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The Study on the Effect of Soil Improvement on the Growth and Quality of De-toxic Mother Plants and Seedlings of Wu Yao

Xiaocheng Wang [1], Jianli Zhong [2]
1Traditional Chinese Medicine Research Center, Cuixi Academy of Biotechnology, Zhuji, 311800, China;
2 Hainan Institute of Biotechnology, Haikou, 570206, Hainan, China
Corresponding email: xiaocheng.wang@jicat.org
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Abstract This study mainly aims to clarify whether different soil improvement methods will affect the growth conditions and quality of the mother plants and seedlings of Wu Yao (*Lindera aggregata*). Several soil treatment methods were examined, such as adding organic fertilizers, adjusting the regular watering habits, and using beneficial microbial communities, to improve the soil environment, promote better plant growth, enhance root development, and increase the biomass of the entire plant and the quality of its medicinal parts. Soil conditions and regional natural environments vary greatly, so when growing Wu Yao, one cannot simply copy methods from other places but must adjust soil management strategies based on local specific circumstances. To ensure the sustainable development of Wu Yao cultivation, this study recommends some environmentally friendly practices, such as implementing crop rotation or using more eco-friendly soil additives. These measures not only benefit soil health but also reduce the ecological burden. This study hopes to provide a scientific basis for soil improvement strategies for the sustainable and efficient cultivation of Wu Yao mother plant gardens, improve seedling quality and yield, and promote the green development of ecological cultivation of traditional Chinese medicinal materials.
Keywords Soil improvement; Wuyao; Organic amendments; Plant growth-promoting bacteria; Sustainable agriculture

1 Introduction

The scientific name of Wu Yao is *Lindera aggregata*, which is a common traditional Chinese medicine plant and plays an important role in traditional Chinese medicine. People often use it to relieve pain, regulate qi and blood, and can also treat conditions such as abdominal pain, frequent urination, and cold body. Its root is the main medicinal part, and the quality of the root directly affects the efficacy of the medicine.

The cultivation of Wu Yao still faces many difficulties, among which the biggest problem is poor soil. If the soil quality is poor, Wu Yao will not grow well, the yield will decrease, and the efficacy will also decline. In addition, the impact of climate change, such as irregular rainfall and more extreme weather, will make the soil worse and be detrimental to the growth of Wu Yao. In fact, this situation has also occurred in other crops. To address these issues, some people have tried improving the soil, such as using organic fertilizers or non soil seedling materials, which can help seedlings grow better (Lei et al., 2017; Zeng et al., 2023). They have already seen some effects in enhancing plant growth by making the root system more developed and absorbing water and fertilizer more effectively (Wang et al., 2019; Li et al., 2022).

This study aims to figure out whether several different soil improvement methods can really help make the mother plants and seedlings of Wu Yao grow stronger. Several operations were tested to improve the soil, and the watering method was appropriately changed to see if it was more beneficial to the plants. Through this research, we hope to provide a scientific basis for soil improvement strategies for the sustainable and efficient cultivation of the mother garden of Wuyao detoxification, enhance the quality and yield of seedlings, and at the same time promote the green development of ecological cultivation of Chinese medicinal materials.

2 Soil Conditions and Growth Requirements of Wu Yao

2.1 Wu Yao's requirements for soil pH, texture, and organic matter content

The content of organic matter, that is, beneficial components such as humus in the soil, must reach a certain level for the normal growth of the black medicinal herb and the development of its root system will also be smoother. Among them, the pH value is particularly important for the medicinal herb of Wu. The pH value directly affects whether plants can effectively absorb nutrients and is also related to the activity and reproductive capacity of beneficial microorganisms in the soil. According to the research by Wang et al. (2021), the most suitable pH range for the Chinese herbal medicine is slightly acidic to neutral. Within this range, its growth performance is relatively ideal and it absorbs nutrients more smoothly. Therefore, to grow Wu Yao well, it is very crucial to keep the soil pH within an appropriate range. Apart from pH value, the "particle structure" or "texture" of the soil also has a significant impact. Compared with sandy soil that drains too quickly and has poor water retention capacity, medium-grained soil like loam is more suitable for the medicinal herb. Loam soil can not only retain water and nutrients, but also provide more stable support for the roots, which is helpful for increasing the yield and quality of aconite (Wang et al., 2021; 2022a).

