

Maximising Crop Protection Performance: How Spray Quality Improves Yield, Quality and Return per Hectare

FROST & SULLIVAN WHITEPAPER

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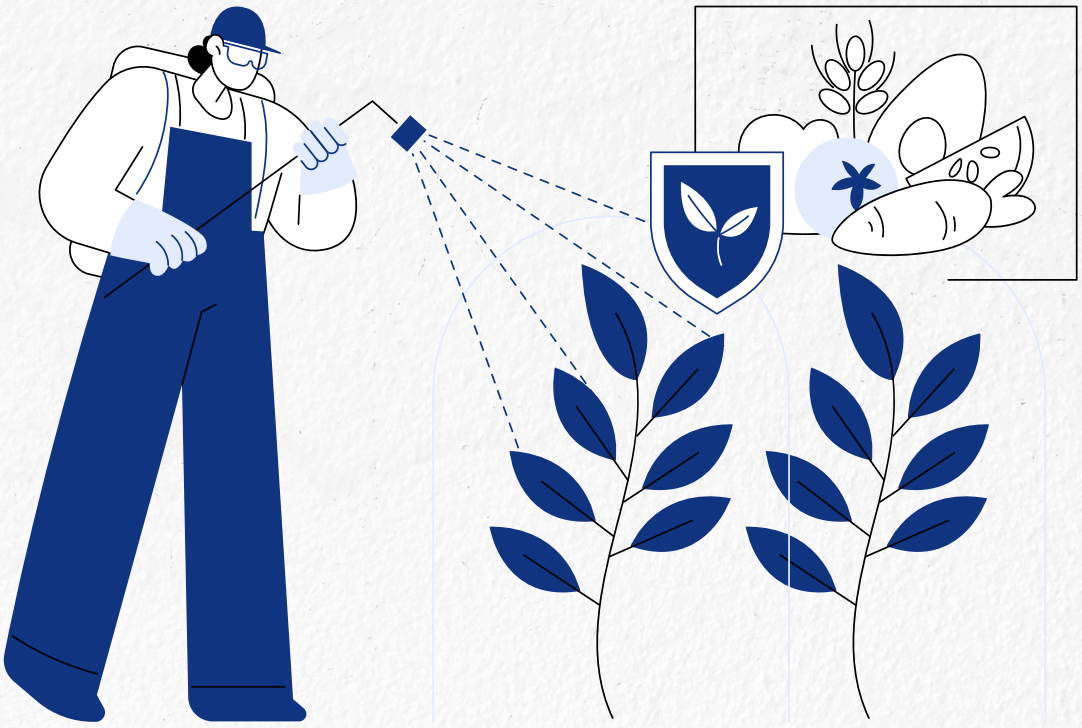
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Introduction: Escalating Biological Threats Across Agricultural Systems

Global agriculture is reaching a critical inflection point as climate variability increasingly alters how crops grow, develop, and defend themselves against external pressures. Among the most significant consequences is the growing incidence and severity of pest and disease outbreaks, which are emerging as a major threat to agricultural productivity, farm profitability, and food system resilience.

The economic consequences are already substantial, with plant diseases costing the global economy more than $220 billion annually, while invasive insects contribute at least $70 billion in additional losses each year.[29]

Cyclical climate phenomena such as **El Niño** and **La Niña** further intensify this variability, affecting agricultural conditions across major production regions, including **Asia, Latin America, Sub-Saharan Africa, and key temperate regions.** Changes in temperature, humidity, and growing seasons are reshaping pest and disease dynamics by:



Accelerating pest life cycles



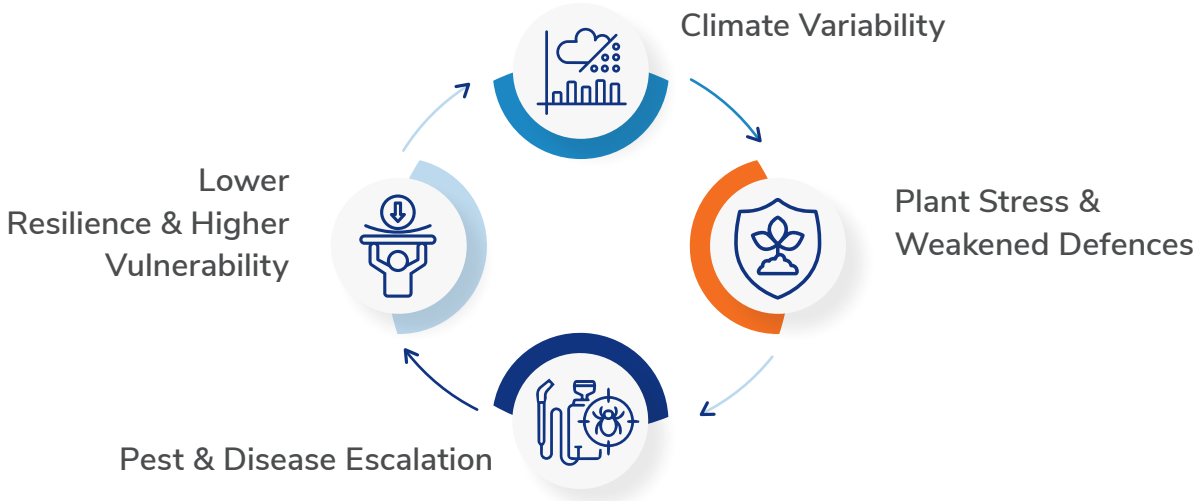
Increasing reproduction rates



Expanding pest and disease geographic spread

Climate-induced stress weakens crop defences, increasing susceptibility to pest and disease pressure. As crop resilience declines and vulnerability increases, agricultural systems become more exposed to subsequent climatic stresses, creating a self-reinforcing cycle of escalating biological risk and productivity losses, as illustrated in the climate-induced risk cycle.

Climate-Induced Risk Cycle



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As global food production demands increase, agricultural systems are intensifying, leading to greater exposure to these risks. High-density cropping, multiple growing cycles, and input-intensive farming practices concentrate biological and economic risk per hectare, reducing growers' tolerance for pest- and disease-related losses.

Pests, diseases, and weeds account for a substantial share of global agricultural yield losses:

- **Pests and diseases: ~20–40% of global crop output lost annually**[4]
- **Weeds: up to ~30–35% losses in unmanaged systems**[9],[23]

Pest and disease damage originating at the production stage extends beyond the farm, propagating and amplifying losses across downstream stages of the food value chain.

Pest & Disease-Driven Loss Cascade Across Food Value Chain [6]



The cascading amplification of pest- and disease-driven losses across the value chain poses a direct threat to food security by affecting the availability, stability, and accessibility of quality produce. Thus, effective crop protection interventions are becoming more important than ever to strengthen crop resilience and protect yields.

