

Study of Pollinator Diversity and their Role in Enhancing Crop Production and Agricultural Sustainability

Kiran Dalal¹ and Dr. Bharat Bhushan²

¹Research Scholar, Department of Botany

²Assistant Professor Guide, Department of Botany

School of Natural and Applied Science

Vikrant University Gwalior (M.P) India

Abstract: Pollinators play a fundamental role in maintaining agricultural productivity, biodiversity, and ecosystem stability. Insects such as honeybees, bumblebees, solitary bees, butterflies, moths, hoverflies, and other pollinating organisms facilitate the transfer of pollen between flowers, contributing to fertilization, fruit development, seed formation, and improved crop quality. This research paper examines pollinator diversity and its contribution to crop production and agricultural sustainability through a review of scientific literature. The study explores the relationship between pollinator abundance, species diversity, crop yield, fruit quality, and ecosystem resilience.

Keywords: Pollinator Diversity, Crop Production, Agricultural Sustainability, Honeybees, Wild Pollinators, Ecosystem Services.

I. INTRODUCTION

Agriculture is a fundamental component of human survival, economic development, and food security. The productivity of agricultural systems depends not only on soil fertility, water availability, climatic conditions, and agricultural technology but also on ecological processes that support crop growth and reproduction. Among these processes, pollination is particularly important because it facilitates sexual reproduction in flowering plants and contributes to the formation of fruits and seeds. Pollination occurs when pollen grains are transferred from the anther of a flower to the stigma of the same or another compatible flower. Although some crops are self-pollinated or wind-pollinated, many economically important crops depend partly or substantially on animals, especially insects, for effective pollination.

Pollinators include a diverse group of organisms, such as honeybees, bumblebees, solitary bees, butterflies, moths, hoverflies, beetles, birds, and bats. Among these, bees are particularly important because their feeding behaviour, body structures, and interactions with flowers make them effective pollen carriers. Both managed honeybees and naturally occurring wild pollinators contribute to agricultural production, although their relative importance varies according to crop type, geographical location, landscape characteristics, and local environmental conditions.

The contribution of pollinators extends beyond the quantity of agricultural output. Effective pollination may improve fruit size, shape, uniformity, seed number, and market quality. In certain crops, inadequate pollination leads to reduced fruit set, malformed produce, lower seed production, and economic losses for farmers. Klein et al. (2007) demonstrated that animal pollination benefits approximately 75% of the leading global food-crop types, although the degree of dependence varies considerably among crops. This distinction is important because benefiting from pollination does not necessarily mean that a crop is completely dependent on pollinators.

Pollinator diversity is equally important for maintaining reliable agricultural ecosystem services. Different pollinator species may visit flowers at different times of the day, forage under different weather conditions, and exhibit different

preferences for flower shapes and sizes. Consequently, a diverse pollinator community can provide complementary pollination services and reduce the vulnerability of agricultural production to the decline of any single species. Garibaldi et al. (2013) found that visits by wild insects were positively associated with fruit set across a wide range of crop systems and that wild insects and honeybees could provide complementary benefits.

However, pollinator populations face numerous environmental pressures. Agricultural intensification, destruction of natural habitats, excessive pesticide use, monoculture, invasive species, diseases, and climate change can reduce pollinator abundance and diversity. Potts et al. (2010) reviewed evidence of widespread concerns about pollinator declines and highlighted the multiple pressures affecting pollinating organisms. These threats create a significant challenge for sustainable agriculture because the loss of pollination services can affect crop productivity, ecological balance, and farmer livelihoods.

In this context, the present study examines the diversity of pollinators, their contribution to crop production, and their importance in sustainable agricultural development. It also identifies conservation practices that can improve pollinator habitats and strengthen the long-term reliability of agricultural pollination services.

RESEARCH OBJECTIVES

The major objectives of the study are:

1. To identify the major groups of pollinators associated with agricultural ecosystems.
2. To examine the contribution of pollinator diversity to crop yield, fruit quality, and seed production.
3. To analyse the relationship between wild pollinators, managed honeybees, and agricultural productivity.
4. To investigate the major environmental and agricultural factors responsible for pollinator decline.
5. To evaluate pollinator conservation practices that support sustainable agriculture.
6. To recommend practical strategies for improving pollinator diversity and long-term agricultural resilience.

