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Reducing the Environmental Impact of Potato Farming through Sustainable Practices

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Abstract Potato is an important food crop in the world. It has a strong genetic basis and adaptability, and can be sustainably cultivated under different climate and soil conditions. By optimizing nitrogen fertilizer and irrigation management, using microbial agents and organic cultivation methods, nitrogen surplus, greenhouse gas emissions and pesticide use can be significantly reduced while maintaining yield. In some areas of the Netherlands and China, field monitoring and life cycle assessment showed that some fields successfully achieved high yields, low nitrogen surpluses and less pesticide use, and greenhouse gas emissions were reduced by more than 48%. The use of microorganisms and organic cultivation can also further reduce CO_2 emissions and improve soil quality, but economic feasibility remains an issue. Regional differences, farmers' knowledge level and economic barriers are the main difficulties in promoting sustainable practices. To address these issues, customized technical guidance should be provided and policy incentives should be used to support promotion, providing a scientific basis and practical solutions for the potato industry to achieve balanced development between the environment and the economy.
Keywords Potato cultivation; Sustainable agriculture; Environmental impact; Genetic origin; Case study

1 Introduction

Potato (*Solanum tuberosum*) is the fourth largest staple food in the world, with high yield, strong adaptability and rich nutrition. Therefore, it is widely planted in many parts of the world, such as China, India, Russia, Europe and America (Wang et al., 2021; Li et al., 2022; Zhang et al., 2024b). As the population continues to increase, people's eating habits are also changing, and the demand for potatoes is also rising, which has promoted the continuous expansion of planting area and yield. Since China began to implement the "potato staple food" policy in 2015, the role of potatoes in food security, diet improvement and farmers' income has become increasingly obvious (Wang et al., 2021; Li et al., 2022). Because potatoes have strong adaptability to climate and soil, they can achieve high yields in many different ecological environments (Li et al., 2022; Zhang et al., 2024b).

Potato cultivation now faces some problems. Long-term high-intensity farming, coupled with insufficient crop rotation, will destroy soil structure, cause organic matter loss, lead to a decrease in soil fertility, and affect the sustainable use of land (Timpanaro et al., 2021; Morugán-Coronado et al., 2024). Potatoes require more water, especially in arid or semi-arid areas. Excessive irrigation will cause water resource shortages and may also cause soil salinization and groundwater decline (Wang et al., 2021; Li et al., 2022; Ravensbergen et al., 2024). In major producing areas such as China and the Netherlands, nitrogen fertilizer use is generally high, which will cause nitrogen loss and increase greenhouse gas emissions (Wang et al., 2021; Li et al., 2022; Di et al., 2024; Ravensbergen et al., 2024). Excessive use of pesticides will also put pressure on the ecosystem, affecting biodiversity and soil microorganisms (Kumar et al., 2023a; Morugán-Coronado et al., 2024; Ollio et al., 2025). In contrast, the carbon emissions and environmental costs of conventional farming methods are much higher than those of organic farming or optimized management (Kumar et al., 2023a; Zhang et al., 2024b). The goal of sustainable agriculture is to ensure both production and income while minimizing the impact on the environment (Timpanaro et al., 2021; Wang et al., 2021; Kumar et al., 2023a; Di et al., 2024; Morugán-Coronado et al., 2024; Zhang et al., 2024b; Ollio et al., 2025).