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Chapter 1: The Operational Reality of Intensified Crop Protection

As production intensity and biological pressures have increased, crop protection has played an increasingly important role in maintaining agricultural productivity and crop quality. This growing dependence is reflected in global pesticide use, which has increased by approximately **14% over the past decade** and nearly **doubled since the 1990s.**[1]

In modern high-intensity systems, crop protection outcomes rely on a limited number of precisely timed interventions, aligned with crop growth stages and pest development thresholds. The success of these interventions is increasingly constrained by reduced effective modes of action, tightening residue and sustainability requirements, and rising cost pressures.

Rising Spray Demand vs. Shrinking Spray Windows

Crop protection programs are becoming more complex, particularly in high-value and quality-sensitive crops, where maintaining baseline protection now requires multiple applications per season.

Spray Intensity and Operational Implications

Crop Type	Spray Application Window	Spray Applications Per Season[7],[8]	Spray Economics and Complexity
Cereals	**Narrow and weather-dependent fungicide windows,** with rainfall variability reducing timely application opportunities	2-5	**High acreage-driven cost** with high **timing dependency.**
Oilseeds	**Moisture-driven infection cycles with a short intervention window** once infection begins	2-6	**Moderate cost** with **high sensitivity to missed applications.**
Vegetables	**Frequent disruption and compression of spray windows** due to humidity and rapid pest development	10-20	**High cost** and operational intensity with **continuous intervention.**

Source: Frost & Sullivan Analysis

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Crop Type	Spray Application Window	Spray Applications Per Season[7],[8]	Spray Economics and Complexity
Fruits	**Persistent pressure with tightly timed protective windows,** where delays directly impact quality and marketability	15-30	**Very high cost** with **strict precision** and **quality dependence.**

Many high-value crops now require double-digit spray applications per season.

Bananas	Tomatoes	Grapes	Citrus
			
30 applications or higher under severe disease pressure	**15–25 applications**	**12–18 applications**	**8–12 applications**

Implication for Growers

Growers are now relying on more frequent and precisely timed interventions to maintain effective protection. This increasing application intensity is also raising the overall investment required for crop protection, with total expenditures in many high-value crops increasing by **more than 20% over the past decade**. Consequently, the margin for error across each production cycle continues to narrow.

Under these conditions, suboptimal spray performance can result in direct yield and quality losses, while leaving limited opportunities for recovery later in the season. This is particularly critical in quality-sensitive crops, where marketability and economic returns are highly dependent on maintaining effective protection throughout the production cycle.

As a result, each spray event now carries greater operational and economic significance, increasing the need for reliable and consistent field-level performance.

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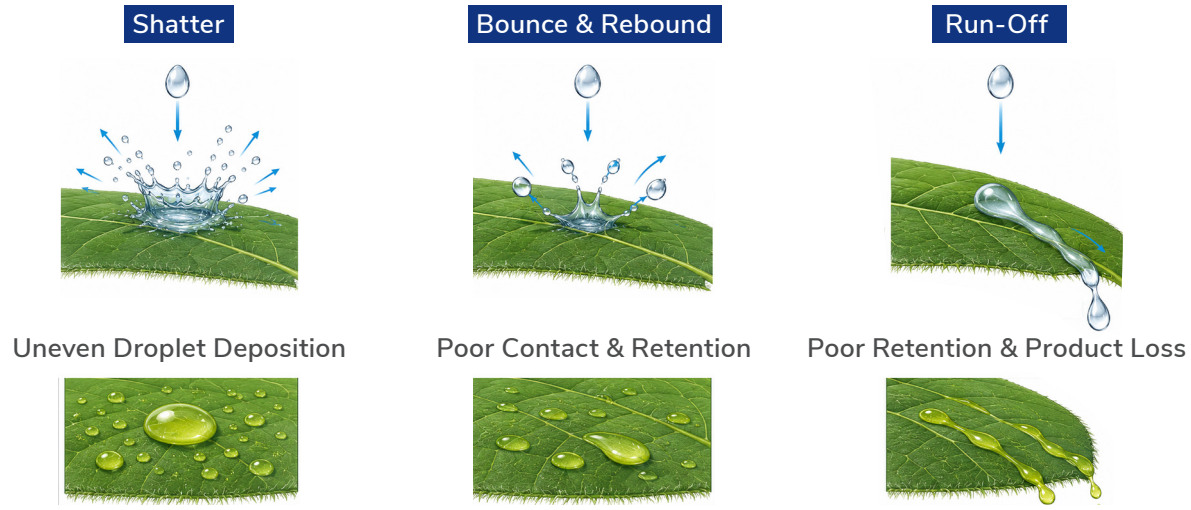
Chapter 2: The Delivery Gap – Why Efficacy Doesn't Always Translate

Under real-world field conditions, a substantial portion of applied spray fails to reach or remain on the intended biological target. Studies indicate that up to **60%** of spray volume can be lost due to physical and environmental factors, creating a significant delivery gap between applied input and effective performance.[10]

Key loss pathways include,

- **Drift** - fine droplets carried away by wind
- **Evaporation** - droplets shrinking or disappearing before reaching the target
- **Off-target deposition** - spray reaching unintended surfaces (between rows or outside the target surface), often resulting from drift

Spray Droplet Behaviour Following Leaf Impact



Spray-drop behaviour determines how much product remains on the target.
Better retention = Better coverage = Better control.

Improving Spray Performance: Role of Agricultural Spray Oils and Adjuvants

The loss pathways highlight a significant challenge in crop protection: the effectiveness of an application relies not only on the active ingredient but also on how well it is delivered to and retained on the target. Consequently, the quality and physical characteristics of spray applications are crucial factors that determine field-level performance; however, they are often neglected.

Agricultural spray oils and adjuvants play a key role in addressing this gap by modifying the physical behaviour of droplets from application through to uptake. They function primarily through contact and surface interaction within the plant, making their effectiveness dependent on spray coverage, deposition, and retention. While both influence spray performance, each plays a distinct role in improving pesticide efficacy.

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- **Spray oils** are typically mineral or plant-based oils that can act both as crop protection agents and as performance enhancers. Key spray oil benefits include enhanced spreading, retention, and penetration on plant and insect surfaces, while in some cases, spray oils also contribute directly to pest control. Spray oils may be used as standalone treatments or in combination with other products.
- **Adjuvants** are additives used in combination with crop protection products to enhance spray performance. These include different formulation types such as mineral oil-based adjuvants, silicone-based surfactants, ethoxylated surfactants, and methylated seed oils (MSO). They improve spray coverage, retention, and penetration on plant surfaces, leading to more consistent weed control and improved herbicide efficacy under field conditions.