RESEARCH QUESTIONS

The study addresses the following research questions:

- What are the major pollinator groups contributing to agricultural production?
- How does pollinator diversity influence crop yield and quality?
- Can wild pollinators complement the pollination services provided by managed honeybees?
- What are the major threats to pollinator diversity in agricultural landscapes?
- Which agricultural and conservation practices can improve pollination services sustainably?

REVIEW OF LITERATURE

1. Pollinator dependence of global crops

Klein et al. (2007) conducted a comprehensive assessment of the dependence of global food crops on animal pollination. Their research indicated that 87 of the leading global food crops benefited from animal pollination, whereas 28 did not depend on it. The authors also highlighted the vulnerability of wild pollinator communities to agricultural intensification. Their findings demonstrate that pollination requirements differ among crops and that conservation strategies should be tailored to the biological requirements of individual crops and their pollinators.

2. Pollinator diversity and fruit production

Garibaldi et al. (2013) investigated the contribution of wild insects and honeybees to crop pollination across multiple agricultural systems. Their findings showed that visits by wild insects were positively associated with fruit set, independently of the contribution of honeybees. This finding suggests that maintaining wild pollinator communities can improve crop production even where managed honeybees are available. The research provides strong support for agricultural practices that preserve natural habitats and encourage diverse pollinator communities.

3. Global pollinator decline and environmental pressures

Potts et al. (2010) reviewed the status of pollinators worldwide and identified habitat loss, climate change, pesticides, invasive species, and pathogens as important pressures affecting pollinator populations. The authors emphasized that the causes and severity of pollinator decline differ across geographical regions and species. Their work indicates that effective conservation requires a combination of habitat protection, improved agricultural management, monitoring, and policy support.

4. Pollinator diversity and ecosystem resilience

Diverse pollinator communities can contribute to more stable pollination services because species differ in their environmental tolerances, flower preferences, and foraging periods. Aizen et al. (2009) examined the relationship between agricultural production and dependence on pollinators, drawing attention to the increasing importance of pollination-dependent crops in global agriculture. Their work supports the need to evaluate pollination services alongside agricultural expansion and changing food-production demands.

5. Pollination and agricultural sustainability

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2016) assessed the relationship between pollinator conservation, food production, and human well-being. The assessment emphasized the contribution of animal pollination to the production, yield, and quality of many leading global food-crop types. It also highlighted the importance of maintaining diverse pollinator communities, suitable habitats, and agricultural systems that reduce environmental pressures.

6. Research gap

Existing research establishes that animal pollination is important for numerous crops and that wild pollinators can complement managed honeybees. However, the magnitude of pollination benefits varies among crops, regions, farm-management systems, and environmental conditions. A key research need is to integrate pollinator species richness, abundance, visitation rates, crop-specific dependence, and economic outcomes within a common assessment framework. Such an approach can help identify whether conservation practices improve pollination effectiveness, yield stability, and farm-level sustainability simultaneously.

The present paper addresses this need by synthesizing established evidence and developing a practical framework for evaluating pollinator diversity in agricultural landscapes.

RESEARCH METHODOLOGY

1. Research design

The study adopts a descriptive and analytical literature-review design. It synthesizes findings from peer-reviewed research articles, scientific reviews, and international assessments concerning pollinator diversity, crop production, agricultural management, and ecosystem sustainability.

No new field experiment or farmer survey is claimed in this paper. Consequently, the analysis is based on published evidence and conceptual synthesis rather than original primary data.

2. Sources of information

The literature base includes research on crop dependence on pollination, wild insect contributions to fruit set, pollinator decline, ecosystem services, and conservation practices. Important sources include studies published in Proceedings of the Royal Society B, Science, Current Biology, and international assessments by IPBES.

3. Analytical approach

The literature is organized into five analytical themes:

- Taxonomic and functional diversity of pollinators.
- Crop-specific dependence on animal pollination.
- Effects on yield, quality, and reproductive success.
- Environmental threats and agricultural management.
- Conservation measures and sustainable agricultural development.

Findings are compared qualitatively, and selected published numerical estimates are presented with appropriate attribution. Because the underlying studies differ in crop types, locations, and measurement methods, their results are not combined into a new statistical estimate.