2.2 The impact of soil drainage and water retention on Wu Yao growth

To grow well, Wu Yao also needs to rely on appropriate drainage and water retention properties. Good drainage can prevent soil water accumulation, prevent root rot or disease. At the same time, the soil should also be able to hold water, so that plants do not lack water during droughts. Research has shown that loam soil has better drainage and water retention properties than sandy soil; Sandy soil is prone to water loss and cannot retain water (Wang et al., 2021; Zhang et al., 2022). In some places where water resources are scarce, it is even more important to pay attention to how to use water efficiently. For example, methods such as micro irrigation can help soil with fast drainage retain some moisture, and Wu Yao can naturally benefit from it (Zhang et al., 2022). As long as the soil is maintained within a suitable humidity range, Wu Yao is more likely to grow healthily (Figure 1).

2.3 Regional variations in soil types and their adaptability for Wu Yao cultivation

The soil in different regions varies greatly, which can also affect whether Wu Yao is suitable for planting there. Some places are clay, some are loam, and some are sandy soil. These types of soil have different characteristics and will have different effects on the growth of Wu Yao. For example, although clay can store a lot of water, it is prone to water accumulation; However, sandy soil has good drainage, but poor fertility and cannot retain water (Hamoud et al., 2019; Ahmad and Li, 2021). Different soils require different management methods. If it is a clay area, consideration can be given to making the soil more aerated and drainage smoother; If it is a sandy area, then we need to find ways to add more organic matter to allow the soil to retain more moisture.

3 Soil Improvement Methods

3.1 Organic soil improvement materials

Organic substances like compost, green manure and biochar are quite effective in improving soil structure and increasing fertility, which can help plants grow better and of higher quality. Compost and green manure contain rich organic components, which can make the nutrients in the soil more easily absorbed by plants. At the same time, they can also activate beneficial microorganisms in the soil, which is particularly beneficial for root growth and can enhance the ability of roots to absorb nutrients (Zeng et al., 2023). The role of biochar is also significant. It can enhance soil aeration and water retention, making it suitable for regulating soil conditions and facilitating the healthy growth of plants. In addition, it can also reduce soil acidity and enhance the soil's ability to retain nutrients, thereby enabling plants to better obtain the required elements (Mao et al., 2021; Huang, 2024).

After using these organic materials, plants usually grow faster and taller in the early stage, and their dry weight also increases significantly. This effect is related to some reactions within plants, such as the production of more antioxidant substances and pigments that are beneficial to photosynthesis, thereby enhancing health levels and yields. In addition, these amendments can also prevent the loss of fertilizers in the soil, reduce the risk of soil being washed away by rainwater, and maintain soil fertility for a longer time (Mao et al., 2021).