In this context, spray oils and adjuvants align closely with integrated pest management (IPM) principles, which emphasize improving the effectiveness of each application rather than increasing input intensity.

Making the Right Choice of Spray Oils and Adjuvants

The effectiveness of spray oils and adjuvants depends on their alignment with crop type, target biology, and field conditions. Selecting the appropriate solution is therefore critical to ensure that improvements in spray behaviour translate into measurable performance gains.

However, crop protection decisions are often evaluated on a cost-per-litre or cost-per-hectare basis, which does not fully capture the impact of application quality on yield, crop quality, and overall system efficiency. This approach overlooks the role of spray performance in determining how effectively inputs are delivered and utilised.

A more relevant decision framework is based on return per hectare, where both biological effectiveness and operational performance determine outcomes. In this context, improving spray performance becomes a multi-dimensional challenge requiring the optimisation of four interdependent parameters,



Efficacy - delivering sufficient and uniform deposition, retention, and uptake of the active ingredient at the target site



Operational Efficiency - achieving effective application within available spray windows while minimising the need for repeat applications, rework, and additional input costs.



Crop Safety - avoiding phytotoxic effects by ensuring that spray composition, dose, and uptake remain within the tolerance limits of the crop



Marketable Output - maximising the proportion of yield that meets quality, residue, and visual standards required for sale

These parameters collectively determine whether a spray treatment delivers economic value in practice.

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Chapter 3: Crop Structure, Application Complexity, and Risk Exposure

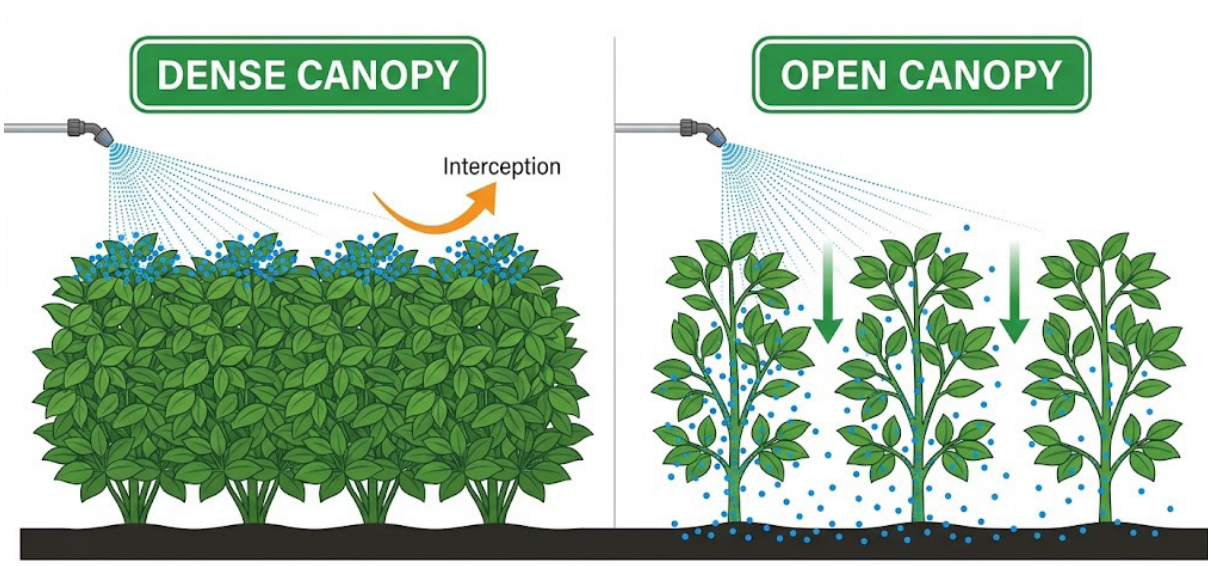
Crop protection programmes cannot be uniformly applied across all crops, as spray performance and control outcomes vary significantly under different canopy (crop foliage) environments. Successful pest, disease, and weed management depends not only on the chemistry applied, but also on how effectively sprays interact with crop structure. Orchards, row crops, vines, and dense tropical systems each present distinct canopy environments, which directly affect spray deposition, retention, and target exposure for pests, diseases, and the crop itself.

Open vs Dense Canopies

Microclimate and Spray Interaction Differences[10],[12]

While crop structure is often described at the species level, in practice, it is not fixed. Canopy architecture is strongly influenced by planting density, cultivar selection, nutrient management, and growth stage.

From a spray-and-deposition perspective, most cropping systems can be broadly classified into two structural types: Dense and Open canopies.



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Feature	Dense Canopy	Open Canopy
Crop Structure	Closely spaced plants with overlapping foliage form a multi-layered canopy	Widely spaced plants with exposed soil between rows
Representative Crops	Bananas, citrus fruits, grapevines, strawberries, sugarcane, soybeans, cotton, forestry, pasture, and forage crops	Almonds, avocados, maize, chickpeas, winter cereals, and certain other crops
Light Penetration	Low; strong self-shading within the canopy	High; reaches lower canopy and soil surface
Airflow & Humidity	Restricted airflow, higher humidity	High airflow, lower humidity
Dominant Risks	Fungal & bacterial diseases, sheltered pests	Weed competition, exposed insect pests
Spray Interaction Challenge	Limited penetration and uneven distribution within the inner canopy layers	High drift risk and inconsistent retention on exposed surfaces
Primary Protection Focus	Deep canopy penetration and retention on inner leaves, stems, and fruiting zones.	Effective herbicide coverage and retention; consistent deposition on exposed foliage

Implications for Spray Performance Across Crop Structures

In **dense canopies**, the primary limitation is **access, penetration, and distribution** within inner canopy layers, where pests and diseases are often most active. Effective control, therefore, depends on the ability of sprays to reach and persist on protected surfaces throughout the canopy profile.

In **open systems**, the challenge shifts to **control and consistency**, maintaining adequate deposition and retention under exposed, variable conditions, particularly for effective weed control and management of exposed pest populations.

Crop structure directly influences the design and execution requirements of crop protection programmes. Spray strategies that perform effectively in one canopy environment may not deliver comparable outcomes in another. This reinforces the importance of field-level validation and crop-specific optimisation to ensure consistent biological control.

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Chapter 4: Evidence From the Field: Crop-Level Insights Across Regions

Crop Protection Insights Across Major Agricultural Regions[1]

Europe

A major producer and exporter of high-value, quality-sensitive horticultural crops.

