opening of cotton bolls before mechanical harvesting is an important agronomic practice to ensure clean fibers and maximize harvesting efficiency (Neupane et al., 2023). In addition to defoliant chemicals, boll openers and growth inhibitors are also employed to aid in mechanical harvesting. These compounds help maintain fiber quality, promote boll opening, and control the regrowth of cotton plants, ensuring a more efficient harvest process. Together, they optimize the timing of defoliation and boll maturation, improving overall yield and harvest quality.

Applying chemical defoliants prior to harvest encourages leaf drop and facilitates boll opening, effectively reducing impurities in raw cotton. This practice enhances harvest efficiency, particularly in fields where mechanical harvesting is used. Various defoliants have been extensively tested and utilized in cotton production worldwide. Chemical defoliants like thidiazuron and dimethipin are commonly employed to aid in mechanical harvesting. These compounds work by promoting the production of endogenous ethylene, inhibiting auxin transport, and inducing early leaf abscission (Fig. 1). Ethephon, used as a boll opener, enhances boll opening by increasing ethylene levels in the leaves and lowering boll moisture content. A mixture of thidiazuron and ethephon accelerate both defoliation and boll opening, streamlining the harvest process (Jin et al., 2020).

In developed nations, such as the United States and Australia, AI technologies are extensively integrated into agricultural practices. These countries leverage advanced tools like drones, satellite imagery, and sophisticated AI algorithms to monitor defoliation in real-time, optimize defoliant application, and enhance crop management. The high level of automation and substantial investment in research and development allows for precise and efficient defoliation monitoring. Conversely, in developing countries like India and Brazil, the adoption of AI-based defoliation monitoring is still emerging.

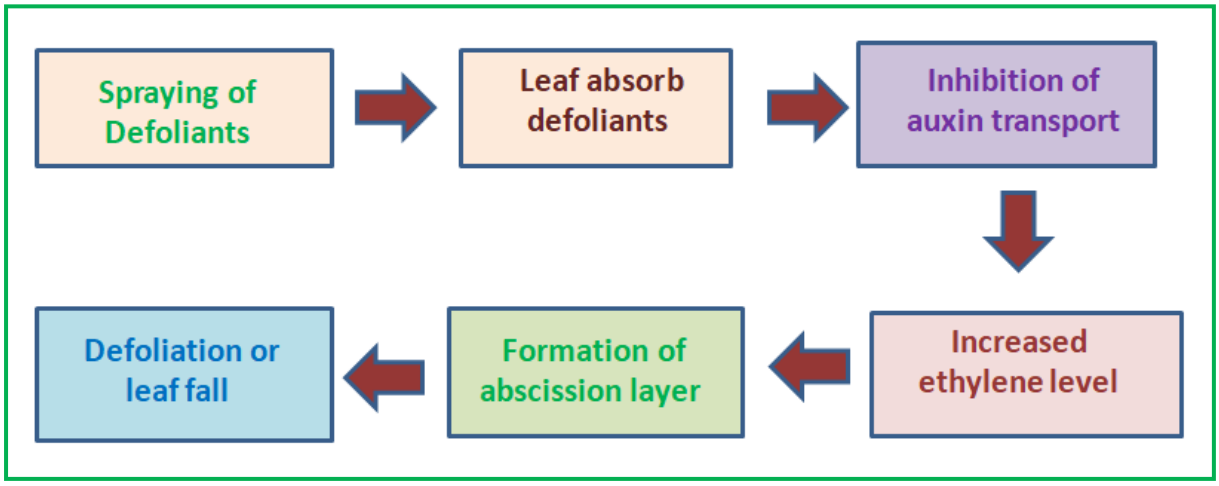


Fig. 1. Mechanism of action of chemical defoliants

Types of Defoliants and Their Actions

Defoliants and harvest aids are substances used to remove leaves from cotton plants to facilitate the harvesting process and improve the quality of the cotton fibers. These chemicals are categorized based on their action mechanism into two main groups: herbicidal and hormonal.

Herbicidal defoliants work by causing damage or injury to the cotton plant. This damage induces the plant to produce ethylene, a natural plant hormone that promotes the shedding of leaves (abscission). Essentially, these chemicals force the plant to prematurely drop its leaves. Some common herbicidal defoliants include: Carfentrazone-ethyl, Thidiazuron, Diuron and Tribufos. For herbicidal defoliants to be effective, it is essential that

every leaf on the plant comes into contact with the chemical. This is because the success of the defoliation process depends on how well the chemical penetrates and spreads over the leaf surface. Inconsistent application or poor coverage can lead to uneven defoliation, where some leaves may not drop as intended.

Hormonal defoliants enhance the production of ethylene in the plant or inhibit the transport of auxins, another type of plant hormone that generally prevents leaf abscission. By manipulating these hormonal pathways, hormonal defoliants effectively promote the shedding of leaves. Hormonal defoliants tend to be more sensitive to environmental factors such as temperature and the specific conditions of the crop. This means that their effectiveness can vary more compared to herbicidal defoliants, which are generally less affected by such factors.