POLLINATOR DIVERSITY IN AGRICULTURAL ECOSYSTEMS

Pollinator diversity includes taxonomic diversity, species abundance, and variation in ecological functions. The presence of multiple species does not automatically guarantee effective pollination; their contribution depends on their ability to transfer compatible pollen and their interactions with crop flowers.

1. Major pollinator groups

Table 1. Major pollinator groups and their agricultural importance

Pollinator group	Examples	Major contribution
Honeybees	<i>Apis mellifera</i> , <i>Apis cerana</i>	Pollination of many fruit, vegetable, oilseed, and seed crops
Bumblebees	<i>Bombus</i> species	Effective pollination of crops such as tomatoes and certain berries
Solitary bees	<i>Osmia</i> , <i>Megachile</i> species	Efficient pollen transfer in orchards and other flowering crops
Butterflies	Various butterfly species	Pollination of suitable flowers, particularly those with accessible nectar
Moths	Hawkmoths and other moths	Pollination of night-blooming and long-tubed flowers
Hoverflies	Syrphidae	Pollination of many flowering crops and wild plants
Beetles	Various flower-visiting beetles	Pollination of certain flowers and specialized crops
Birds and bats	Nectar-feeding species	Pollination of selected crops and flowering plants in suitable regions

Source: Synthesized from Ollerton et al. (2011), Klein et al. (2007), and IPBES (2016).

The table demonstrates that pollination is an ecological service provided by a range of organisms rather than by honeybees alone. The effectiveness of each group depends on crop-specific floral characteristics, local species availability, and environmental conditions. Although honeybees are valuable for managed pollination, other pollinators can provide complementary services that help maintain agricultural productivity.

2. Species richness and abundance

Species richness refers to the number of different species present in an area, whereas abundance refers to the number of individuals within a species or community. Both measures are important for understanding pollination services.

A farm may have many individual honeybees but relatively few pollinator species. Another farm may support fewer total insects but a more diverse community of wild bees, hoverflies, butterflies, and other pollinators. These communities may differ in their effectiveness across crop species and environmental conditions.

Garibaldi et al. (2013) demonstrated the importance of wild-insect visitation for fruit set across agricultural systems. Therefore, conservation assessments should consider not only the total number of pollinators but also their identity, diversity, and actual contribution to pollen transfer.

3. Functional diversity

Functional diversity concerns the ecological characteristics that influence how organisms perform pollination. Examples include body size, tongue length, pollen-carrying structures, foraging period, and tolerance of temperature or weather conditions.

For example, a pollinator with a long tongue may be able to access nectar in flowers that are less accessible to other species. Certain bees can also vibrate flowers to release pollen, a behaviour that is particularly useful for some crops. Different activity periods and weather tolerances may allow several pollinator species to provide services under varying environmental conditions.

Consequently, conserving functional diversity can be as important as conserving species numbers alone.

ROLE OF POLLINATOR DIVERSITY IN ENHANCING CROP PRODUCTION

1. Improvement in crop yield

Pollination contributes to successful fertilization and the development of fruits and seeds. In crops that depend on animal pollination, insufficient pollen transfer may reduce fruit set and seed formation. The magnitude of this effect depends on crop biology, environmental conditions, and the availability of effective pollinators.

Klein et al. (2007) identified substantial differences in pollination dependence among major food crops. Some crops require animal pollination for successful production, while others experience increases in yield or quality when pollinators are present. These findings suggest that farmers should prioritize pollinator conservation in crops where pollination is a major production-limiting factor.

2. Improvement in fruit quality

Pollination can influence several commercially important characteristics, including fruit size, shape, uniformity, and seed development. In some crops, adequate pollination supports more uniform fruit development and can increase the proportion of produce meeting market-quality standards.

However, the relationship between pollination and quality is not identical across all crops. Fruit quality is also influenced by irrigation, soil nutrients, temperature, pest pressure, and harvesting practices. Therefore, pollination should be considered one important contributor to produce quality rather than its sole determinant.

3. Increased seed production

Many flowering crops depend on successful fertilization for seed production. Pollinators transport pollen between compatible flowers, supporting fertilization and the development of viable seeds. This is particularly relevant to crops cultivated for seed, oil, and reproductive planting material.

Pollination services can therefore contribute to both current agricultural production and the availability of seed for future planting cycles.

