Molecular Soil Biology 2025, Vol.16, No.3, 103-113
http://bioscipublisher.com/index.php/msb

Feature Review Open Access

The Application and Effect Evaluation of Eco-Friendly Soil Improvement Techniques in the Cultivation of *Chrysanthemum* × *morifolium* (Ramat.) Hemsl.

Xichen Wang, Chuchu Liu
Institute of Life Science, Jiyang College of Zhejiang A&F University, Zhuji, 311800, China
Corresponding email: chuchu.liu@jicat.org

Molecular Soil Biology, 2025, Vol.16, No.3 doi: 10.5376/msb.2025.16.0011
Received: 23 Mar., 2025
Accepted: 26 Apr., 2025
Published: 08 May, 2025

Preferred citation for this article:
Wang X.C., and Liu C.C., 2025, The application and effect evaluation of eco-friendly soil improvement techniques in the cultivation of *Chrysanthemum* × *morifolium* (Ramat.) Hemsl., Molecular Soil Biology, 16(3): 103-113 (doi: 10.5376/msb.2025.16.0011)

Abstract We have sorted out the research in recent years and found that many environmentally friendly methods, such as using organic materials to mix soil, adding biological fertilizers, adding microorganisms, planting with other crops, and scientific fertilization methods, can make chrysanthemum grow better, have higher yields, and have more beautiful flowers. Moreover, these methods can also improve the soil environment, such as making the nutrients in the soil more sufficient and the types of microorganisms more diverse. Some studies used coconut bran, earthworm manure, and leaf mold (mixed in a ratio of 2:1:1) as the substrate, and found that chrysanthemum grew stronger and the flowers were more beautiful. In addition, using biological fertilizers or microbial strains can improve the fertility of the soil and make the beneficial microorganisms in the soil more active. Planting chrysanthemum with corn not only increases the yield of chrysanthemum and the effective ingredients, but also helps increase the number of good microorganisms and improve the ecological environment of the soil. There is an organic liquid fertilizer called Jeevamrit, which, combined with scientific nutrient management, can also make the nutrients in the soil richer and the number of microorganisms more abundant. Some studies have also found that after removing viruses, the roots will grow better and the soil quality will improve. These eco-friendly soil improvement techniques can not only improve the yield and quality of chrysanthemums, but also improve the soil environment. For those who want to grow flowers sustainably, these practices are quite valuable for reference.

Keywords Chrysanthemum (*Chrysanthemum* × *morifolium* (Ramat.) Hemsl.); Eco-friendly; Soil improvement; Microbial fertilizer; Intercropping

1 Introduction

Chrysanthemum × *morifolium* is a famous flower with many colors and beautiful flower shapes. It can also be used as medicine. Because of these characteristics, it plays an important role in horticulture and traditional Chinese medicine (Pandey et al., 2018; Liu et al., 2023; Liao et al., 2024). People usually plant it in flower beds, sell it as cut flowers and potted plants, and use it as a Chinese medicine. Therefore, its economic and cultural value is very high (Pandey et al., 2018; Liao et al., 2024).

If you want to grow more and better chrysanthemum, the soil must be healthy. Good soil can provide plants with enough nutrients, make the roots grow better, and make various beneficial microorganisms more active. In this way, the plants will be more resistant to diseases and easier to increase yields (Prasanna et al., 2016; Chen et al., 2020; Yang et al., 2022; Liao et al., 2024; Lohia et al., 2024). But now many people have been using chemical fertilizers or traditional soil improvement materials. If this continues, the soil structure will deteriorate, microorganisms will become fewer and fewer, and even cause pollution (Prasanna et al., 2016; Pandey et al., 2018; Kumar et al., 2022). Many traditional methods, such as using a large amount of peat or chemical fertilizers, can increase yields in a short period of time, but peat is a non-renewable resource, and using too much will damage the environment (Liu et al., 2023). If too much fertilizer is used or the method is wrong, it will easily cause an imbalance of nutrients in the soil, disrupt the microbial system, and even aggravate water pollution. Now that people are paying more and more attention to environmental protection and sustainability, it is particularly important to use some greener and more ecological methods to improve the soil. This is also particularly suitable for growing chrysanthemums.

This study mainly summarizes the application of eco-friendly soil improvement technologies in chrysanthemum cultivation in recent years, including the use of organic materials such as rice husks and leaf mold instead of peat, the use of biofertilizers, the addition of beneficial microorganisms, and the use of treated wastewater for irrigation. We want to see whether these methods are helpful for the growth, yield, flower quality and soil health of chrysanthemum, and also analyze their benefits to the environment and whether they can be promoted in the future. These results can provide some theoretical support and practical experience for the green cultivation of chrysanthemum and other flowers.

2 Overview of Soil-Related Challenges in Chrysanthemum Cultivation

2.1 Soil degradation issues in continuous cropping systems

If *Chrysanthemum* × *morifolium* is planted in the same field for a long time, the soil condition will deteriorate. Many studies have found that continuous planting for several years will reduce the organic carbon and nitrogen in the soil, inhibit soil respiration and the activity of various enzymes, reduce the number and types of bacteria, and reduce the overall function of the soil (Li et al., 2023; Liu et al., 2023; Feng et al., 2024). In addition, continuous cropping can easily lead to the increase of some soil-borne pathogens, such as Fusarium solani, which is particularly easy to breed in this case and can cause wilt disease of Chrysanthemum, which has a great impact on yield and quality (Liu et al., 2023).