In the process of potato cultivation, taking some measures, such as scientific management of fertilizer and water, use of biofertilizers and beneficial microorganisms, reduction of pesticide use, promotion of organic planting and crop rotation, are all effective ways to achieve sustainable development (Wang et al., 2021; Kumar et al., 2023a; Di et al., 2024; Morugán-Coronado et al., 2024; Ravensbergen et al., 2024; Ollio et al., 2025). Some field studies and life cycle assessments have found that as long as nitrogen fertilizers and pesticides are appropriately reduced, it will not only not affect yields, but also greatly reduce nitrogen excess and greenhouse gas emissions (Wang et al., 2021; Li et al., 2022; Di et al., 2024; Ravensbergen et al., 2024). The use of microbial products and organic farming can also help improve soil quality and crop quality, reduce CO_2 emissions and reduce costs (Kumar et al., 2023a; Tensi et al., 2024; Ollio et al., 2025). Different conditions in different regions, as well as farmers' knowledge levels and economic capabilities, are difficulties in promoting sustainable methods. Technical guidance needs to be provided according to specific circumstances, accompanied by policy support (Timpanaro et al., 2021; Wang et al., 2021; Morugán-Coronado et al., 2024).

This study mainly analyzes the effects of various sustainable practices in potato cultivation from an environmental perspective. We will also compare the actual application of these methods in different regions and under different management models, and discuss the genetic origin and evolution of potatoes to see if they can provide inspiration for sustainable cultivation. Through case analysis, this study will also demonstrate some specific ways to optimize management and point out the difficulties they encounter in promotion. It will combine field data, life cycle analysis, comprehensive economic and environmental assessments, and farmers' actual practices, and strive to provide practical reference for the green development of the potato industry.

2 Environmental Impacts of Traditional Potato Cultivation

2.1 Soil health: erosion, compaction and nutrient depletion

The traditional way of growing potatoes is very harmful to the soil. Repeated mechanical tillage will destroy the soil structure and easily cause erosion and compaction. The compacted soil is not breathable, water cannot penetrate, roots cannot grow well, crop yields will be reduced, and the soil ecology will be disrupted (Grados and Schrevens, 2019; Holka and Kowalska, 2025).

If you only grow potatoes without crop rotation, the nutrients in the soil will become less and less, the organic matter will also decrease, and the fertility will decrease. In order to increase production, farmers can only add more fertilizers, resulting in a vicious cycle.

In these traditional practices, excessive use of fertilizers is the main cause of soil degradation, especially nitrogen fertilizers and potash fertilizers. Applying too much fertilizer is not good, as it will make the soil acidic and salty, and the yield will not increase (Kumar et al., 2023a; Wei et al., 2024; Holka and Kowalska, 2025). Once the soil becomes acidic, beneficial microorganisms cannot survive, the soil loses its self-repairing ability, and crops are more susceptible to disease (Wei et al., 2024). Nitrogen, phosphorus and other substances lost in the soil will also be washed into rivers and lakes by rainwater, causing eutrophication of water bodies, poor water quality, and algae growth (Economou et al., 2023).

2.2 Water resource utilization: high water consumption and inefficient irrigation

Potato cultivation is very water-consuming, especially in arid or semi-arid areas, where irrigation is essential. Traditional irrigation methods are inefficient and often waste water. Irrigation and the use of machinery are one of the causes of climate warming and land acidification (Economou et al., 2023).

In some places, too much water can cause the groundwater level to drop and even cause soil salinization, affecting agricultural development (Busch and Wydra, 2023; Kumar et al., 2023a).

Excessive water use also increases costs and makes water resources more scarce. In places with little water, excessive use can make the ecosystem worse (Grados and Schrevens, 2019; Economou et al., 2023). In addition, fertilizers and pesticides are easily lost with water during irrigation, further polluting the water body (Economou et al., 2023).

2.3 Pesticide and fertilizer use: impact on ecosystems and human health

Traditional potato farming relies heavily on chemical fertilizers and pesticides, and using too much will naturally cause trouble. Fertilizer application is the most serious step in affecting the environment, especially nitrogen fertilizer. Applying too much is not only inefficient, but also releases greenhouse gases and disrupts the ecology of microorganisms in the soil (Kumar et al., 2023a; Wei et al., 2024; Holka and Kowalska, 2025). Excess nitrogen fertilizer will also flow into rivers and lakes, making the water eutrophic and the ecology unbalanced (Economou et al., 2023).