Changing temperature and precipitation patterns are reshaping pest and disease dynamics, while stringent quality, residue, and sustainability requirements leave limited tolerance for control failures.

India & Rest of Asia

Accounts for over **50%**[1] of global agricultural output and is the world's leading producer of cereals and pulses.

Monsoon-driven weather, multiple crop cycles, and diverse production systems create persistent pest pressure and narrow intervention windows.



North America

A leading producer and exporter of high-value, quality-sensitive crops, alongside globally significant production of industrially important cereals and oilseeds.

Temperature extremes, changing rainfall and winter patterns, and expanding invasive pest ranges are increasing crop protection complexity.

Latin America

The world's **second-largest** agricultural region, contributing over **20%**[1] of global agricultural exports.

Tropical growing conditions and year-round pest pressure increase the importance of timely and effective crop protection interventions.

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I. Dense Canopy Crops

1. Citrus Crops (Oranges, Mandarins, Lemons, Limes, Grapefruit, and Other Citrus Crops)

Economic Relevance

Citrus is a high-value, globally traded crop with major production hubs in **LATAM (Brazil, Mexico, Argentina)** and **Asia (China, India)**[18]. External fruit quality directly determines marketability, particularly in export markets. Even minor pest or disease damage can lead to downgrading or rejection, resulting in significant economic loss. In export-oriented systems, maintaining cosmetic quality and compliance with residue limits is critical to realising full value from each harvest.

Structural Constraints

- Dense, multi-layered canopy with limited airflow and elevated internal humidity
- Fruit positioned within inner canopy zones
- Microclimatic conditions conducive to fungal diseases, especially under high humidity
- High sensitivity to cosmetic damage and strict residue compliance requirements

Common Pests and Diseases[9], [14]

- **Direct fruit pests:** fruit flies (Bactrocera, Ceratitis), scale insects (Aonidiella aurantii)
- **Vector-driven pests:** Asian citrus psyllid (HLB vector)



- **Foliar & fruit diseases:** citrus canker, scab, Cladosporium (fungal infection)



- **Secondary stressors:** mites, whiteflies

Spray Performance Challenges

- Uneven spray penetration into inner canopy zones
- Poor retention on fruit surfaces under humid conditions
- Reduced efficacy against concealed or protected pests, particularly scale insects and psyllids

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Field Evidence – Effectiveness of Spray Oils

Spray oils have been proven as an effective solution to prevent and mitigate the impacts of citrus diseases. Multiple field and industrial studies highlight their role in improving control, protecting fruit quality, and reducing disease risk.

(1) Field-Level Pest Control: Scale Management (Argentina, LATAM)

Gulf's spray oil field study conducted for the control of Australian red scale in lemon crops were observed to outperform both untreated and standard mineral oil programs, delivering superior control outcomes.

Key Outcomes



Infestation reduced from ~70% → ~30%



Packable fruit increased from ~50% → ~85%



Improved uniformity and no phytotoxicity

(2) Other Regional Studies

- **Citrus Psyllid and HLB Management (LATAM and Asia):** Spray oil programs are known to contribute to suppression of Asian citrus psyllid populations, reduced feeding and oviposition activity, and support lower HLB transmission risk.
- **Post-Harvest Cladosporium Management (Peru, LATAM):** Mineral oil-based treatment protocols used in mandarins and limes improved storage stability, reduced Cladosporium incidence, and lowered export rejection risk. Spray oils are also included within integrated Cladosporium management guidelines developed by Procitrus in Peru.[30]

Implication for Growers

For citrus growers, selecting the right spray oil is critical to improving spray coverage protecting fruit quality, and reducing downgrading and rejection risk in export markets.

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2. Grapevines (Table and Wine Grapes)

Economic Relevance

Grapevines represent a globally important crop, with major production **across LATAM (Peru, Chile), Europe (Spain, Italy, France), and Asia (India, China).**[18] Export markets in LATAM, Europe, and parts of Asia are primarily driven by table grape production, where fruit appearance, uniformity, and shelf life directly determine marketability and pricing. In contrast, wine grape production is more concentrated in **Europe,** followed by the **United States, Argentina, Chile, Australia, and South Africa,** where value is influenced by intrinsic quality parameters such as sugar content, flavour profile, and composition.

Structural Constraints

- Canopies rapidly transition to dense, multi-layered foliage during the season
- Shaded, humid microclimates favour disease development within inner canopy zones

Common Pests and Diseases[9],[15],[28]

- **Powdery mildew (Erysiphe necator)** – infects all green tissues; persists across diverse climates with yield losses up to **75-100%** if uncontrolled



- **Downy mildew (Plasmopara viticola)** – yield losses as high as **30–40%**; increasing under changing climate patterns



- **Vector-driven pests -** sharpshooters (vectors of Xylella fastidiosa)

Spray Performance Challenges

- Shadowing and uneven spray penetration and distribution into cluster zones and across bunches
- Reduced persistence under humid conditions, enabling rapid disease development

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Field Evidence – Effectiveness of Spray Oils

Field-Level Pest Control: Powdery Mildew (Peru, LATAM)

Spray oils demonstrate effectiveness in improving disease control under dense canopy conditions typical of table grape production systems. Gulf's spray oils tested on the field[35]demonstrated significantly lower infestation rates compared to untreated and standard programs.

Key Outcomes

Infestation reduced from **~16% → 5.5–8%** across treatments

Efficacy improved from **~80% → ~88%** at higher rates

A clear dose-response relationship and no phytotoxicity

Implication for Growers

In table grape production, where cosmetic quality determines marketability, improving spray delivery through spray oils ensures effective disease control within clusters, directly reducing rejection risk and improving export-grade yield.



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3. Berries (Strawberries, Blueberries, Raspberries, Blackberries, and Related Berry Crops)

Economic Relevance

Berries, including strawberries, blueberries, raspberries, and blackberries, represent a high-value, trade-intensive segment with production concentrated across **North America (US, Mexico), LATAM (Mexico, Chile, Peru), Europe (Spain, Poland), and Asia (China).**[18] With near-zero tolerance for cosmetic defects, even minor pest damage can render fruit unmarketable, directly impacting profitability.