2.2 Common abiotic stress factors: pH imbalance, salinity, compaction, poor aeration

In the process of growing chrysanthemum, there are some common abiotic problems that will also affect its growth. For example, unstable soil pH, high salt content, soil compaction or poor ventilation will make it difficult for roots to absorb nutrients and affect plant health (Feng et al., 2024; Lu et al., 2024). Studies have shown that the pH of the soil often decreases or becomes abnormal after continuous cropping, which will affect the activity of microorganisms and the utilization of nutrients in the soil. If the watering is not done correctly or the substrate is not suitable, it is easy to make the soil hard and airtight, which will affect the growth of chrysanthemum and the quality of the flowers.

2.3 Microbial imbalance and its effects on chrysanthemum root health and yield

Continuous cropping will also cause great changes in the microbial structure in the soil. There are fewer good bacteria and more bad bacteria, the types of microorganisms are not as rich, and the entire microbial network has become simpler (Chen et al., 2020; Hai-Kun et al., 2020; Fang et al., 2023; Li et al., 2023; Liu et al., 2023; Feng et al., 2024). This change will weaken the soil's ability to inhibit pathogens, slow down the nutrient cycle in the soil, and affect the health of the root system. As a result, chrysanthemum is more susceptible to disease, and its yield and quality will decrease. For example, studies have found that the number of beneficial bacteria such as Actinobacteria and Nocardia in continuous cropping soils decreases, while harmful fungi such as Fusarium and Trichoderma increase. These changes will directly affect the health of the roots, and the plants will not grow as well as before (Chen et al., 2020; Fang et al., 2023; Li et al., 2023; Liu et al., 2023; Feng et al., 2024) (Figure 1).

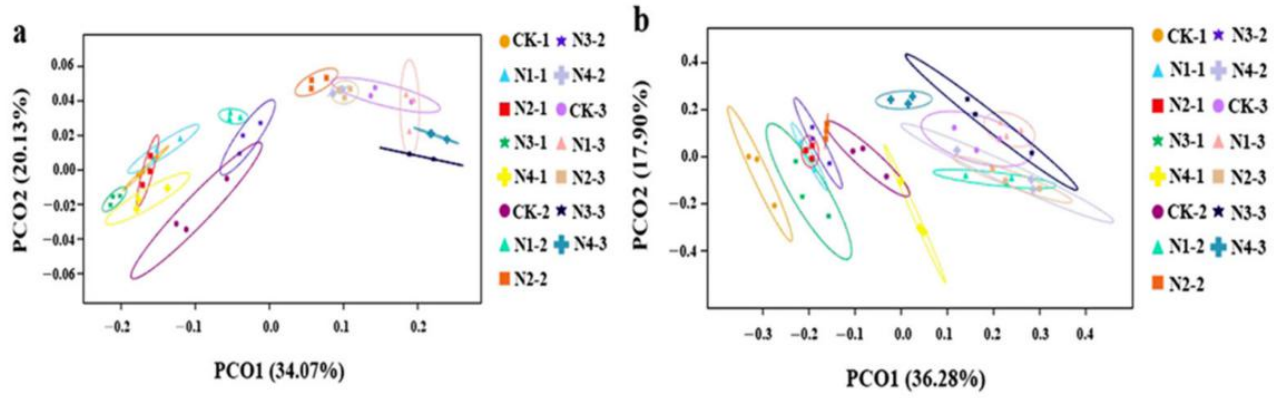

Figure 1 Principal coordinates analysis (PCoA) plot of (a) bacterial and (a) fungal community structures based on Bray–Curtis differences (Adopted from Fang et al., 2023)

3 Principles of Eco-Friendly Soil Improvement

3.1 Definition and criteria of eco-friendly approaches

Eco-friendly soil improvement methods mean using less or no chemical fertilizers, and using more natural methods to improve the soil, such as adding organic matter, biological fertilizers, microbial agents, or planting several different crops together. These methods focus more on using renewable resources and pay more attention to the microecological environment in the soil, hoping to keep the soil healthy and minimize the impact on the environment. For example, some people use rice husks and leaf compost instead of peat, and use biological organic fertilizers, microbial agents, or intercropping to improve the soil (Prasanna et al., 2016; Ardebili and Sharifi, 2018; Pandey et al., 2018; Chen et al., 2020; Kumar et al., 2022; Liu et al., 2023; Liao et al., 2024; Lohia et al., 2024).

3.2 Benefits over traditional chemical amendments

Compared with traditional fertilizers or other chemical amendments, these ecological methods have many advantages: Improve soil health: Organic matter and biological agents can improve soil structure, increase organic carbon and nutrients, make aggregates easier to form, and naturally improve fertility (Ardebili and Sharifi, 2018; Pandey et al., 2018; Yang et al., 2022; Gurjar et al., 2023; Liu et al., 2023; Liao et al., 2024; Lohia et al., 2024). Promoting microbial diversity:

Methods such as inoculating microorganisms and adopting intercropping can increase the number of beneficial bacteria in the soil and enrich the species of bacteria, which can suppress pathogens and improve the environment around the roots (Prasanna et al., 2016; Chen et al., 2020; Kumar et al., 2022; Yang et al., 2022; Liao et al., 2024). Crop growth and quality improvement: Ecological improvement methods can also make chrysanthemum grow more vigorously, photosynthesize more efficiently, produce more flowers and better quality, and use less chemical fertilizers (Ardebili and Sharifi, 2018; Kumar et al., 2022; Liu et al., 2023; Liao et al., 2024; Lohia et al., 2024). Environmental risk reduction: Organic or biological methods can reduce chemical residues and heavy metal accumulation, avoiding damage to the environment (Kumar et al., 2022; Gurjar et al., 2023; Lohia et al., 2024).