Excessive use of pesticides is also harmful, increasing the toxicity of soil and water, affecting the survival of insects, birds and microorganisms. The ecological toxicity and health risks of traditional farming methods are significantly higher than those of organic farming (Kumar et al., 2023a). Pesticide residues may also affect human health through the food chain, possibly causing poisoning or chronic diseases (Kumar et al., 2023a; Holka and Kowalska, 2025). The manufacture, transportation and use of fertilizers and pesticides also require a lot of energy, increasing carbon emissions and more environmental costs (Zhang et al., 2024b).

2.4 Greenhouse gas emissions: contribution of agricultural machinery, fertilizers and transportation

In the process of potato cultivation, greenhouse gases mainly come from three aspects: agricultural machinery use, fertilizer application and product transportation. Among them, fertilizers, especially nitrogen fertilizers, release a lot of CO_2 and N_2O during manufacture and application, and are the main source of emissions (Li et al., 2022; Economou et al., 2023; Kumar et al., 2023a; Zhang et al., 2024b).

In major producing areas such as China and India, greenhouse gas emissions from potatoes are about 2 000 to 2 800 kg CO_2 equivalent per hectare, which is much higher than organic or optimized cultivation (Li et al., 2022; Kumar et al., 2023a).

In addition, machines used for field cultivation and transportation also use a lot of diesel, which not only increases carbon emissions, but also may acidify the soil and harm the ecological environment (Economou et al., 2023; Zhang et al., 2024b).

Transportation and refrigeration also increase carbon footprint, especially in the case of long-distance transportation. Promoting energy-saving equipment, local sales and scientific fertilizer use can reduce emissions and make potato cultivation more environmentally friendly (Li et al., 2022; Zhang et al., 2024b).

2.5 Biodiversity loss: the impact of monoculture on local flora and fauna

Traditional potato farming generally only grows one crop, which reduces the number of plant species around it, making the ecosystem unstable and more vulnerable to natural disasters (Câmara-Salim et al., 2021; Holka and Kowalska, 2025).

When biodiversity decreases, ecological functions such as pollination and pest control will also deteriorate, and farmers will rely more on fertilizers and pesticides, which will become more and more serious.

Excessive use of fertilizers and pesticides will also harm beneficial insects, birds and good bacteria in the soil. When water and soil deteriorate, the living environment of many organisms will also be affected, and the number Adopting crop rotation, diversified planting and ecological agricultural methods can help restore biodiversity and enhance the adaptive capacity of ecosystems.

3 Sustainable Potato Farming Practices

3.1 Soil management

Potatoes can be grown by planting cover crops, crop rotation, and less tillage. Planting cover crops and crop rotation can add more organic matter to the soil, reduce pests and diseases, and prevent soil from being washed away or compacted (Morugán-Coronado et al., 2024). Less tillage can protect soil structure and increase the variety and activity of microorganisms in the soil.

Long-term use of organic fertilizers can increase yields, land utilization, and profits (Zhang et al., 2024a). Organic fertilizers and green manures can supplement nutrients, improve soil, and make beneficial microorganisms grow better (Waheed et al., 2023; Zhang et al., 2024a).

Methods such as straw mulching can retain water, prevent evaporation, and increase the number of beneficial bacteria, reducing soil acidification and nutrient loss (Waheed et al., 2023). Returning rice straw or corn stalks to the fields can improve soil quality and reduce the pollution and waste caused by burning straw.

3.2 Water resource protection

Drip irrigation can use water more accurately, avoid waste, and improve water utilization (Wang et al., 2021). Collecting rainwater is important in arid areas. It is a good way to replenish water and allow crops to grow smoothly.

Breeding the right varieties is critical. Through experiments, farmers can select varieties that are suitable for local weather and soil, which are both high-yielding and water-saving (Wang et al., 2021; Morugán-Coronado et al., 2024). Coupled with reasonable field management and irrigation arrangements, water can be used more efficiently and water pollution can be reduced (Wang et al., 2021).