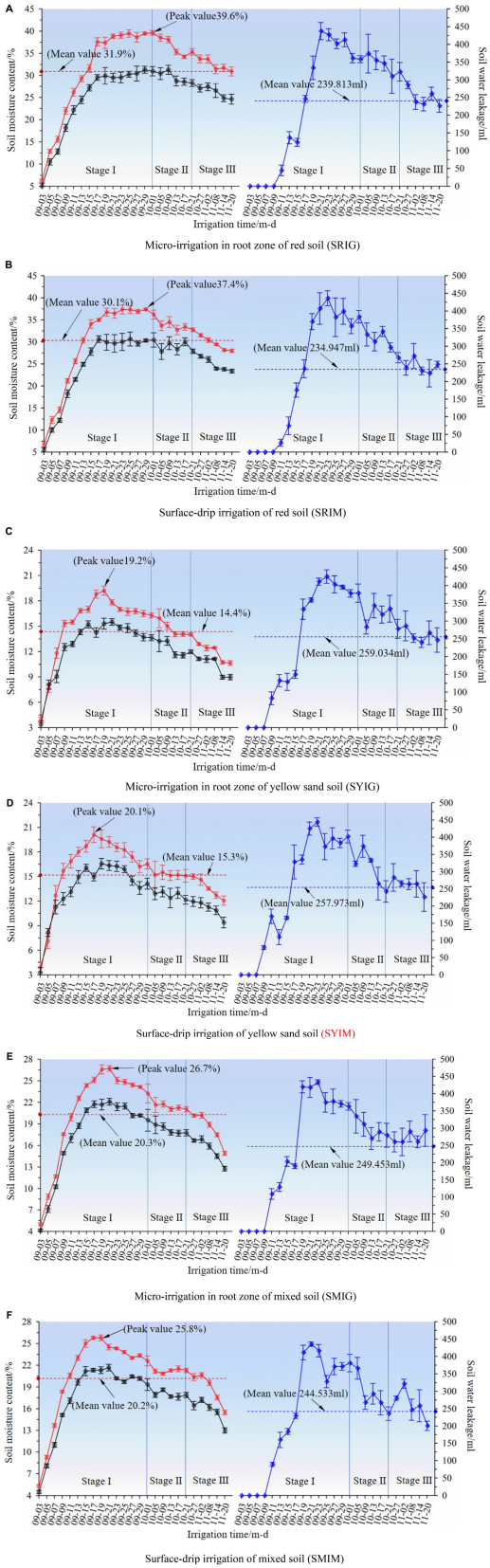

Figure 1 Variation map of moisture content (TDR and weighing method) and water drainage of non-crop soil against time (Adopted from Zhang et al., 2022)

Image caption: represents moisture meter method, represents weighing method, represents amount of soil water leakage. Stages I, II, and III represents three time-interval gradients, i.e., 2, 4, and 6 days, respectively (Adopted from Zhang et al., 2022)

3.2 Inorganic soil conditioning methods

Inorganic soil conditioners usually include various fertilizers, lime, gypsum, etc. They are mainly used to adjust the pH of the soil or supplement the nutrient elements needed for plant growth. Basic nutrients like nitrogen, phosphorus and potassium are indispensable in the development process of crops. Scientific fertilization can enable crops to grow faster during the seedling stage and absorb nutrients more efficiently (Mao et al., 2021). Among them, lime is mainly used to neutralize the acidity of the soil and help increase the pH value to neutral or slightly alkaline, so that plants can absorb nutrients more easily and at the same time reduce the release of harmful metals (Zeng et al., 2023).

As for gypsum, it is quite effective in improving soil structure. Gypsum can make the originally compacted soil softer, enhance the aggregate structure, facilitate the downward growth of the root system, and make it easier for water to seep in. Sometimes, farmers also use gypsum together with fertilizers. This can simultaneously improve the nutrient status and physical conditions of the soil, allowing plants to grow better (Mao et al., 2021). This combination is particularly suitable for use on nutrient-deficient or degraded land, which helps restore soil fertility and promote more sustainable agricultural development (Zeng et al., 2023).

3.3 New soil management techniques

In recent years, some more advanced soil management methods have emerged, such as precise fertilization, mycorrhizal fungus inoculation, and water regulation techniques. Precise fertilization refers to applying fertilizers in a targeted manner based on specific crop types and soil conditions, reducing unnecessary waste and environmental pollution. Providing plants with appropriate nutrients at the right time can improve their absorption efficiency and thereby promote growth and yield (Mao et al., 2021; Sun and Qian, 2024). Mycorrhizal inoculation involves introducing certain beneficial fungi (the most common being arbuscular mycorrhizal AMF) into the roots of plants. These fungi can coexist with the root system, helping plants absorb nutrients more effectively and also improving soil structure. Zhang et al. (2019) once found that mycorrhizal inoculation could promote the formation of more aggregates in the soil, making it easier for the root system to expand and enhancing its ability to absorb water and nutrients.

In terms of water management, a material called "superabsorbent polymer" is widely used. It can lock in moisture in the soil and release it slowly when plants need it. This approach can reduce the impact of drought, make photosynthesis smoother, and also make the overall growth of plants more stable (Mao et al., 2021).