3.3 Link to sustainability and low-input agriculture

These ecological improvement technologies are very consistent with the sustainable agriculture and low-input agriculture currently advocated: Resource recycling: They encourage the use of agricultural and forestry waste, such as rice husks, fallen leaves, etc., plus organic fertilizers and biological agents, to turn waste into resources, and also reduce dependence on non-renewable resources such as peat and fertilizers (Ardebili and Sharifi, 2018; Pandey et al., 2018; Kumar et al., 2022; Liu et al., 2023; Lohia et al., 2024). Long-term soil productivity maintenance: By increasing soil organic matter, enhancing microbial activity, and improving nutrient cycling, these methods can help soil maintain productivity for a long time and avoid degradation due to excessive use of chemical fertilizers (Prasanna et al., 2016; Pandey et al., 2018; Kumar et al., 2022; Yang et al., 2022; Liao et al., 2024). Economic and ecological dual benefits: These ecological methods are low-cost and can also increase yield and quality. They are not only profitable, but also environmentally friendly, having the best of both worlds (Kumar et al., 2022; Liao et al., 2024; Lohia et al., 2024). Promoting green production models: These technologies provide good support for the green cultivation of cash crops such as chrysanthemum, and also adapt to the needs of green transformation of modern agriculture (Pandey et al., 2018; Kumar et al., 2022; Liu et al., 2023; Liao et al., 2024; Lohia et al., 2024).

4 Types of Eco-Friendly Soil Improvement Techniques

4.1 Organic Amendments

4.1.1 Compost, vermicompost, and biochar

When growing *Chrysanthemum* × *morifolium*, many people use rice husks and leaf mold instead of peat. The best results are achieved when these two materials are mixed at a ratio of 20% to 30%. It can improve soil conditions, allowing plants to grow faster, with larger leaves, more chlorophyll, and stronger photosynthesis (Liu et al., 2023). Using vermicompost also has obvious benefits. It can make plants grow faster and stronger. If nano zinc fertilizer is added, the effect will be even better (Ardebili and Sharifi, 2018).

4.1.2 Impact on physical and chemical properties of soil

Organic amendments can keep soil pH, electrical conductivity (EC) and nutrients such as nitrogen, phosphorus and potassium in an appropriate range, increase organic carbon content and make soil structure more stable (Ardebili and Sharifi, 2018; Yang et al., 2022; Liu et al., 2023). Some studies have found that irrigation with wastewater can also increase organic matter, major nutrients and some trace elements in the soil, and will not cause excessive accumulation of heavy metals (Gurjar et al., 2023).

4.2 Microbial Inoculants

4.2.1 Biofertilizers (e.g., nitrogen fixers, phosphate solubilizers)

Some biofertilizers, such as nitrogen-fixing bacteria, phosphate-solubilizing bacteria and potassium-solubilizing bacteria, can be used with a little chemical fertilizer to reduce the amount of chemical fertilizers and increase flower yields and income (Kumar et al., 2022). If deep tillage and bio-organic fertilizers are added, chrysanthemum will grow better, and the number of beneficial bacteria in the soil, such as Pseudomonas and Bacillus, will also increase (Chen et al., 2020).

4.2.2 Mycorrhizal fungi and plant-growth-promoting rhizobacteria (PGPR)

There are also some species, such as cyanobacteria, Trichoderma, nitrogen-fixing bacteria, etc., which can increase the soil's microbial biomass carbon, nitrification capacity and the activity of various enzymes, which can help chrysanthemum grow faster, take root better, and make the soil more fertile (Prasanna et al., 2016). These microorganisms can also improve the species and structure of microorganisms around the roots (Prasanna et al., 2016; Chen et al., 2020; Yang et al., 2022).

4.3 Cover Cropping and Green Manuring

4.3.1 Leguminous and non-leguminous green manures

Intercropping corn and chrysanthemum is a relatively effective method. It can increase the number of beneficial bacteria such as Bacillus and Sphingomonas, and also increase nutrients such as nitrogen, potassium, copper, and zinc in the soil, thereby helping chrysanthemum grow better and the flowers have better quality (Liao et al., 2024) (Figure 2).

4.3.2 Soil structure improvement and nutrient cycling

Growing green manure or covering crops can also help improve soil structure, make the soil looser and the aggregates more stable. They can also promote nutrient circulation, make enzyme activity stronger, and increase the number of microorganisms (Yang et al., 2022; Liao et al., 2024).

4.4 Physical Methods

4.4.1 Soil solarization and mulching using biodegradable materials

Combining deep tillage, bio-organic fertilizer and soil fumigation methods can regulate the types and proportions of microorganisms in the soil, improve enzyme activity and nutrient utilization efficiency, and promote the healthy growth of chrysanthemum (Chen et al., 2020).

4.4.2 Reduced tillage effects

Reducing the frequency of tillage is very helpful in protecting soil structure. This can maintain organic matter in the soil and is also conducive to microbial diversity. In this way, the roots of chrysanthemums can grow better and the soil quality will be improved (Yang et al., 2022).

5 Mechanisms of Action in Enhancing Soil Quality

5.1 Nutrient release and retention

Eco-friendly improvement methods can help the soil release and retain nutrients in many ways. For example, using rice husks and leaf mold instead of peat can not only make the physical and chemical properties of the soil more stable, but also maintain the appropriate pH, electrical conductivity (EC) and the levels of major nutrients such as nitrogen, phosphorus and potassium, so that chrysanthemum grows better and photosynthesis is stronger (Liu et al., 2023). Deep tillage and bio-organic fertilizers can increase the available nitrogen, phosphorus and

potassium in the soil and strengthen its nutrient supply capacity (Chen et al., 2020). Proper use of wastewater can also add more organic matter, major nutrients and trace elements to the soil without exceeding the heavy metal standard (Gurjar et al., 2023). If bio-fertilizers are used together with chemical fertilizers, it can not only reduce the amount of chemical fertilizers used, but also increase the yield of flowers and the nutrient level of the soil (Kumar et al., 2022).