4. Complementarity between wild and managed pollinators

Managed honeybees are widely used in agricultural pollination, but dependence on a single species can create vulnerability when disease, weather conditions, or other pressures reduce its effectiveness. Wild pollinators may complement honeybees through differences in behaviour, flower preference, and activity patterns.

Garibaldi et al. (2013) reported positive associations between wild-insect visitation and fruit set across crop systems. This supports a combined strategy in which managed pollinators are used where appropriate while natural habitats are maintained to sustain wild pollinator populations.

5. Economic contribution

Pollination contributes to the economic value of agriculture through crop quantity, produce quality, and the reliability of harvests. Its economic importance is particularly significant for crops with high pollination dependence and high market value.

Pollination also supports agricultural diversification by enabling the production of various fruits, vegetables, nuts, and seeds. However, the economic value of pollination should be calculated for specific crops and locations because a global estimate cannot accurately represent the benefits received by every individual farm.

Table 2. Major agricultural benefits associated with pollination

Agricultural outcome	Contribution of pollination	Potential farm-level benefit
Fruit set	Supports fertilization and fruit development	Greater marketable harvest where pollination

		is limiting
Seed production	Improves opportunities for successful fertilization	Improved seed availability and reproductive success
Fruit quality	May improve size, shape, and uniformity	Better grading and market acceptance
Crop diversity	Supports production of pollinator-dependent crops	Greater opportunities for diversified cultivation
Production stability	Diverse pollinators can provide complementary services	Reduced vulnerability to the loss of one pollinator group
Farm income	May increase marketable output and quality	Potential improvement in profitability

Source: Author's synthesis based on Klein et al. (2007), Garibaldi et al. (2013), and IPBES (2016). Benefits depend on crop type and local conditions.

PUBLISHED EVIDENCE ON POLLINATION AND CROP PRODUCTION

Published studies provide useful quantitative evidence for understanding the importance of pollination. These findings should be interpreted within the scope of the original studies rather than as universal estimates for all crops.

Table 3. Selected published evidence on pollination

Study	Research focus	Major finding	Implication
Klein et al. (2007)	Global food-crop dependence	87 leading crops benefited from animal pollination, while 28 did not rely on it in the assessed crop classification	Pollination needs vary among crops
Aizen et al. (2009)	Global crop production trends	Agricultural production had become increasingly dependent on pollinators	Pollination needs should be considered in long-term agricultural planning
Potts et al. (2010)	Global pollinator declines	Identified habitat loss, agrochemicals, pathogens, invasive species, and climate change as important drivers	Multiple pressures require coordinated management
Ollerton et al. (2011)	Animal pollination of flowering plants	Estimated that 87.5% of flowering plant species were animal-pollinated	Pollinator conservation has importance beyond agriculture
Garibaldi et al. (2013)	Wild insects and crop fruit set	Wild-insect visits were positively associated with fruit set across crop systems	Wild pollinators can complement managed pollination
IPBES (2016)	Pollinators, pollination, and food production	More than three-quarters of leading global food-crop types benefited from animal pollination	Pollinator protection is relevant to food production and sustainability

Source: Original publications cited in the reference list. Numerical statements reflect the classifications and scope of the respective studies.

The findings summarized in Table 3 show that pollination is an important agricultural ecosystem service, but its significance differs according to the research question and crop classification. For example, the finding that many crop types benefit from animal pollination does not imply that most global agricultural tonnage depends entirely on pollinators. Major cereals and root crops contribute substantially to total production without requiring animal pollination. By contrast, many fruits, nuts, and seed-producing crops experience substantial benefits from animal pollination.

This distinction highlights the importance of evaluating both total agricultural output and the diversity and nutritional value of food production.

FACTORS AFFECTING POLLINATOR DIVERSITY

1. Habitat loss and fragmentation

Natural habitats provide pollinators with nesting sites, shelter, and flowering plants. The removal of hedgerows, field margins, grasslands, and flowering vegetation can reduce food availability and disrupt movement between nesting and feeding sites.

Habitat fragmentation can isolate pollinator populations and make it difficult for some species to find suitable resources throughout their life cycles. Potts et al. (2010) identified habitat loss and fragmentation among the major pressures affecting pollinator populations.

2. Excessive and inappropriate pesticide use

Pesticides can affect pollinators through direct toxicity and sublethal effects, depending on the active ingredient, exposure route, dose, and species involved. Exposure may interfere with orientation, foraging, reproduction, or colony development.