Choosing the right type of defoliant is crucial for achieving efficient and effective results. Herbicidal defoliants require precise application to ensure that all leaves are treated, while hormonal defoliants need to be selected based on the prevailing environmental conditions and the specific needs of the cotton crop. Proper application techniques, timing, and environmental considerations all play a significant role in determining the success of defoliation and, ultimately, the quality and quantity of the harvested cotton.

Some common defoliants are:

- **Thidiazuron (TDZ)**: Inhibits auxin transport and stimulates ethylene production, promoting abscission. Recent studies on thidiazuron (TDZ) have revealed that it can regulate cotton defoliation by enhancing the activity of cell wall-degrading enzymes and increasing ethylene production. Additionally, the crosstalk between cytokinin and ethylene signaling pathways plays a key role in controlling cotton defoliation in response to TDZ.
- **Ethephon**: Releases ethylene upon decomposition, directly increasing ethylene levels in the plant. Ethephon is an ethylene precursor that is used as both defoliation and boll-opening compound in cotton.
- **Diuron and Paraquat**: Cause oxidative stress and disrupt photosynthesis, leading to accelerated senescence and abscission.

Importance of Defoliation

Defoliants play a crucial role in modern cotton farming by aiding in the efficient and timely harvesting of cotton. These chemicals are applied to cotton plants to cause the leaves to drop off, which reduce plant debris and facilitates easier mechanical harvesting. By removing the leaves, defoliants improve the visibility of cotton bolls, reducing the amount of plant material that enters the harvester and, in turn, minimizing the need for post-harvest cleaning. Defoliation in cotton plays a crucial role in optimizing the harvesting process and improving fiber quality.

- Facilitates Mechanical Harvesting: Defoliation removes leaves, preventing them from interfering with cotton pickers. This allows for a more efficient and cleaner harvest, reducing the need for manual labor.
- Improves Fiber Quality: By removing leaves before harvesting, defoliation minimizes leaf trash and contamination in harvested cotton, leading to cleaner fibers, which are essential for producing high-quality textiles.
- Enhances Boll Opening: Defoliation is often combined with boll openers to promote simultaneous leaf drop and boll opening, ensuring that the cotton bolls are fully exposed for easier picking.
- Reduces Disease and Pest Risk: Removing leaves reduces the humidity around the bolls, decreasing the risk of fungal diseases and pests that thrive in dense foliage.

- Maximizes Harvest Efficiency: Timely defoliation synchronizes the maturity of cotton plants, allowing for a one-time harvest instead of multiple passes, saving time and reducing operational costs.
- Reduces Post-Harvest Processing: With fewer leaves in the harvested cotton, the need for post-harvest cleaning and ginning is minimized, speeding up processing and improving the overall profitability of cotton production.

Factors affection defoliation

An improper defoliation strategy can significantly affect both seed cotton yield and fiber quality. Research indicates that applying defoliants too early, before the optimal stage of boll development, can lead to yield losses. However, no yield loss or reduction in fiber quality is observed when defoliants are applied after at least 60% of the bolls have opened or when there are fewer than four nodes above the cracked bolls. Timing defoliation correctly ensures that cotton plants have reached a sufficient level of maturity, protecting both the quantity and quality of the harvest. Currently, the common evaluation indices for the defoliation effect include the defoliation rate, boll-opening rate, and yield (Zhang et al., 2021).

Several factors influence defoliation in cotton, including:

- **Environmental Conditions**: Temperature, humidity, and rainfall can significantly impact the effectiveness of defoliants. Whereas extremely dry condition during defoliants application may hinder the defoliants activity. Terminating the irrigation at least 24 days before the defoliation result in good defoliation with single application of defoliant (Neupane et al., 2020). In general, excessive watering before and during defoliation can result in more vegetative growth of plants
- **Cotton Variety**: Different cotton cultivars respond variably to defoliants, with some varieties being more resistant to defoliation due to differences in leaf structure or physiological traits (Faircloth et al., 2004).
- **Plant Maturity**: The growth stage of the cotton plant affects its response to defoliants. Defoliation is more effective when the plant has reached full maturity, with open bolls and reduced physiological activity (Gormus et al., 2017). Ensure that at least 60% of the cotton bolls have opened, or that there are fewer than four nodes above the uppermost cracked boll, which indicates the cotton is mature enough for defoliation.
- **Defoliant Type and Dosage**: The choice of defoliant and the application rate can influence how well leaves drop. Some defoliants work faster or more effectively than others, and improper dosing can lead to incomplete defoliation or leaf burn. Choose a defoliant that suits the cotton variety, environmental conditions, and maturity of the plants. Consider combining defoliants with boll openers if necessary for better results. Mixture of two or more defoliants such TDZ and Ethephon can be applied for enhanced outcome. Economically, the application of a single defoliant may give satisfactory outcome however the mixtures would perform better under less desirable defoliation conditions. The manufacturer recommendations for defoliant dosages should be followed. Over-application can cause leaf burn and fiber damage, while under-application may result in incomplete defoliation. Furthermore, the defoliants may be sprayed in batches.
- **Application Timing**: Applying defoliants too early or too late in the growing season can affect their performance. Proper timing ensures optimal leaf drop and minimal impact on boll quality. Defoliants should be applied at the right time to avoid premature leaf drop, which can harm yield, or applying too late, which can affect fiber quality. Timing should align with boll maturity and weather forecasts. Premature defoliation can seriously affect crop photosynthesis and transpiration Delaying defoliation gives immature bolls more time to develop, potentially increasing yield. However, it can also delay leaf abscission,