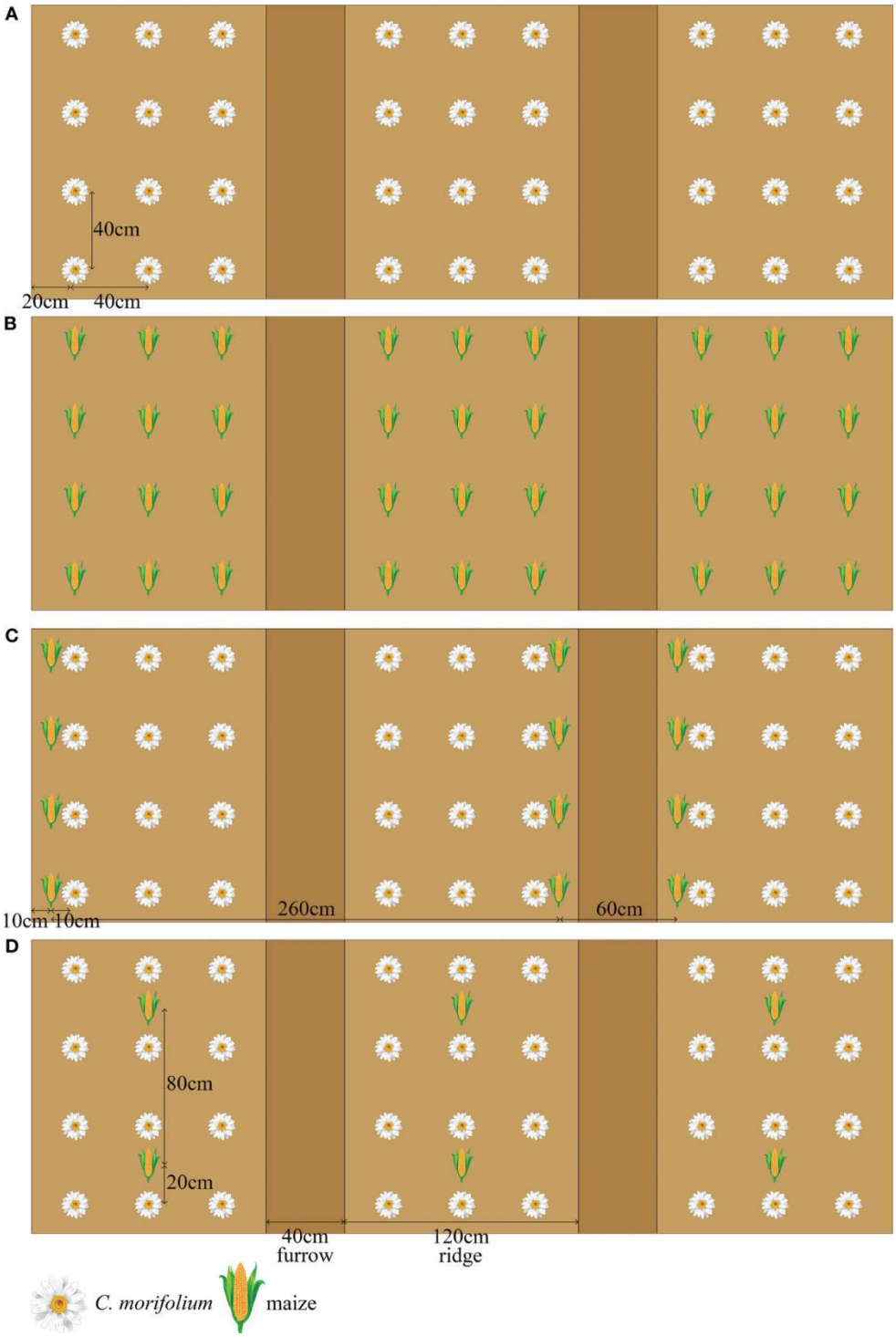

Figure 2 Schematic diagram of *C. morifolium*-maize intercropping and monoculture treatments. (A) monoculture *C. morifolium* (MC); (B) monoculture maize (MM); (C) *C. morifolium*-maize intercropping, *C. morifolium*-maize narrow-wide row planting (IS, *C. morifolium* and maize of IS known as ISC and ISM, respectively); (D) *C. morifolium*-maize intercropping, *C. morifolium*-maize middle row planting (IM, *C. morifolium* and maize of IM known as IMC and IMM, respectively) (Adopted from Liao et al., 2024)

5.2 Enhanced microbial activity and soil food web restoration

Adding microbial agents and organic materials can greatly increase the activity and variety of microorganisms in the soil. After using organic agents such as "Jeevamrit", the number of beneficial bacteria, fungi, and actinomycetes will increase, which can help restore the soil's micro-ecosystem (Lohia et al., 2024). Deep tillage combined with biological organic fertilizers can also increase the number of growth-promoting bacteria, such as Pseudomonas and Bacillus, and make soil enzymes more active (Chen et al., 2020). The use of microbial agents can also increase the microbial carbon content and nitrification capacity in the soil, helping to optimize the microbial community structure (Prasanna et al., 2016). After virus removal treatment, the roots of chrysanthemum will secrete more substances, which can attract more beneficial microorganisms to gather near the roots (Yang et al., 2022). Planting with other crops (such as intercropping) can also increase the number of good bacteria in the soil and make the relationship network between microorganisms healthier (Liao et al., 2024).