Structural Constraints

- Low-growing, dense canopy with fruiting close to the soil surface
- High humidity within the fruiting zone, favouring pest development
- Target zones are often shielded by foliage

Common Pests and Diseases[9],[16]

- **Fruit-feeding and quality-damaging pests:** Lygus bugs and spotted wing drosophila (D. suzukii), directly impacting fruit shape and marketability



- **Canopy and foliage pests:** two-spotted spider mite (Tetranychus urticae), thrips, and aphids, affecting plant health and acting as vectors for secondary damage



- **Fungal diseases:** Botrytis (gray mold) and powdery mildew, driving both field losses and post-harvest rejection under humid conditions

Spray Performance Challenges

- Limited spray penetration into the lower canopy and fruiting zones
- Obstruction from foliage and fruit positioning, resulting in inconsistent spray contact
- Poor retention on smooth, delicate fruit surfaces, reducing the persistence of protection

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Field Evidence – Effectiveness of Spray Oils

Published studies on strawberries and other berry crops, as well as Gulf's field trials in Argentina, demonstrate that oil-based treatments can reduce mite populations, suppress pest reproduction, and improve crop protection performance under challenging field conditions.

Key Outcomes

Adult mite populations reduced by up to **~66%**

Egg incidence reduced by up to **~44%**

No phytotoxicity observed

Implication for Growers

In berry production systems, effective pest control depends on achieving consistent coverage in the lower canopy and fruiting zones. Spray oil applications improve contact and disrupt pest population dynamics, resulting in better fruit quality, reduced rejection risk, and reliable performance under humid conditions.



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4. Bananas

Economic Relevance

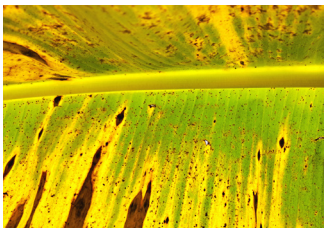
Bananas are a critical global crop with major production in **India, Southeast Asia, LATAM, and Africa**[18], supporting both export markets and smallholder livelihoods. In export systems, uniform fruit appearance and quality are key. Thus, disease management is a critical determinant of productivity, requiring frequent and highly effective spray programs to maintain yield and market access.

Structural Constraints

- Dense, perennial canopy with overlapping leaves and high humidity
- Year-round cropping cycles sustain continuous pest and disease pressure
- Large plant structure and protected zones limit spray reach and uniformity

Common Pests and Diseases[9],[17],[31]

- **Sigatoka leaf diseases (Black and Yellow Sigatoka)** – affects leaf photosynthesis and yield loss up to **~20-50%**





- **Banana freckle** - Surface-level disease affecting both leaves and fruit
- **Cordana leaf spot** – Secondary foliar disease under humid conditions
- **Thrips** – fruit scarring affecting market quality

Spray Performance Challenges

- Incomplete coverage of leaf surfaces results in uneven disease suppression and faster symptom progression
- Reduced persistence under wet and humid conditions
- Contact dependency is critical, making application quality and calibration a primary determinant of outcome



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Field Evidence – Effectiveness of Spray Oils

(1) Sigatoka Suppression and Yield Improvement (India)[31],[34]

Field studies in bananas show that adding mineral oil to fungicide programs significantly enhances disease control and yields, achieving **up to 50%** reduced disease incidence and a better benefits-to-costs ratio compared to fungicide-only applications.

The spray programs recommended by the Indian Council of Agricultural Research - National Research Centre for Banana (ICAR-NRCB) include the use of mineral oil in combination with fungicides for managing Sigatoka in bananas, which has the potential to **improve yield by up to 20%, with better penetration and fungistatic effect.**

(2) Ongoing Evaluation – Sigatoka disease in dense Banana canopies (Brazil)

In Brazil, Gulf spray oils are being assessed as part of Sigatoka management programs. Improved spray coverage, more uniform deposition, and compatibility with high-frequency spray schedules are expected to enhance fungicide performance and support more effective disease suppression in dense canopies.

Implication for Growers

Integrating spray oils within fungicide programs improves deposition and retention, translating into lower disease severity and higher yield in bananas. This reinforces the effectiveness of spray oils when supported by well-executed spray programs, where calibration, coverage uniformity, and timing are critical.



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5. Tomatoes

Economic Relevance

Tomatoes are among the most widely cultivated crops globally, with strong production in **China, India, and LATAM**[18], serving both fresh and processing markets. High sensitivity to quality defects and pest damage makes effective crop protection critical for both yield and marketability.

Structural Constraints

- Canopy transitions from semi-open to dense as the crop develops
- High foliage density and limited airflow in later stages
- Fruit and lower canopy zones are often difficult to access

Common Pests and Diseases[9]

- **Tomato leafminer (Tuta absoluta)** – invasive pest causing **11–43%** yield loss; near-total loss in severe outbreaks



- **Fruit borers (Helicoverpa spp.)** – direct fruit damage (**20–30%** loss)



- **Whiteflies (Bemisia tabaci)** – vector of Tomato Yellow Leaf Curl Virus (TYLCV)
- **Thrips** – transmit viral diseases and damage flowers and fruits

Spray Performance Challenges

- Limited penetration into the lower canopy and fruiting zones
- Shielding of leaf undersides and internal foliage, reducing direct spray contact with larvae and eggs
- Reduced efficacy under high pest pressure, due to rapid reproduction cycles



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Field Evidence – Effectiveness of Spray Oils

Gulf conducted field trials to asses the control of leafminer in industrial tomatoes. Gulf spray oils contributed to improved suppression of Tuta absoluta, with reduced larval survival and activity.

Key Outcomes

- Reduced larval survival and adult moth activity
- Evidence of larval mummification, indicating direct impact on pest development
- Effective suppression and no phytotoxicity

Implication for Growers

In tomato systems, improved spray delivery enhances control of invasive pests such as *Tuta absoluta*, reducing fruit damage and increasing marketable yield, while ensuring more consistent fruit quality.



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6. Other Dense Cropping Systems

6.1. Industrial Field Crops (Soybean, Cotton, Sugarcane)

Economic Relevance

Soybean, cotton, and sugarcane are cornerstone crops across **LATAM, India, and the US**[18], supporting global food, fibre, and energy systems. Their dense canopies and long growing seasons sustain continuous pest pressure at scale.

Structural Constraints

- High biomass and canopy closure during peak growth stages
- Extended crop duration with multiple pest cycles
- Large field areas requiring consistent, repeatable spray performance

Common Pests and Diseases[9]

Crop	Key Pest Complex	Impact on Yield & Quality [9],[20]
Soybean	Caterpillars (Spodoptera), stink bugs, aphids	**20–50%** yield loss (aphids); defoliation & pod damage
Cotton	Bollworms, pink bollworm, whiteflies	**20–30%** yield loss; fibre quality penalties
Sugarcane	Stem borers, spittlebugs	**5–20%** yield loss; >30% sugar loss in severe cases

Spray Performance Challenges

- Performance variability increases across large acreages
- Rapid pest reinfestation under continuous cropping cycles reduces the effective protection window between applications

Commercial Adoption of Spray Oils

Studies indicate that spray oils are known to improve spreading and canopy coverage, enhance performance consistency across large field areas, and support integration with insecticides and fungicide programs.