4 Effect of Soil Improvement on Wu Yao Mother Plants

4.1 The promotion of root development and growth rate through soil improvement

Soil amendments, such as organic and biological fertilizers, loosen the soil and make it more porous, making nutrients more accessible to the plant. This allows the roots of Linderae acuminata to grow deeper, increasing their overall range and volume. With more porosity and improved aeration in the soil, the root system can more easily expand. These changes directly enhance the plant's ability to absorb water and nutrients, leading to faster and stronger plant growth (Angelopoulou et al., 2014). Biological fertilizers also activate the soil microbiome. These invisible microorganisms help break down nutrients in the soil, converting previously inaccessible elements into usable nutrients for the plant. They also promote the growth of root hairs and fine root systems, effectively creating more "supply straws" for the plant and improving root absorption efficiency (Bira et al., 2016). Stronger roots lead to healthier plants, ultimately increasing yields.

4.2 The enhancement of active ingredient content (such as essential oils, flavonoids) due to soil improvement

Improved soil not only promotes the growth of Wu Yao, but also benefits the active ingredients in its body. For example, the content of active ingredients such as volatile oils and flavonoids will also increase accordingly. Organic fertilizers and proper nutrient management can provide the raw materials needed for synthesizing these components, as well as increase the activity of related enzymes, promoting the production of these substances (Feng et al., 2024). Some beneficial microorganisms can also work. They reduce the stress on plants and help absorb more nutrients. They will affect the substances secreted by the root system, thereby stimulating plants to

synthesize more active ingredients, making the medicinal value of Wu Yao higher (Figure 2) (Wang et al., 2022b).

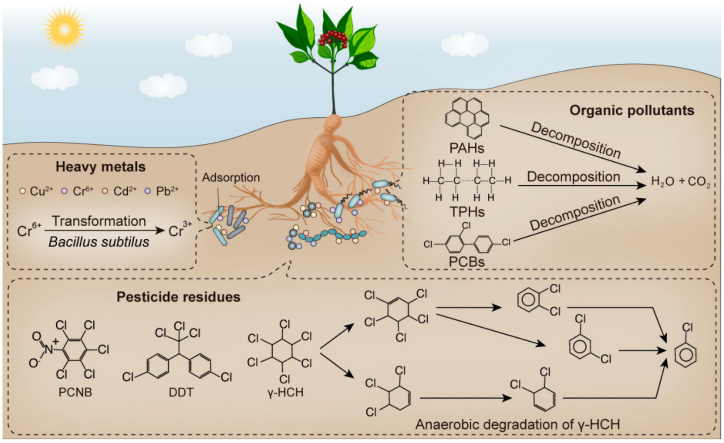

Figure 2 Removal of soil contaminants (pesticide residues, heavy metals and organic pollutants) by microorganisms and the potential mechanism (Adopted from Wang et al., 2022b)

Image caption: Heavy metals are adsorbed and fixed on the cell surface by microorganisms. Highly toxic metallic elements can be converted to less or non-toxic substances by redox reactions. The chemical pesticides and organic pollutants are broken down by soil microbes into small molecule compounds, H_2O and CO_2 (Adopted from Wang et al., 2022b)

4.3 Improved disease resistance and stress tolerance in mother plants

Soil improvement can also make Wu Yao more resistant to diseases. The improved soil microbial community is healthier, and these "good" microorganisms can inhibit the growth of "bad" bacteria, acting as natural disease prevention helpers. They can also activate the plant's own defense mechanisms, reduce root and leaf diseases, and make Wu Yao grow healthier and yield more stable (Wei et al., 2019). Wu Yao can also exhibit stronger resilience in harsh environments such as drought and salt alkali. This is because the improved soil has better water retention, more abundant nutrients, and stronger root systems. These advantages can help Wu Yao grow normally in difficult to grow areas, maintain the continuous production of medicinal ingredients, and are also important for future cultivation (El Kady and Borham, 2013).

5 Effect of Soil Improvement on Wu Yao Seedlings

5.1 The promotion of root development and growth in seedlings

Improving soil is beneficial for the root development of seedlings. Adding organic fertilizer or using appropriate thickness of cover to the soil can not only supplement nutrients, but also loosen the soil structure, enhance air circulation, and be more suitable for root growth. In the process of rice cultivation, applying organic fertilizer or nutrient rich soil directly during sowing can enhance plant roots, effectively improve seed germination rate and seedling growth (Zeng et al., 2023). Lei et al. (2017) used soilless substrates for seedling cultivation, significantly increasing root length and aboveground growth, indicating that this type of substrate can also support root development well. Good root growth not only helps plants stand firm, but also helps them absorb more water and nutrients. For Wu Yao seedlings, this is crucial (Zeng et al., 2023).