5.3 pH regulation, organic matter buildup, and improved water-holding capacity

Ecological materials such as rice husks and leaf humus can be used as soil substrates to help the soil maintain a suitable pH and avoid acidification or salinization (Liu et al., 2023). At the same time, using wastewater for irrigation or adding organic fertilizers can also increase the organic carbon in the soil, make the soil structure more stable, and improve water retention (Yang et al., 2022; Gurjar et al., 2023). If organic fertilizers and biological fertilizers are used together, the soil can accumulate more organic matter and the overall physical and chemical state will also improve (Ardebili and Sharifi, 2018; Pandey et al., 2018).

5.4 Suppression of soil-borne pathogens

Eco-friendly practices can also help reduce harmful pathogens in the soil. Deep tillage combined with biological organic fertilizers and soil fumigation can reduce the number of pathogens and make good bacteria dominate in the soil, so that there will be fewer problems with continuous cropping (Chen et al., 2020). Adding microbial agents such as Trichoderma and nitrogen-fixing bacteria can not only increase the activity of defense enzymes in the soil, but also enhance disease resistance (Prasanna et al., 2016). Intercropping can also indirectly inhibit the spread of pathogens by increasing the number of beneficial bacteria (Liao et al., 2024).

6 Effectiveness of Eco-Friendly Techniques in Chrysanthemum Cultivation

6.1 Growth and yield metrics (flower number, size, plant height)

Using organic fertilizers (such as bio-organic fertilizers, vermicompost, jeevamrit, etc.) and a reasonable substrate combination can make chrysanthemum grow faster, bloom more, and have higher yields. Studies have found that jeevamrit treatment (T6 and T7) can significantly increase yields (Lohia et al., 2024). Another approach is to use vermicompost and microbial strains together, so that the chrysanthemums grown in this way grow stronger and have more flowers (Khan et al., 2020). If a reasonable soil preparation method is used, such as mixing coconut bran, peat moss, perlite and pine needles in a ratio of 2:4:2:2, the plants can also be made taller, the flowers larger, and the number of flowers can also be increased (Lu et al., 2024). NPK fertilizers can also be used in a drip irrigation manner to effectively increase the diameter, number and weight of flower buds (Choudhary et al., 2022).

6.2 Improvement in soil physicochemical parameters

Eco-friendly practices, such as using jeevamrit or organic fertilizers, can increase the number of good bacteria in the soil, such as bacteria, fungi, and actinomycetes, and can also increase the total amount and activity of soil microorganisms and improve fertility (Lohia et al., 2024; Pathania et al., 2024). If organic fertilizers and microbial agents are used together, the main nutrients such as organic carbon, nitrogen, phosphorus, and potassium in the soil will increase, and the soil micro-ecosystem will become healthier (Khan et al., 2020; Choudhary et al., 2022). Overall, organic fertilization has a significant effect on increasing soil activity and improving soil fertility, laying the foundation for long-term cultivation (Pathania et al., 2024).

6.3 Resistance to biotic and abiotic stresses

The resistance of chrysanthemum to pests can be improved through hybrid breeding and regulating the odor released by plants. Studies have found that hybrids of aromatic wild chrysanthemums are particularly resistant to aphids, and they can also release some odor substances (such as cis-4-thujanol), which can effectively drive away

aphids (Zhong et al., 2022). This provides a new idea for ecological pest management. Current molecular breeding and omics research are also slowly helping to improve the stress resistance of chrysanthemums, such as drought resistance and disease resistance (Su et al., 2019).

6.4 Quality characteristics (color, scent, phytochemical profile)

Ecological planting not only increases yields, but also makes chrysanthemum flowers more beautiful, more fragrant, and richer in ingredients. For example, drip irrigation can increase the content of carotene and chlorophyll in flowers and improve biochemical activity (Choudhary et al., 2022). Organic cultivation can also improve the color and aroma of the flowers, while providing more active ingredients, which meets people's expectations for high-quality chrysanthemum (Choudhary et al., 2022; Lohia et al., 2024). In addition, molecular breeding and omics methods also provide theoretical support for improving these quality characteristics (Su et al., 2019).

7 Comparative Analysis of Techniques

7.1 Synergistic vs. standalone effects

Many studies have found that the combination of several ecological methods is more effective than using one alone. For example, when deep plowing, bio-organic fertilizer and soil fumigation are used together (DB+40dp), chrysanthemum grows better, and the enzyme activity and number of good bacteria in the soil are also increased more (Chen et al., 2020). The application of nano zinc and earthworm manure together can make the plants grow faster and increase the pigments related to photosynthesis, which is more effective than using them alone (Ardebili and Sharifi, 2018). Microbial agents combined with organic management can also significantly increase the types and number of microorganisms in the soil, and the nutrient supply is more sufficient (Prasanna et al., 2016). On the contrary, if only one method is used, such as replacing peat with a high proportion of rice husk (up to 80%), or only one fertilizer is used, it may be counterproductive and sometimes inhibit plant growth (Ardebili and Sharifi, 2018; Liu et al., 2023).

7.2 Site- and soil-specific effectiveness

Different methods have different effects on different plots and soil types. For example, when using rice husks and leaf humus to replace peat, the ratio should be controlled at 20% to 30%. If the ratio is too high, the conductivity and potassium will be too high, which will affect plant growth (Liu et al., 2023). In continuous cropping soil or greenhouse, the use of microbial agents and biological organic fertilizers can more significantly improve the structure and enzyme activity of soil microorganisms (Prasanna et al., 2016; Chen et al., 2020). The intercropping pattern of chrysanthemum and corn is also very effective in soil nutrients, enzyme activity and microbial diversity, and is particularly suitable for fields with severe continuous cropping obstacles (Liao et al., 2024). In plots with low soil organic matter and few trace elements, irrigation with wastewater can increase nutrition, but attention should also be paid to the accumulation of heavy metals (Gurjar et al., 2023).