Implication for Growers

In high-biomass field crops, spray oils support repeatable, reliable crop protection outcomes, which are critical for maintaining yield and quality in large-acre, high-input production systems.

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6.2. Long-Cycle, High Biomass Crops (Pasture and Forestry)

Economic Relevance

Pasture and forestry systems underpin livestock productivity and long-term biomass value, where pest outbreaks can have cascading economic effects.

Structural Constraints

- Continuous or long-duration growth cycles
- Large-scale exposure to pest outbreaks
- Limited recovery potential once damage occurs

Common Pests and Diseases[9]

System	Key Pest	Impact [9],[21],[22]
Pasture	Spittlebugs, armyworms, locusts	**30–66%** forage loss; **>70%** livestock productivity impact
Forestry	Bark beetles, defoliators	**20–30%** growth loss; large-scale tree mortality

Spray Performance Challenges

- Access limitations in large-scale, uneven terrain systems, reducing consistency of spray delivery
- Delayed detection and rapid pest escalation, limiting the effectiveness of spray interventions

Commercial Adoption of Spray Oils

Spray oils see limited adoption in pasture and forestry systems, primarily as part of integrated pest management (IPM) programs. Spray oils support insecticide efficacy, deposition uniformity, and early-stage infestations, including in aerial and high-volume spray systems.

Implication for Growers

In long-cycle systems, early and effective intervention is critical, as delayed or ineffective control leads to prolonged economic and ecological damage. Outcomes are strongly influenced by timing, scale of application, and operational execution, making spray oils a supporting tool within broader pest management strategies.

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II. Open Canopy Crops

1. Almonds

Economic Relevance

Almonds are high-value export crops with major production in **North America, the Mediterranean region, and Australia**[18]. Strict grading standards for kernel quality and safety mean even minor pest damage can lead to direct economic loss.

Structural Constraints

- Open canopy structure with exposed foliage and fruiting sites
- High exposure to environmental conditions (heat, wind, low humidity)

Common Pests and Diseases[9], [22]

- **Navel orangeworm** – direct kernel damage and aflatoxin risk (**5–10%** loss common)



- **Spider mites** – reduce photosynthesis and impact nut development



- **Hull and seed borers** – premature nut drop and reduced yield
- **Aphids and scale insects** – secondary but locally damaging

Spray Performance Challenges

- High exposure leads to spray drift and evaporation losses, reducing effective deposition on target surfaces
- Limited retention under dry and windy conditions, impacting persistence of protection on leaves and nuts



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Field Evidence – Effectiveness of Spray Oils

Control of Spider Mite in Almond Orchards (Chile)

Gulf conducted field trials in almond orchards in Chile to evaluate the impact of spray oil-based crop protection programs on mite management and crop safety.

Key Outcomes

~95% reduction in Bryobia rubrioculus adult populations

~2.4× higher mortality in Panonychus ulmi vs reference treatment

Lower egg counts and no phytotoxicity

Implication for Growers

In almond systems, where fruiting sites are exposed and quality standards are stringent, effective pest control depends on maintaining adequate spray retention and coverage under adverse environmental conditions. Field evidence indicates that spray oil applications improve mite control and suppress population development, supporting protection of leaf function and nut quality.



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2. Avocado (Palto)

Economic Relevance

Avocado is a high-value export crop, particularly in **Peru, Mexico, and Chile**, where fruit quality, appearance, and shelf life directly determine marketability and pricing in international markets.

Structural Constraints

- Open canopy with exposed fruit and foliage to weather conditions
- High sensitivity of fruit surface to pest damage and residues

Common Pests and Diseases

- Thrips – cause fruit scarring and downgrade export quality
- Mites – affect leaf function and fruit development



- Scale insects – affect plant health and fruit quality



- Anthracnose / post-harvest pathogens – impact export viability

Spray Performance Challenges

- Spray drift and evaporation reduce effective deposition on exposed fruit surfaces
- Limited retention on smooth fruit skins, impacting the persistence of protection

Field Evidence – Effectiveness of Spray Oils

- Studies indicate that mineral oil applications are effective in controlling avocado red mite populations, with activity against both egg and motile stages in LATAM orchard systems.[32]
- In addition, the use of spray oils in combination with insecticides improves coverage and interaction with target pests such as thrips, contributing to reduced fruit scarring and improved marketable yield.[33]

Implication for Growers

In avocado systems, improving spray coverage is critical to minimising downgrade risk. Spray oil use supports more reliable crop protection under exposed orchard conditions, enabling higher pack-out rates and more consistent export-grade fruit.

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3. Field Crops (Maize and Winter Cereals)

Economic Relevance

Maize and winter cereals are foundational to global food systems, with strong production across **India, LATAM, Africa, and major global markets.** As large-scale, open-field crops, even small percentage losses translate into significant impacts on food security and farmer income.

Structural Constraints

- Open canopies with high exposure to wind, temperature, and environmental variability
- Large-scale spraying requiring uniform coverage across wide areas
- Early growth stages are highly vulnerable to weed competition
- Performance is dependent on consistent deposition and retention, rather than penetration

Common Pests and Diseases[9], [23]