Although drip irrigation technology is very effective, the equipment is expensive and requires manual operation, which is a major difficulty in promotion (Wang et al., 2021). Therefore, the government should provide more technical assistance and subsidy policies to encourage everyone to use drip irrigation systems and water-saving varieties (Wang et al., 2021; Morugán-Coronado et al., 2024).

3.3 Integrated pest management (IPM)

Integrated pest management is to reduce the use of pesticides through some natural methods, such as biological control, planting disease-resistant varieties and crop rotation. For example, using natural enemies and microorganisms to fight pests can reduce pesticide residues and reduce damage to the environment (Contreras-Liza et al., 2024; Morugán-Coronado et al., 2024). Promoting disease-resistant varieties can also reduce the occurrence of pests and diseases and improve crop resistance (Morugán-Coronado et al., 2024).

Introducing or protecting useful insects and microorganisms in the field is an important IPM practice, which controls pests more naturally and reduces the use of pesticides (Contreras-Liza et al., 2024). Insect-resistant and disease-resistant crop varieties can also improve crop health and reduce diseases (Contreras-Liza et al., 2024; Morugán-Coronado et al., 2024).

Promoting IPM can not only protect the environment and biodiversity, but also save money and improve the safety of agricultural products. However, many farmers do not understand IPM technology and lack technical services, which are difficulties in promotion. More training and guidance should be provided to enable more people to use this method (Morugán-Coronado et al., 2024).

3.4 Fertilizer management

Precision agriculture can monitor soil and crops to apply fertilizers on demand, reduce nutrient loss and pollution (Wang et al., 2021). Reducing the amount of nitrogen fertilizer and adding reasonable irrigation will not affect the yield, but also improve the utilization rate of nitrogen and reduce excess nitrogen emissions.

Using organic fertilizers and compost is a good way to reduce the use of synthetic fertilizers. Long-term use of these natural fertilizers can increase yields, soil quality and income (Zhang et al., 2024a). They can increase soil organic matter, promote the reproduction of beneficial microorganisms, improve soil structure, and reduce the use of chemical fertilizers and pesticides (Waheed et al., 2023; Zhang et al., 2024a).

Returning straw to the field and planting green manure can also increase soil nutrients and reduce the input of chemical fertilizers (Waheed et al., 2023). The government can strengthen the promotion of organic fertilizers, provide more training, and help farmers apply fertilizers scientifically to grow potatoes more green and efficient (Zhang et al., 2024a).

3.5 Energy efficiency and greenhouse gas emission reduction

Using solar energy and wind energy when planting potatoes can reduce the use of kerosene and diesel, which also reduces carbon emissions. For example, using solar energy for irrigation and wind power for power generation not only saves energy, but also reduces emissions, which is very helpful for the green development of agriculture (Rajendran et al., 2024) (Figure 1).