7.3 Economic considerations (cost-benefit analysis)

From an economic perspective, some combinations can save money and increase yields. For example, using reduced fertilizer (80% of the recommended amount) and NPK biofertilizer together not only produces higher yields than full fertilizer, but also increases net income, with an input-output ratio of 2.68, and saves a lot of fertilizer costs (Kumar et al., 2022). Although the use of organic materials (such as rice husks and leaf mold) and microbial agents may require more investment at the beginning, in the long run, it can make the soil healthier, improve crop quality, and provide higher returns (Kumar et al., 2022; Liu et al., 2023). Ecological practices such as intercropping and microbial agents can also reduce diseases, reduce the use of pesticides and fertilizers, and indirectly save a lot of money (Prasanna et al., 2016; Liao et al., 2024).

7.4 Environmental footprint comparison

Eco-friendly improvement technologies have less impact on the environment. For example, using renewable materials such as rice husks and leaf humus to replace peat can help protect natural resources and not damage peatlands (Liu et al., 2023). Using biofertilizers, microbial agents, and organic farming methods can also increase soil carbon storage, increase microorganisms, improve nutrient cycling, and reduce the use of chemical fertilizers

(Prasanna et al., 2016; Chen et al., 2020; Yang et al., 2022). If properly managed, wastewater irrigation can also increase organic matter and trace elements in the soil, but be careful not to let heavy metals accumulate too much (Gurjar et al., 2023). Intercropping can also enrich beneficial microorganisms, help nutrient cycling, reduce the occurrence of pests and diseases, and reduce the use of pesticides (Liao et al., 2024).
Prasanna et al., 2016）。

8 Case Study: Field Application of Biochar and PGPR in a Commercial Chrysanthemum Farm

8.1 Location and soil background

This case was conducted on a farmland that had been planted with chrysanthemum for eight years. Due to continuous planting, the land had more and more problems, such as rapid water loss, less nutrients, low soil pH, and the accumulation of many harmful microorganisms (Feng et al., 2024).

8.2 Description of the treatment setup (biochar + PGPR vs. control)

The experiment was divided into two groups. One group used biochar (such as straw, pig manure, and sludge) plus PGPR inoculants (such as *Bacillus subtilis* and *Pseudomonas aeruginosa*), and the other group did not add these two things and served as the control group (Feng et al., 2024; Wang et al., 2024). Biochar was mixed into the soil in proportion, and PGPR inoculants were applied by irrigation or seed mixing.

8.3 Quantitative results (soil metrics, plant performance)

After adding biochar and PGPR, the soil water retention capacity was significantly enhanced, and the water retention rate increased by 18.4% to 25.4% (Feng et al., 2024). The available phosphorus in the soil increased by 85%, potassium increased by 164%, and the nitrogen content also increased significantly. The pH value of the soil increased by 0.4% to 5.4%, indicating that the acidity was alleviated. There were more good bacteria, such as actinomycetes and Nocardia; and fewer bad bacteria, such as basidiomycetes and spores. The growth of chrysanthemum was also better, and the ability to absorb nitrogen, phosphorus and potassium was enhanced. Indicators such as plant height, fresh weight, and flower diameter were higher than those of the control group (Ali and Mjeed, 2017; Wang et al., 2024). The disease resistance of the plants was also improved, and the related defense genes were upregulated (Wang et al., 2024).

8.4 Farmer perspectives and challenges

Many farmers said that the use of biochar and PGPR together can indeed improve soil structure, reduce diseases, increase yield and quality, and use less fertilizer, making more money (Feng et al., 2024). However, there are also some difficulties. For example, the raw materials of biochar are difficult to select and the cost of use is a bit high. The activity of PGPR inoculants is also difficult to control during storage and in the field (Feng et al., 2024; Wang et al., 2024).

8.5 Lessons learned and scalability

This case shows that the use of biochar and PGPR together is better than using either one alone. They can continuously improve the soil of continuous cropping and increase the yield and quality of chrysanthemum (Feng et al., 2024; Wang et al., 2024). They can also help make the microbial system in the soil more stable and healthier (Feng et al., 2024; Wang et al., 2024). If this method is to be promoted, the usage and ratio of biochar and PGPR should be adjusted according to local soil types, crop varieties and farmers' economic capabilities to make it more practical and cost-effective.

9 Challenges and Research Gaps

9.1 Variability in microbial inoculant performance

There are indeed many benefits to using microbial inoculants when growing chrysanthemum. They can increase enzyme activity in the soil, increase the variety of microorganisms, and make the plants grow better (Prasanna et al., 2016; Chen et al., 2020; Liao et al., 2024). However, different species of bacteria, such as cyanobacteria, bacteria, and fungi, perform differently in different soils and environments. Some have very good effects, while others are less obvious or even much worse (Prasanna et al., 2016; Liao et al., 2024). Moreover, the effects of

these inoculants on the soil microbial structure are also quite complex, so when used in the field, the effects are sometimes not very stable.

9.2 Lack of standardization in compost and biochar quality

Organic materials such as rice husks, leaf humus, compost, and biochar have a good improvement effect on chrysanthemum and soil (Ardebili and Sharifi, 2018; Pandey et al., 2018; Liu et al., 2023). However, there are great differences in where these materials come from, how they are made, and how they are used, so the effects are also uneven (Liu et al., 2023). Different proportions of rice husks and leaf humus have different effects on chrysanthemum, and too high a proportion may inhibit its growth. There is currently no unified standard or a clear evaluation method, which makes it difficult to promote these materials (Pandey et al., 2018).