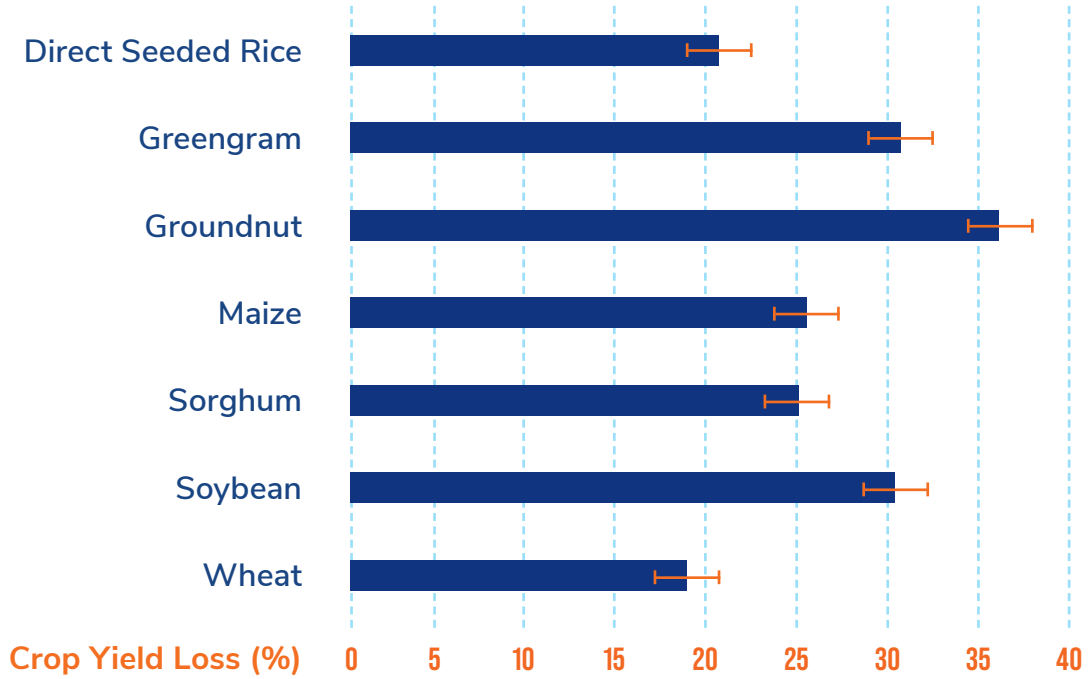
Crop	Key Threat	Impact
Maize	Fall armyworm, stem borers, ear feeders, rootworms	**15–50%** yield loss; near-total loss in severe cases
Winter Cereals	Aphids (BYDV), Hessian fly, armyworms	**5–30%** yield loss; grain quality reduction
Both	Weeds (early-stage competition)	Significant yield loss (**30%** for wheat and maize, and **up to 90%** for rice) via nutrient and water competition

Weed competition is one of the most significant and often underestimated constraints in open-field cropping systems. In India, yield losses from uncontrolled weed growth vary widely across major crops, with substantial reductions observed in cereals, pulses, and oilseeds.



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Yield losses due to weeds, India[23]



These losses are driven by early-season competition for nutrients, water, and light, which can irreversibly reduce crop establishment and yield potential if not effectively managed. Importantly, the extent of yield loss is highly sensitive to the effectiveness and consistency of herbicide application under field conditions.

Field Evidence – Effectiveness of Adjuvants

Gulf conducted field trials[36] in Argentina to evaluate the impact of adjuvants for herbicides on the control of Amaranthus weeds. The trials demonstrated improved weed management performance.

Key Outcomes

17% better weed control vs other adjuvants	**35%** better weed control vs herbicide alone	Stronger and more consistent weed control	Higher adjuvant rates improved persistence of control

Implication for Growers

Field evidence shows that adjuvants significantly improve herbicide performance by enhancing deposition and retention on target weeds, resulting in more consistent and durable control. This translates to stronger crop establishment and higher likelihood of achieving full yield potential.

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Chapter 5: The Economics of Spray Performance: From Efficacy to Returns

Spray Performance is the Primary Driver of Economic Outcome

The true value of crop protection lies in the volume of crops that are successfully protected and brought to market, not in the mere quantity of inputs applied. The effectiveness of the spray plays an important role in realising that value.

For growers, a more complete view considers how spray application quality influences yield outcomes, price realisation, and operational cost dynamics, which shifts the focus from input cost to return per hectare. Understanding these linkages provides a broader perspective on how crop protection performance contributes to farm-level profitability.



Marketable Yield, Quality, and Return per Hectare

In crop production, farm profitability depends not only on total yield, but on the proportion of output that can be sold at commercial quality standards. Spray application quality influences the marketable yield through effective pest control and consistent crop quality, improving the harvest value and grade realisation. This is particularly important in high-value crops where cosmetic appearance, uniformity, and quality standards directly influence pricing. Under such conditions, even modest improvements in spray performance can generate meaningful economic gains through higher proportions of commercially saleable output.



Operational Efficiency and the Cost of Re-Sprays

The economics of spray performance are also shaped by how efficiently a crop protection program can be executed in the field. Inconsistent spray application quality can create additional operational burden through repeat applications, higher machinery use, more labour hours, and added pressure on already constrained spray schedules. Over large acreages or across repeated spray cycles, these inefficiencies can materially increase the overall cost of crop protection.



Spray Oils: Value Creation Through Improved Crop Outcomes

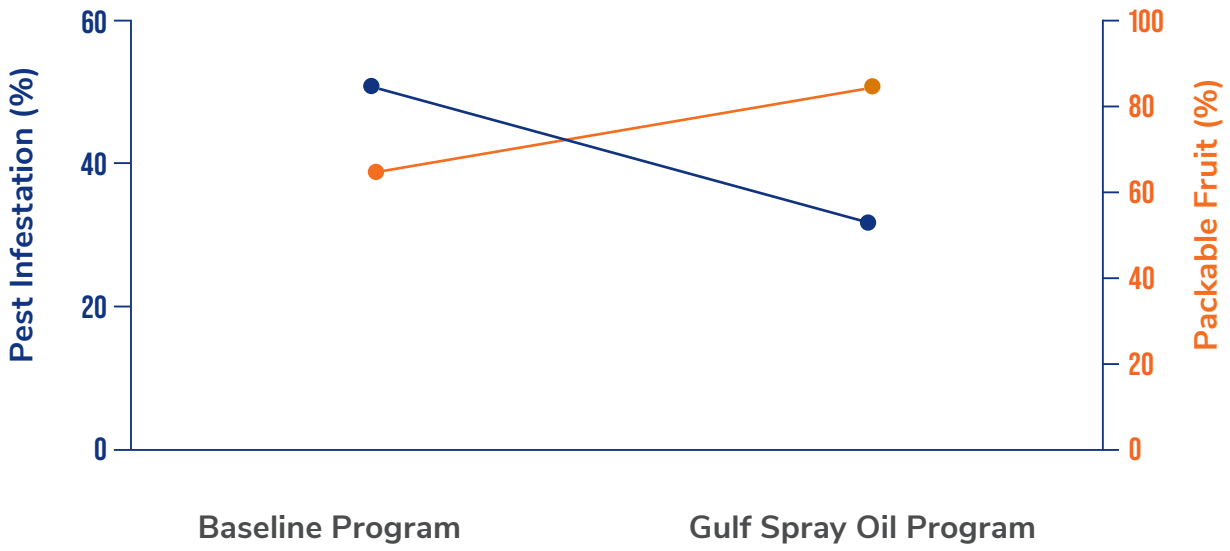
As demonstrated in the field examples spray oil-based crop protection programs have consistently contributed to lower pest infestation levels across a range of crops and production environments.

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Across citrus, grapevines, strawberries, and almonds, field evaluations demonstrated infestation reductions ranging from approximately **36% to 95%** relative to baseline programs.