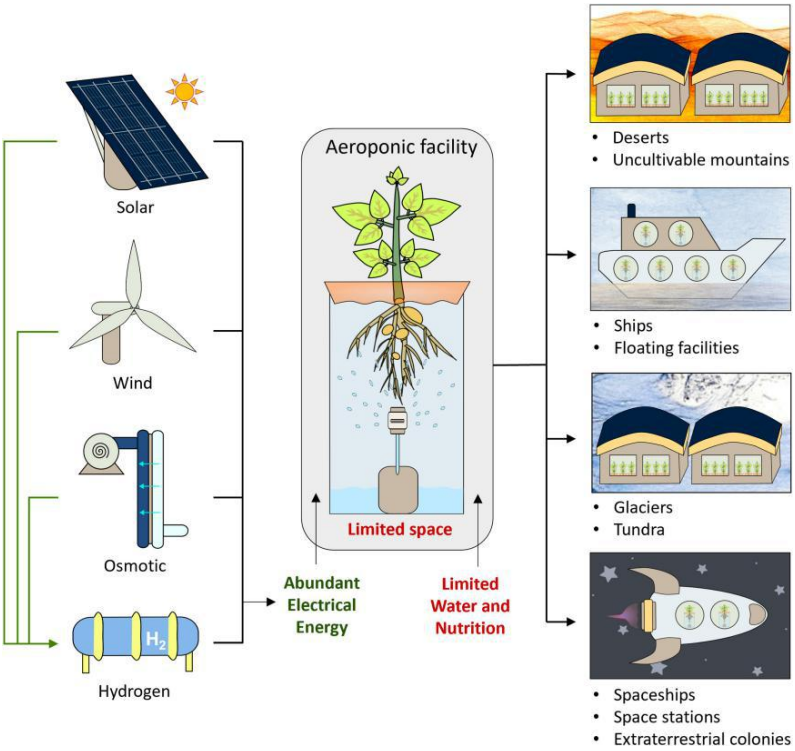

Figure 1 Feasibility of aeroponics farming to support potato cultivation irrespective of agroecosystem (Rajendran et al., 2024)

Using energy-saving agricultural machinery or no-till farming can reduce fuel consumption during mechanical operations and protect soil microorganisms and structures (Morugán-Coronado et al., 2024; Rajendran et al., 2024). Promoting energy-saving equipment and rational use of agricultural machinery can also save costs and improve efficiency (Rajendran et al., 2024).

4 Case Studies of Sustainable Potato Cultivation

4.1 Typical cases of sustainable soil management and water-saving irrigation

In northern China, farmers are conducting field trials to understand the effects of different nitrogen fertilizers and irrigation management methods on potato yield, quality, and the environment. In 2017 and 2018, the research team conducted a two-year experiment in farmland and found that when nitrogen in the soil was sufficient, increasing nitrogen fertilizer did not increase yield, and even reduced the quality of tubers. Reducing the amount of nitrogen fertilizer and combining it with efficient irrigation methods such as drip irrigation not only maintained yield and quality, but also improved nitrogen fertilizer utilization efficiency and reduced nitrogen loss and environmental burden (Wang et al., 2021).

When nitrogen fertilizer input was reduced from the conventional 189~252 kg/ha to 109~181 kg/ha and combined with irrigation management, yield and quality were not affected. Only when nitrogen fertilizer was further reduced to 9~117 kg/ha did the yield of some plots drop by about 18%. The application of drip irrigation effectively improved soil moisture and promoted crop growth, but high costs and labor requirements became the main obstacles to its promotion. Farmers are generally willing to reduce nitrogen fertilizer input by 10%~20%, but emphasize the need to regularly monitor and formulate management measures based on soil nitrogen and moisture conditions.

4.2 Successful cases of integrated pest and disease management to reduce the use of chemical pesticides

In agriculturally developed countries such as the Netherlands, microbial agents and biological control technologies have been introduced into potato planting systems. After microbial intervention, CO_2 emissions were reduced by 60% and the use of active pesticides decreased by 6.6% (Figure 2). Although the cost of microbial agents is currently high and not yet fully economically feasible, they are very useful in reducing environmental pollution and improving ecological health (Tensi et al., 2024).