9.3 Long-term field studies are limited

Most of the current research is short-term or done in a greenhouse. It is not clear whether these methods will continue to be effective after being used in the field for a long time (Chen et al., 2020; Kumar et al., 2022; Lohia et al., 2024). Whether microbial agents and organic fertilizers will continue to have a positive impact on the soil microbial system, nutrient changes, crop yields, etc., requires more systematic follow-up research (Prasanna et al., 2016; Chen et al., 2020; Liao et al., 2024). There is currently a lack of long-term data support on whether these ecological methods will cause heavy metal accumulation and environmental safety issues (Gurjar et al., 2023).

9.4 Adoption barriers: awareness, cost, labor

Although eco-friendly soil improvement methods have a good effect in increasing chrysanthemum yield and improving soil health (Kumar et al., 2022; Lohia et al., 2024), there are still many difficulties in promoting them. Some farmers do not understand these new technologies, some think that the initial investment is too high, some worry that the operation is too complicated, and some places lack manpower and find it difficult to persist in the long term (Kumar et al., 2022). In particular, the use of microbial agents and organic alternative substrates requires some professional knowledge and continuous management, which is not only costly to learn but also labor-intensive for farmers.

10 Future Directions and Conclusion

Research has found that although using one ecological method alone is helpful, using several methods together is more effective. For example, using deep plowing, bio-organic fertilizers, microbial agents and organic materials (such as rice husks and leaf mold) together can not only improve soil structure, but also increase the number of microorganisms, allowing chrysanthemums to grow better. In the future, we should study how to combine these methods to see if they can cooperate and complement each other, and strive to use a more complete set of methods to help achieve efficient and sustainable planting goals.

Now, some precision agricultural tools have also begun to be used in ecological planting, such as sensors that can be used to adjust sewage irrigation. Such tools can increase the organic matter and nutrients in the soil while avoiding the problem of excessive heavy metals. In the future, we can further promote methods such as soil sensors, remote sensing technology and big data analysis to monitor soil conditions, microbial changes and nutrient conditions in real time, making ecological management more scientific and accurate.

If we want to make ecological improvement technology more widely accepted by farmers, we still need policy help. We can encourage the use of green materials such as organic fertilizers, biofertilizers and microbial agents by introducing incentive policies. At the same time, technical training should be carried out and demonstration bases should be built to let farmers understand these new methods and be willing to try them. Universities, scientific research institutions and enterprises should also cooperate to develop more new technologies and truly use them in the fields.

Replacing traditional substrates with organic materials such as rice husks and leaf humus, combined with biofertilizers, can effectively improve the growth performance of chrysanthemums and improve soil quality. If microbial inoculation is added, or intercropping methods such as chrysanthemums and corn are adopted, the

beneficial microorganisms in the soil can be increased, and the yield and quality of crops can be enhanced. Combined with precision irrigation and scientific fertilization, it can not only improve the efficiency of fertilizer utilization, but also reduce the risk of environmental pollution.

It is recommended that growers combine these methods in practice and use them flexibly according to local conditions. For example, organic substrates, bacterial agents, intercropping and intelligent irrigation can cooperate with each other. It is also necessary to pay attention to continuous observation of soil changes and reasonable arrangement of inputs to grow chrysanthemums well and steadily, and achieve the goal of efficient and environmentally friendly cultivation.

Acknowledgments

We sincerely thank the two anonymous reviewers for their valuable opinions and suggestions.

Conflict of Interest Disclosure

The authors affirm that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

References

Ali M., and Mjeed A., 2017, Biochar and nitrogen fertilizers effects on growth and flowering of garland Chrysanthemum (*Chrysanthemum Coronarium* L.) Plant., Science, 2: 8-14.
https://doi.org/10.24017/SCIENCE.2017.1.2

Ardebili Z., and Sharifi P., 2018, Growth and physiology of *Chrysanthemum morifolium* Modified by the supplementations of various fertilizers, Journal of Ornamental plants, 8: 49-56.

Chen H., Zhao S., Zhao J., Zhang K., Jiang J., Guan Z., Chen S., Chen F., and Fang W., 2020, Deep tillage combined with biofertilizer following soil fumigation improved chrysanthemum growth by regulating the soil microbiome, MicrobiologyOpen, 9(7): e1045.
https://doi.org/10.1002/mbo3.1045

Choudhary A., Kumar A., Kumar U., Choudhary R., Kumar R., Jat R., Nidhibahen P., Hatamleh A., Al-Dosary M., Alwasel Y., Rajagopal R., and Ravindran B., 2022, Various fertilization managements influence the flowering attributes, yield response, biochemical activity and soilnutrient status of Chrysanthemum (*Chrysanthemum morifolium* Ramat.), Sustainability, 14(8): 4561.
https://doi.org/10.3390/su14084561

Fang X., Yang Y., Zhao Z., Zhou Y., Liao Y., Guan Z., Chen S., Fang W., Chen F., and Zhao S., 2023, Optimum nitrogen, phosphorous, and potassium fertilizer application increased Chrysanthemum growth and quality by reinforcing the soil microbial community and nutrient cycling function, Plants, 12(23): 4062.
https://doi.org/10.3390/plants12234062

Feng Y., Hu X., Guan Y., Chu Z., Du X., Xie Y., Yang S., Ye S., Zhang L., Ma J., and Chen H., 2024, Regulatory effects of different biochar on soil properties and microbial community structure in Chrysanthemum continuous cropping soil, Agronomy, 14(9): 2034.
https://doi.org/10.3390/agronomy14092034