5.2 The impact of soil improvement on seedling survival rates and early growth

Improving soil conditions is crucial for enhancing the early survival and growth status of seedlings. For example, laying a suitable mulch on the seedbed and applying organic fertilizer as the base treatment can increase the germination rate and make the seedlings grow taller and thicker (Zeng et al., 2023). This method is particularly effective when the seedlings have just emerged from the soil and their root systems are still unstable, as the soil conditions at that time will directly determine whether the seedlings can survive. Using soilless materials (such as coconut coir, vermiculite, etc.) for seedling cultivation can also enhance the overall quality of the seedlings. Although the seedlings raised in this way will have a short "accelution" process after transplanting, such as a slower return of green leaves, overall, the growth performance is not much different from that of seedlings raised in traditional nutrient soil (Lei et al., 2017). This type of seedling raising method can also reduce soil-borne

diseases and is more conducive to the health management during the seedling stage.

5.3 Increased stress tolerance and adaptability in seedlings due to soil improvement

In addition to its impact on growth rate, soil improvement can also enhance the seedlings' ability to cope with adverse environments. When seedlings encounter situations such as drought or lack of nutrients, improved soil can act as a buffer to help plants get through difficult times. Organic cover materials, humus, etc. not only improve the soil structure, but also prompt plants to activate some "self-protection mechanisms" by themselves, such as increasing the activity of antioxidant enzymes and the production of photosynthetic pigments, in order to reduce the damage caused by external pressure (Zeng et al., 2023). Improving the soil can also make seedlings more adaptable to different planting conditions. Lei et al. (2017) conducted an experiment. Although the seedlings grown by soilless seedling cultivation recovered slightly slower at the initial stage of transplanting, they could still adapt to the natural environment in the field later on, and their final growth was no worse than that of the traditional method. This adaptability is of great significance to the herb "Wu Yao", as it ensures that the seedlings can grow normally even in unstable plots, forming strong and highly resistant plants.

6 Synergistic Effects of Soil Improvement and Other Agricultural Practices

6.1 The combined effect of fertilization and soil improvement on Wu Yao growth

Combining fertilization and soil improvement methods can accelerate the growth of black medicine more efficiently. Mao et al. (2021) conducted research on adding soil improvement materials such as humic acid and biochar while fertilizing. They found that after adding soil improvement materials, not only did the soil quality improve, but nutrients also became easier for plants to absorb, and black medicine grew faster and the yield increased. Applying compound fertilizers and super absorbent materials in degraded soil can improve the physiological state of seedlings. Under similar conditions, these two methods may also be effective for black medicine. The combination of organic and inorganic fertilizers can improve water utilization efficiency, allowing plants to absorb more nutrients through water absorption, which is beneficial for the stable growth of black medicine (Shi et al., 2023). In order to cultivate stronger plants, it is necessary to apply fertilizers in a planned manner to improve the structure and chemical properties of the soil. Jiang et al. (2024) pointed out in their study that reasonable fertilization combined with scientific irrigation can improve the utilization efficiency of water and nitrogen, which is beneficial for the health and yield of Wu Yao plants.

6.2 Synergistic effects of irrigation management and soil improvement

In the cultivation of *Linderae agglomerata*, rationally managing watering patterns and improving the soil are crucial for enhancing plant growth and efficiency. Combining irrigation and soil improvement not only promotes healthier plant growth but also reduces the environmental burden of agricultural production, making the entire cultivation process greener and more sustainable. A practical approach is to determine watering timing based on soil moisture, commonly known as "soil-based watering." This approach avoids unnecessary waste and directs water use when it's truly needed, making it particularly suitable for areas with severe water shortages (Jiang et al., 2024). Combining this water-saving irrigation method with appropriate soil improvement measures can more effectively conserve water and fertilizer in the soil, reduce pollution caused by overfertilization, and be more eco-friendly (Li et al., 2018).