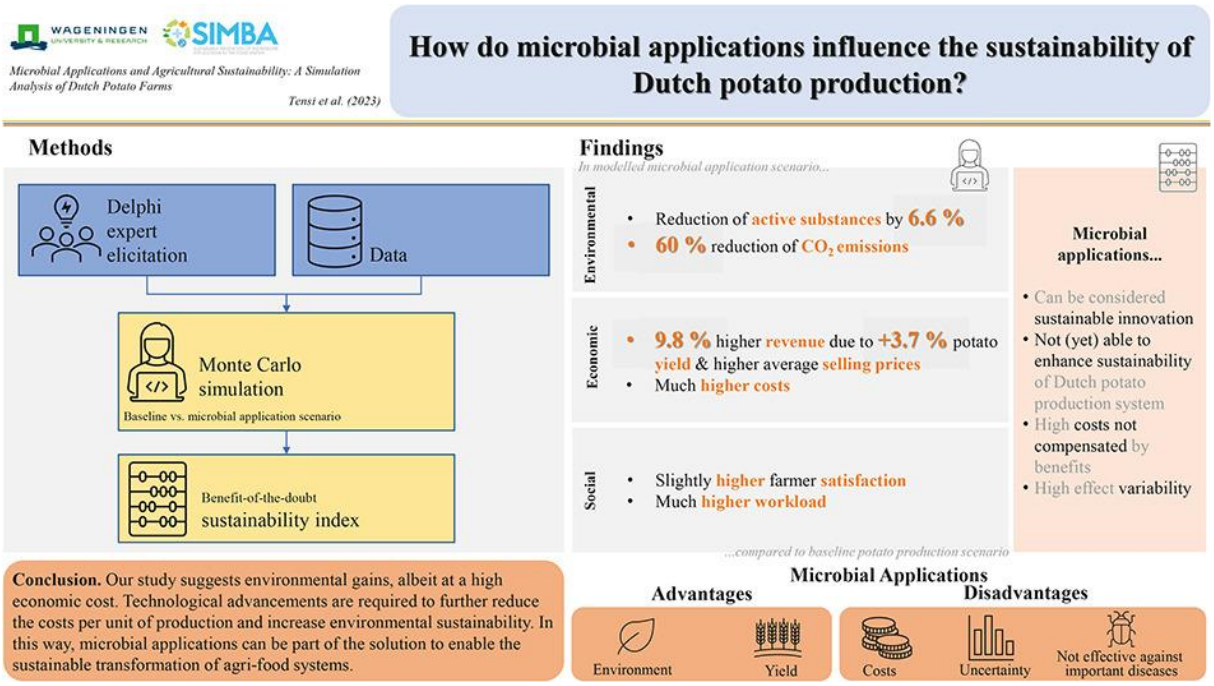

Figure 2 Assessing the sustainability impact of microbial applications in dutch potato farming (Adapted from Tensi et al., 2024)

Combining the use of biological control and disease-resistant varieties, by introducing or protecting beneficial insects and microorganisms in the field, pests can be effectively controlled and dependence on chemical pesticides can be reduced. At the same time, planting insect-resistant and disease-resistant varieties can effectively reduce the incidence of pests and diseases and improve crop health.

4.3 Cases of precision agriculture and organic fertilizer application to improve efficiency and sustainability

A study involving 546 potato farmers in Shandong Province, China found that the continuous use of organic fertilizers can significantly improve production efficiency, labor productivity and land output. Compared with farmland without organic fertilizer, farmland using organic fertilizers has significantly improved unit net profit, yield and input-output ratio. Appropriate scale operation can further improve production efficiency, while the continuous use of organic fertilizers can reduce input waste and environmental risks (Zhang et al., 2024a).

The introduction of precision agriculture allows farmers to optimize the use ratio of organic fertilizers and chemical fertilizers through scientific soil nutrient and crop demand monitoring. The continued use of organic fertilizers not only improves soil fertility and crop yields, but also promotes microbial diversity, improves soil structure, and reduces the need for chemical fertilizers and pesticides.

5 Challenges in Adopting Sustainable Practices

5.1 Economic barriers

Many sustainable practices, such as drip irrigation systems, organic fertilizer alternatives, and precision agriculture technologies, require high initial investments and have long payback periods. This problem is exacerbated without government subsidies and financial support. Farmers are often reluctant to try these new technologies due to the high cost of equipment, technology, and training (Yadav et al., 2020; Debnath et al., 2024; Indriastuty et al., 2024).

Economic barriers are not only direct costs, but also possible indirect losses during the transition process. Farmers may face yield fluctuations or short-term declines in returns when learning and adapting to new technologies. This uncertainty makes many farmers prefer to continue using traditional production methods.