leading to higher seed cotton trash content and elevates the risk of exposure to early frost and unfavorable weather conditions (Faircloth et al., 2004).

- **Nutrient Status**: A well-nourished plant may resist defoliation more than one under nutrient stress, particularly with high nitrogen levels, which can delay leaf abscission.
- **Abiotic/biotic Stress**: Cotton plants under drought stress may exhibit incomplete defoliation, as water-stressed plants are less responsive to defoliants. Conversely, excessive water can delay maturity and slow defoliation. Infestations or infections can weaken the plant, making it more responsive to defoliants, or, in some cases, defoliants may exacerbate existing damage caused by pests or diseases.
- **Sprayer type and mode of spraying:** Studies have found that the type of sprayer and spraying method affect the defoliation efficiency (Singh et al., 2017; Neupane et al., 2020). Use of the proper sprayer ensures uniform application of the defoliant across the entire field. Inconsistent application can lead to uneven defoliation and complicate mechanical harvesting.

Defoliation practices in different countries

Mechanized harvesting is the trend of cotton production in developed nations since it is the key measure to improve harvesting efficiency and solve the problem of labor shortage. There are some methods used by cotton growers to determine when defoliants can be applied to ensure sufficient maturity of cotton at harvest, including the percent of open bolls (POB), nodes above cracked boll (NACB) and boll cutting technique. Defoliants are sprayed when approximately 60% of cotton bolls are open, or four to five nodes above cracked boll. Technologies such as pulse width modulation (PWM), LiDAR-guided systems, unmanned aerial vehicles (UAVs), Artificial intelligence (AI) based monitoring models, remote sensing and ground robots are used as aids in cotton defoliation not only enhance mechanical harvesting and reduce labor costs but also help in efficient monitoring of the defoliation process. The use of UAV with sensors helps to obtain images of canopy after defoliant spray (Ma et al., 2023)

Fig. 2. Advanced methods for spraying of defoliants

In USA, chemical defoliants are applied through ground-based or aerial-based vehicles such as tractor-mounted boom sprayer, unmanned aerial spraying (drone spraying), and unmanned ground sprayer (robots spraying). Conventional spraying systems result in higher losses of chemical due to off target application. Thus, to tackle this problem many advance technologies such as pulse width modulation technology are developed including LiDAR-guided system, unmanned aerial vehicles, unmanned ground vehicles such as mobile robots, are used to minimize the off-target loss and maximize the efficiency of chemical spraying. For cotton defoliation sprayers, US farmers usually use a boom sprayer (Neupane et al., 2023). Although, UAV sprayings are found to be more

efficient than traditional ground based spraying, but there are some regulatory issues and Federal Aviation Authority (FAA) policy.

In India, the defoliants are generally sprayed 20 days before the cotton harvesting. The commonly used defoliants are 2-Chloroethyl-phosphonic acid (Ethrel), Dropp ultra, mepiquat chloride, Thiadiazuron, Diuron and formulations developed by mixing different defoilants. The defoliants are manually sprayed by ground-based spraying systems. Mainly used sprayers for spraying defoliants are Mobile Backpack (MBP) electrostatic sprayer (ESS, Make: USA) and hand operated knapsack sprayer (Singh et al., 2017). The aerial UAV based spraying of defoliants has not yet started in India. Moreover, AI based monitoring of canopy and defoliation efficiency is under process.

Conclusion

Defoliation plays a crucial role in cotton harvesting, affecting not only the quality and yield of the crop but also making the harvesting process more efficient. In developed countries, cutting-edge technologies and tools, such as AI-based monitoring systems and advanced sprayers, are utilized for defoliant application and monitoring. These technologies enhance the effectiveness of defoliants, precisely control the leaf drop process, and increase the efficiency of mechanical harvesting.

In developing countries, such as India, traditional and less technical methods are often used for applying defoliants. The lack of advanced technologies limits the potential improvements in the defoliation process, which can negatively impact crop harvesting and quality. In the future, adopting advanced technologies by developing countries could improve the defoliation process, leading to enhanced crop quality and harvesting efficiency.

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