6.3 The integration of crop rotation and soil improvement to enhance soil health and long-term sustainability

The combination of crop rotation and soil improvement is also an effective measure to improve soil health, which can ensure the long-term planting quality of black medicine. Li et al. (2024) found in their research that planting black medicine and other crops alternately, combined with improved materials such as biochar or earthworm compost, resulted in a healthier soil structure, higher organic matter content, and more active microorganisms. These are all very beneficial phenomena for soil ecology. These changes in soil are not only beneficial for the growth of black medicinal plants, but also make the soil more tolerant to external pressures such as drought and salinity. Another benefit of crop rotation is to interrupt the reproductive cycle of pests and pathogens, reduce dependence on pesticides and other chemicals during planting, and make plants healthier and the planting process

more sustainable. This "combination management" approach can not only amplify the effect of soil improvement, but also promote the long-term stable development of agriculture.

7 Challenges and Limitations

7.1 The costs, technical implementation difficulties, and economic feasibility of soil improvement

Although improving soil structure has many benefits for planting, it is not easy to actually implement it. Some new improvement technologies, such as the use of plant growth-promoting bacteria (PGPB) or nanomaterials, although they can indeed help plants detoxify and stimulate growth, their raw materials and equipment prices are usually not low (Sun et al., 2022). These techniques also involve rather complex reaction processes between soil and crops, and they are not easy for everyone to master. Farmers may need to learn some basic knowledge first before they can use them correctly. In addition to the input cost, the final economic return also needs to be considered in the actual planting process. If an improvement measure costs a lot of money but does not significantly increase production or fails to fetch a good price, it is actually not very cost-effective. For instance, the addition of plant hormones (such as indoleacetic acid IAA) can indeed promote crop growth and reduce the accumulation of heavy metals in plants. However, if the benefits do not cover the inputs, this method loses its significance (He et al., 2021). So before deciding whether to carry out soil improvement or not, it is best to conduct a detailed income and expenditure analysis. Only when the returns can exceed the investment in the long term are these measures worth continuing to promote and apply.

7.2 Regional differences leading to variations in soil improvement effectiveness

The soil conditions vary greatly in different regions, which can result in different effects of the same improvement methods in different places. In the arid Pilbara region of Australia, scientists tried using inorganic amendments such as gypsum and urea, and found that although seedlings grew faster, the rate of dead seedlings also increased (Bateman et al., 2019). This indicates that not all places can use the same method, and it depends on the local climate, soil type, and agricultural habits. In some places, the available resources are also relatively limited. Lack of topsoil or suitable organic materials poses difficulties for soil improvement. In this case, some people began to try soilless seedling cultivation methods, although this approach also has problems, such as slower greening after transplantation and changes in plant hormone levels (Lei et al., 2017). So in practical operation, it is necessary to find a more suitable solution based on local conditions, and not blindly apply the experience of other places.

7.3 Potential environmental impacts and risks associated with certain soil improvement measures

Although most soil improvement methods are beneficial to crop growth and can reduce some harmful components, in some cases, they may also bring considerable environmental risks. Therefore, when using these materials, one should not only focus on the immediate benefits but also take into account the long-term ecological impact. Take nanomaterials for example. If the usage methods are not appropriate, they may bring some unexpected problems to the environment. For example, although iron oxide nanoparticles can reduce the toxicity of arsenic in plants, it is still unclear whether they will have side effects in the ecosystem in the long term (Sun et al., 2022). Special attention should be paid to the application of such materials. Regular monitoring should be carried out to avoid causing damage to the microbial community in the soil or water. Inorganic improvers are not 100% safe either. If used in excessive amounts, it may alter the chemical state of the soil and interfere with the normal activities of beneficial microorganisms in the soil. Some studies have pointed out that when conducting mine land restoration, if the dosage of gypsum and urea is too large, although the soil quality in some areas has improved, the problem of increased seedling mortality rate has also emerged (Bateman et al., 2019). Therefore, when applying these substances, it is necessary to control the dosage well to avoid "good intentions leading to bad results".