Agricultural pest management should therefore consider the risks to beneficial insects. Applying pesticides according to approved labels, avoiding unnecessary applications during flowering, and using integrated pest management can reduce exposure while maintaining crop protection.

3. Climate change

Climate change can affect pollinator activity, geographical distribution, and seasonal timing. Changes in temperature and rainfall may alter the flowering periods of crops and wild plants. If flowering and pollinator activity become less synchronized, pollination services may decline.

Different species respond differently to environmental changes. A diverse pollinator community may therefore provide some buffering capacity, although diversity alone cannot eliminate the risks of severe climatic change.

4. Agricultural intensification and monoculture

Large-scale monoculture may provide abundant flowers during a limited period but insufficient resources during other seasons. Intensive land management can also reduce nesting sites and eliminate flowering weeds that provide food to beneficial insects.

The challenge is not that every monoculture is necessarily unsuitable for pollinators, but that landscapes dominated by simplified habitats may fail to provide continuous and diverse resources.

5. Diseases, parasites, and invasive species

Pollinators may be affected by parasites, pathogens, competition, and the introduction of non-native species. These pressures can interact with nutritional stress and pesticide exposure, making populations less resilient.

Effective management requires species-appropriate monitoring, responsible management of managed colonies, and measures to prevent the spread of pests and diseases.

Table 4. Major threats to pollinator diversity and possible management responses

Threat	Likely ecological effect	Recommended response
Habitat destruction	Loss of nesting and feeding resources	Protect natural habitats and restore field margins
Pesticide exposure	Mortality or impaired behaviour and reproduction	Apply integrated pest management and reduce unnecessary exposure
Climate change	Altered flowering and foraging periods	Increase habitat diversity and monitor seasonal changes
Monoculture	Seasonal shortages of floral resources	Introduce suitable flowering vegetation and crop rotations
Diseases and parasites	Reduced survival and reproductive success	Improve monitoring and responsible colony management
Invasive species	Competition or ecological disruption	Monitor introductions and manage invasive species appropriately

Source: Author's synthesis based on Potts et al. (2010) and IPBES (2016).

Pollinator Conservation for Agricultural Sustainability

1. Protection and restoration of natural habitats

Maintaining natural vegetation near agricultural fields can provide nesting sites, shelter, and floral resources. Field margins, hedgerows, grasslands, and suitable uncultivated patches can serve as important habitats.

Conservation activities should be adapted to local conditions. Planting a diversity of native flowering species that bloom at different times can help provide resources throughout the growing season. Habitat restoration should also consider the needs of ground-nesting bees and other species that require specific nesting conditions.

2. Integrated pest management

Integrated pest management combines monitoring, biological control, cultural practices, and selective chemical control when necessary. This approach can reduce unnecessary pesticide applications and protect beneficial organisms.

Farmers should follow pesticide labels and local regulations, select lower-risk alternatives where feasible, and avoid spraying flowering crops when pollinators are actively foraging whenever the product label and crop-management requirements permit.

3. Pollinator-friendly crop management

Farmers can improve pollinator resources by maintaining flowering field margins, using diverse crop rotations, and retaining suitable nesting habitats. Where feasible, flowering cover crops and native plants can provide additional forage.

These practices should be planned carefully to avoid introducing invasive plants, creating pest reservoirs, or competing excessively with the main crop for water and nutrients.

4. Responsible management of honeybees

Managed honeybee colonies can support crops that require additional pollination. However, stocking density should be appropriate to the crop, flowering period, and local landscape. Excessive colony concentrations may increase competition for floral resources or create additional disease-management concerns.

Managed honeybees should therefore be used as part of an integrated pollination strategy rather than as a replacement for the conservation of wild pollinators.

5. Farmer education and community participation

Farmers, agricultural extension workers, researchers, and local institutions should work together to improve awareness of pollinator identification, habitat management, pesticide safety, and the economic value of pollination.

Demonstration farms and community-based monitoring can help farmers observe changes in pollinator visitation and crop performance. These programmes are particularly useful when conservation recommendations are adapted to local crops and farming systems.

6. Policy and institutional support

Governments and agricultural institutions can support pollinator conservation through habitat restoration, biodiversity-friendly agricultural incentives, research funding, pesticide risk assessment, and extension services.