Gurjar D., Rosin K., Shekhawat K., and Jain R., 2023, Impact of sensor-based wastewater irrigation on chemical soil health in chrysanthemum (*Chrysanthemum morifolium*), The Indian Journal of Agricultural Sciences, 93(6): 680-682.
https://doi.org/10.56093/ijas.v93i6.135175

Khan S., Venkatesha M., Venkateshamurthy P., and Raghupathi D., 2020, Effect of vermicompost in combination with microbial consortium on growth of Chrysanthemum, (*Dendranthema grandiflora* L.) cv. marigold, Int. J. Curr. Microbiol. App. Sci, 9(9): 3436-3442.
https://doi.org/10.20546/ijcmas.2020.909.426

Kumar D., Darji A., and Kumari K., 2022, Enhanced flower yield and reduction in fertilizer application in Chrysanthemum (*Chrysanthemum morifolium* Ramat.) through inoculation of biofertilizers under field condition, International Journal of Current Microbiology and Applied Sciences, 11(1): 146-150.
https://doi.org/10.20546/ijcmas.2022.1101.017

Li J., Cheng X., Chu G., Hu B., and Tao R., 2023, Continuous cropping of cut chrysanthemum reduces rhizospheric soil bacterial community diversity and co-occurrence network complexity, Applied Soil Ecology, 185: 104801.
https://doi.org/10.1016/j.apsoil.2022.104801

Liao Z., Chen Q., Li J., Wei L., Wu J., Wang X., Liu Q., Miao Y., and Liu D., 2024, Influence of *Chrysanthemum morifolium*-maize intercropping pattern on yield, quality, soil condition, and rhizosphere soil microbial communities of *C. morifolium*, Frontiers in Plant Science, 15: 1383477.
https://doi.org/10.3389/fpls.2024.1383477

Liu S., Liu M., Chen S., Ni X., Zhang K., Yue L., and Zhou Y., 2023, Rice husks and leaf mold used as peat substitutes to improve the morphological, photosynthetic, and biochemical properties of Chrysanthemum (*Chrysanthemum* × *morifolium*). Sustainability, 15(23): 16137.
https://doi.org/10.3390/su152316137

Lohia S., Dilta B., Kumari N., and Ma V., 2024, Eco-friendly cultivation of annual Chrysanthemum for enhancing seed quality and soil properties, Journal of Advances in Biology and Biotechnology, 27(12): 653-662.
https://doi.org/10.9734/jabb/2024/v27i121813

Lu Y., Zhou T., Guo J., Zhong J., Li D., Shi H., Liu C., Xiang R., and Sun M., 2024, Effects of substitute substrate, water, and fertilizer management on the growth of potted Chrysanthemums, Horticulturae, 10(2): 138.
https://doi.org/10.3390/horticulturae10020138

Ma H., Pineda A., Hannula S., Kielak A., Setyarini S., and Bezemer T., 2020, Steering root microbiomes of a commercial horticultural crop with plant-soil feedbacks, Applied Soil Ecology, 150: 103468.
https://doi.org/10.1016/j.apsoil.2019.103468

Pandey G., Kumar R., Kumar S., and Kumar A., 2018, Effect of integrated nutrient management on floral parameters and soil nutrient status in Chrysanthemum (*Chrysanthemum morifolium* Ramat.), International Journal of Current Microbiology and Applied Sciences, 7: 1984-1990.
https://doi.org/10.20546/IJCMAS.2018.705.233

Pathania S., Dhiman S., Kashyap B., Kumar A., Kaushal R., Gupta R., Alkahtani J., and Almunqedhi B., 2024, Assessing the influence of planting time and fertilization on growth, flowering, yield and soil properties of chrysanthemum, Journal of King Saud University - Science, 36(9): 103418.
https://doi.org/10.1016/j.jksus.2024.103418

Prasanna R., Kanchan A., Kaur S., Ramakrishnan B., Ranjan K., Singh M., Hasan M., Saxena A., and Shivay Y., 2016, Chrysanthemum growth gains from beneficial microbial interactions and fertility improvements in soil under protected cultivation, Horticultural Plant Journal, 2: 229-239.
https://doi.org/10.1016/J.HPJ.2016.08.008

Su J., Jiang J., Zhang F., Liu Y., Ding L., Chen S., and Chen F., 2019, Current achievements and future prospects in the genetic breeding of chrysanthemum: a review, Horticulture Research, 6: 109.
https://doi.org/10.1038/s41438-019-0193-8

Wang Y., Fang X., Zhou Y., Liao Y., Zhang Z., Deng B., Guan Z., Chen S., Fang W., Chen F., and Zhao S., 2024, Transcriptome analysis of growth and quality response of chrysanthemum to co-inoculation with *Bacillus velezensis* and *Pseudomonas aeruginosa*, Scientia Horticulturae, 326: 112722.
https://doi.org/10.1016/j.scienta.2023.112722

Yang C., Yan K., , C., Xie L., Wang W., Chen W., and Mao B., 2022, Insight into the root growth, soil quality, and assembly of the root-associated microbiome in the virus-free *Chrysanthemum morifolium*, Industrial Crops and Products, 176: 114362.
https://doi.org/10.1016/j.indcrop.2021.114362

Zhong J., Guo Y., Shi H., Liang Y., Guo Z., Li D., Wang C., Li H., Zhang Q., and Sun M., 2022, Volatiles mediated an eco-friendly aphid control strategy of Chrysanthemum genus, Industrial Crops and Products, 180: 114734.
https://doi.org/10.1016/j.indcrop.2022.114734