8 Future Directions and Research Needs

8.1 The need for research on promoting soil improvement techniques in different regions

Soil and climate conditions vary in different regions, so the implementation of soil improvement technologies needs to be adapted to local conditions and cannot be applied universally. Lei et al. (2019) conducted a study in the gully areas of the Loess Plateau in China. They used organic fertilizers and fly ash, effectively improving the local soil conditions and increasing the crop yield. But if this method is applied to other regions, it won't work

because the soil types and climates are different. Wu et al. (2024) pointed out that the content of available potassium in soils of different regions also varies. Before implementing measures, we need to fully understand the local soil characteristics. After grasping this information, farmers or researchers can adjust their management strategies based on the actual situation, such as what kind of fertilizer to use, how to apply conditioners, and what crops to grow, etc. Conducting more research in different regions can identify more suitable improvement methods for each area, thereby enhancing both agricultural output and sustainability.

8.2 Studies on the effects of soil improvement on plant gene expression and active ingredient synthesis

Nowadays, more and more people are beginning to pay attention to the impact of soil improvement on the genes and components of plants. This is also a relatively new research direction for scientists. Many improvement methods (such as the use of special fertilizers or amendments), in addition to improving the growth of plants, may also affect the expression mode of genes in plants and even the substances synthesized by plants (Zhao et al., 2018). These influencing factors are of great significance to medicinal plants like Wu Yao. The metabolic process of plants is actually closely related to the soil environment. Changes such as respiration, microbial activities, and nutrient release in the soil all affect substances absorbed and synthesized by plants (Hou et al., 2021). Only by understanding the underlying mechanisms can researchers identify the soil conditions that best stimulate plants to produce target components and develop more precise improvement methods.

8.3 The application prospects of sustainable soil management techniques in Wu Yao cultivation

Nowadays, many sustainable soil management technologies have been applied in agriculture, and these technologies also have great potential in the cultivation of Wu Yao. For example, practices such as deep tillage and the use of organic fertilizers can improve soil structure, make microorganisms more active, and better utilize water and nutrients. This can also increase the yield and quality of Wu Yao (He et al., 2019). In addition to these, modern agricultural methods such as precision irrigation and scientific fertilization can also be incorporated. By using water and fertilizer more reasonably, not only can planting efficiency be improved, but environmental pressure can also be reduced (Fang et al., 2010). With more and more research in this area, the cultivation of Wu Yao in the future can also be more intelligent and efficient. Not only is it beneficial for farmers, but it is also a positive promotion for environmental protection.

9 Conclusion

Soil improvement has a significant impact on the growth, root quality and the components of the medicinal parts of the aconite. For instance, in the experiments on rice, it was found that raising seedlings with soilless materials could make the seedlings healthier and grow faster. This indicates that similar practices may also bring benefits when applied to the cultivation of Wu Yao. Some other studies have pointed out that substances like plant growth-promoting bacteria or nanomaterials can alleviate the stress on plants caused by heavy metals in the soil, which is particularly crucial for growing aconitum carmichaelii in polluted areas. After applying these methods, not only can the plants grow faster, but the overall biomass will also increase, which may enhance the efficacy of the black medicinal herb.

By improving the soil, the yield and quality of the medicinal materials can also be significantly enhanced. For instance, when exogenous plant hormones (such as indoleacetic acid IAA) are applied to rice, it not only promotes the growth rate but also reduces the accumulation of harmful elements. This kind of experience is also worth learning from in the cultivation of Wu Yao. In addition, research has found that the combined use of microbial communities that promote plant root development and iron oxide nanoparticles can help crops maintain their growth state even under adverse conditions, indicating that such a combination approach may also be applicable to the herb "Wu Yao".

To ensure that the black medicine can be stably planted in different environments, a more economical and environmentally friendly soil management approach is indispensable. For instance, reducing reliance on traditional nutrient soil and promoting alternative models like hydroponics can make planting methods more sustainable. At the same time, using some environmentally friendly materials, such as probiotics or functional nanoparticles, not only helps protect the soil but also ensures the quality of the medicinal herb. Overall, taking the

green development path is not only for ecological security, but also helps to enhance the medicinal and economic value of the black medicine in the long term.

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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.

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