Pollinator conservation should be incorporated into broader policies on sustainable agriculture, biodiversity, climate adaptation, and rural livelihoods. Policy effectiveness should be assessed using measurable outcomes rather than the number of initiatives announced.

PROPOSED FRAMEWORK FOR ASSESSING POLLINATOR DIVERSITY

To evaluate pollinator diversity and its contribution to agricultural sustainability, future field studies should measure both ecological indicators and crop outcomes.

Table 5. Proposed indicators for field-based assessment

Indicator	Measurement method	Purpose
Species richness	Number of distinct pollinator species recorded	Measures taxonomic diversity
Pollinator abundance	Individuals observed per standardized sampling effort	Measures the number of pollinators

Flower visitation rate	Visits per flower per unit of time	Measures pollinator activity
Fruit-set percentage	Fruits formed relative to flowers observed	Evaluates reproductive outcome
Seed production	Seeds per fruit or plant, where appropriate	Evaluates fertilization and reproduction
Marketable yield	Harvested marketable produce per unit area	Measures agricultural output
Produce quality	Crop-specific grading criteria	Evaluates commercial quality
Habitat availability	Area or proportion of land under suitable habitat	Measures resource availability
Pesticide exposure indicators	Application records and exposure assessments	Evaluates a potential stressor
Farm profitability	Revenue minus relevant production costs	Assesses economic outcomes

Source: Proposed assessment framework developed for this paper; these indicators are recommendations, not measurements collected in the present study.

1. Suggested formulas

Researchers can use the following formulas when collecting field data.

A. Pollinator species richness

$$S = \text{Number of distinct pollinator species recorded}$$

B. Pollinator visitation rate

$$V = \frac{\text{Total flower visits}}{\text{Observation time}}$$

For comparisons between fields, the number of flowers observed should also be standardized or included in the analysis.

C. Fruit-set percentage

$$\text{Fruit Set (\%)} = \frac{\text{Number of fruits formed}}{\text{Number of flowers observed}} \times 100$$

D. Relative yield improvement

$$\text{Yield Improvement (\%)} = \frac{Y_p - Y_c}{Y_c} \times 100$$

Where:

- (Y_p) = yield under the treatment or management practice being evaluated.
- (Y_c) = yield under the comparison condition.

A comparison might involve pollinator-friendly habitat management versus conventional field management. The result should be interpreted carefully because differences in soil, irrigation, crop variety, and pest control can also influence yield.

E. Pollinator visitation comparison

$$\text{Relative Change (\%)} = \frac{V_2 - V_1}{V_1} \times 100$$

Where (V_1) and (V_2) represent visitation rates before and after an intervention, respectively. A controlled study is preferable because seasonal changes can affect visitation independently of the intervention.

These formulas provide a basis for future empirical research, but no numerical values should be inserted unless supported by actual observations.

II. CONCLUSION

Pollinator diversity is an important component of sustainable agriculture because it supports the reproduction of flowering plants, contributes to the production of many food crops, and helps maintain the ecological processes on which agricultural systems depend. Evidence from published research demonstrates that animal pollination benefits numerous major food crops and that wild pollinators can complement the services provided by managed honeybees. Their contributions extend beyond crop quantity to include fruit set, seed production, produce quality, and the stability of agricultural ecosystem services.

The study also highlights the major threats to pollinator diversity, including habitat destruction, pesticide exposure, agricultural intensification, climate change, and diseases. These pressures can interact and reduce the reliability of pollination services. Therefore, pollinator conservation should be treated as an integral part of agricultural planning rather than as a separate environmental concern.

A sustainable strategy should combine habitat protection, flowering-resource management, integrated pest management, responsible honeybee management, farmer education, and long-term ecological monitoring. Such measures should be adapted to local crop requirements and evaluated using measurable indicators, including pollinator richness, visitation rates, fruit set, marketable yield, and farm profitability.

In conclusion, the conservation of diverse and effective pollinator communities is a valuable strategy for strengthening agricultural sustainability, supporting food-system resilience, and protecting biodiversity. However, successful implementation requires cooperation among farmers, researchers, policymakers, and local communities. Continued empirical research will be essential for determining which conservation interventions provide the greatest ecological and economic benefits under different agricultural conditions.

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