Lower infestation levels help preserve a greater proportion of commercially marketable produce, particularly in quality-sensitive crops where cosmetic defects, blemishes, or pest damage can directly affect pack-out rates and realised value.

Lower Pest Infestation Translates into Higher Marketable Yield



In citrus production, a reduction in pest infestation of approximately **25%** was associated with a nearly **20%** improvement in marketable yield. By increasing the proportion of harvestable output that meets commercial standards, improved crop protection performance can directly contribute to higher returns per hectare.



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Adjuvants: Value Optimisation Within Existing Programs

The economic role of adjuvants lies in improving the efficiency and consistency of herbicide performance, helping growers achieve stronger and more reliable results of already planned applications.

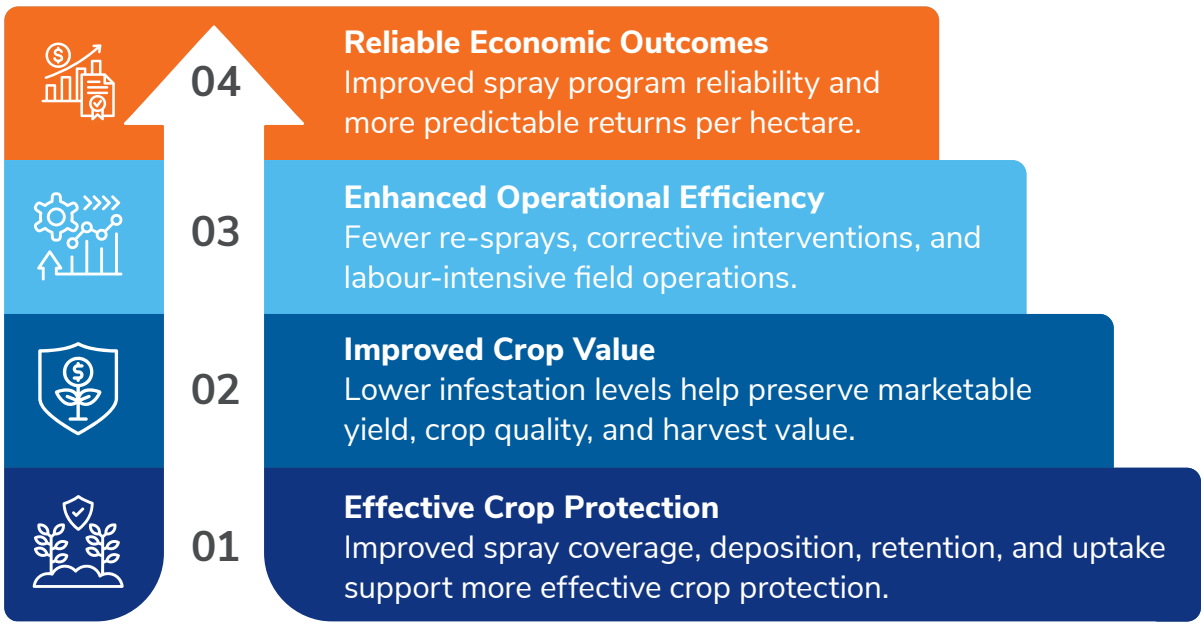
Field evidence demonstrates up to **35%** improvements in weed control performance when adjuvants are incorporated into herbicide programs, resulting in stronger and more consistent control while reducing weed escapes.

Improvements in weed control can create economic value through multiple pathways:

- Better weed control, translating into improved yield retention
- Reduced re-sprays, translating into lower operational costs

This makes adjuvants an important value lever within the spray program. In this sense, their contribution is best understood as one of value optimisation: improving the return from planned crop protection investment while helping contain inefficiencies in the field.

Building More Predictable Revenue Outcomes



The economic value of crop protection ultimately hinges on how consistently field performance translates into commercial outcomes. Factors such as weather variability, pest pressure, canopy complexity, and application conditions all influence this relationship, making spray performance a crucial factor in determining farm profitability.

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The Future of Crop Protection: Priorities for Growers

Climate pressures are expected to intensify future crop protection challenges. Modelling studies indicate that yield losses in key staples such as wheat, rice, and maize could increase significantly with rising temperatures, while the geographic range of invasive weeds is projected to expand over the coming decades[9],[26]. These shifts point to a production environment that is more variable, less predictable, and increasingly difficult to manage through conventional approaches alone.

At the same time, growers are under increasing pressure to optimise input and resource use while maintaining crop quality, productivity, and profitability. Pest resistance development in crops, evolving regulatory requirements, sustainability expectations, and rising production costs are further increasing the complexity of crop protection decision-making. Collectively, these trends are reducing tolerance for avoidable losses and placing greater importance on ensuring that every crop protection intervention delivers consistent field performance.

Ultimately, the future of crop protection will be shaped by the ability to consistently translate crop protection investments into reliable agronomic and economic outcomes. In response to the evolving challenges, two strategic priorities are emerging for growers.

Strategic Priorities for Growers



Shift from spray intensity to spray effectiveness

Focus on maximising the effectiveness of each application through greater precision, improved delivery, and validated field performance.



Adopt a return-on-investment approach to crop protection decisions

Evaluate crop protection programs on their ability to protect marketable yield, reduce operational inefficiencies, and generate reliable economic returns.

In this evolving environment, technologies that improve spray application performance and reduce field-level variability will become valuable. Agricultural spray oils and adjuvants are therefore expected to play an important role in helping growers achieve more reliable crop protection outcomes and improve the predictability of agronomic and economic returns.

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About Gulf

Gulf's approach to crop protection focuses on ensuring that product formulation translates into reliable field performance. Gulf has evaluated and collected evidence from various cropping systems, climatic conditions, and pest pressures in major agricultural regions. This includes production environments in Latin America, such as Brazil, Peru, Chile, and Argentina, as well as key areas in Asia, particularly India.

Built on decades of expertise in mineral oil systems, the company has developed spray solutions designed to function with precise control under real operating conditions.

Gulf Agri Spray Oils are highly refined, pre-emulsified mineral oil-based solutions formulated within an optimal "narrow" range. They enable effective pesticidal action, strong surface persistence, and uniform coverage while minimising phytotoxicity and supporting healthy crop development.

Gulf Agri Adjuvants are highly refined, mineral oil-based solutions that enhance the performance of crop protection products by improving spray formation, retention, penetration, and uptake. These additives increase the bioavailability and effectiveness of active ingredients, allowing for more efficient and consistent application outcomes.

As crop protection programs become more operationally demanding and performance-sensitive, Gulf's approach aligns with a broader industry shift toward more precise, efficient, and commercially reliable crop protection strategies.

Find out more at: www.gulfoilltd.com

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