5.2 Knowledge and training gaps

Many farmers do not fully understand the principles, operation methods, and long-term benefits of sustainable planting technologies. This makes it difficult for them to use new technologies correctly in actual operations (Kumar et al., 2023b; Indriastuty et al., 2024; Sithole and Olorunfemi, 2024). Due to limited training resources and an imperfect technical service system, it is difficult for farmers to get the required technical guidance or answers to their questions in a timely manner.

Information dissemination channels are also limited, and farmers mainly rely on traditional experience or neighborhood exchanges to acquire new knowledge, which lacks scientific basis and systematicity. Even if some farmers are willing to try new technologies, they often give up when they encounter practical difficulties due to the lack of continuous technical support and follow-up services.

5.3 Resistance to traditional farming methods

After years of practice, the traditional agricultural model has formed a stable production process and risk response mechanism, and farmers have a strong sense of trust in it. The adoption of sustainable practices often requires adjusting farming habits, purchasing new equipment, or changing crop planting structures. The uncertainty and learning costs brought about by such changes make them feel uneasy (Debnath et al., 2024; Indriastuty et al., 2024).

Some farmers are also skeptical about the long-term benefits of sustainable practices. They are worried that new technologies may not bring the expected yields and benefits, and may even increase production risks. Social and cultural factors also affect farmers' decisions to a certain extent.

5.4 Policy and regulatory challenges

In some regions, there is a lack of clear policies and incentives for sustainable agriculture (Yadav et al., 2020; Indriastuty et al., 2024; Sithole and Olorunfemi, 2024). Existing agricultural subsidies and financial policies mainly target production output and neglect support for environmentally friendly production methods.

The imperfect supervision system makes it difficult to detect and correct some irregular operations in a timely manner. In the process of policy implementation, there are problems such as information asymmetry and uneven resource allocation, which prevents some farmers from enjoying the benefits of the policy (Yadav et al., 2020; Indriastuty et al., 2024; Sithole and Olorunfemi, 2024).

6 Challenges in Adopting Sustainable Practices

6.1 Government and policy support

Governments can encourage farmers to adopt sustainable planting methods by setting environmental regulations, providing subsidies and rewards. Environmental policies also set clear rules for agriculture, and farmers need to operate according to these standards. Governments use economic incentives to guide people to use green technologies and more environmentally friendly management methods (Behera, 2023; Vishvas, 2024).

Globally, such policies and market mechanisms can also help different countries exchange green technologies and promote the sharing of agricultural experiences (Adanma and Ogunbiyi, 2024). Policymakers must also consider economic goals and should not only emphasize environmental protection, but also ensure that farmers have income and industries can develop (Behera, 2023; Adanma and Ogunbiyi, 2024).

Some policies are not fully implemented, some places have uneven resource allocation, and some have weak supervision and insufficient enforcement (Yuan and Zhang, 2020; Vishvas, 2024). If potato cultivation is to achieve true sustainable development, these problems need to be improved, such as improving policy content, strengthening supervision, arranging subsidies reasonably, and promoting international cooperation at multiple levels (Yuan and Zhang, 2020; Behera, 2023; Adanma and Ogunbiyi, 2024).

6.2 Technological innovation

New technologies are being increasingly used in agriculture, such as precision agriculture, green biotechnology and data analysis. These technologies can greatly improve resource utilization efficiency and reduce environmental pressure. Precision agriculture uses data to help farmers make decisions, which can use fertilizers, pesticides and water more accurately, reducing waste and pollution (Al-Emran and Griffy-Brown, 2023; Adanma and Ogunbiyi, 2024).

Green biotechnology, such as pest-resistant and disease-resistant genetically modified crops, can also reduce the use of pesticides, making crops more disease-resistant and higher-yielding (Mahardhani, 2023; Adanma and Ogunbiyi, 2024). Data analysis and intelligent monitoring systems can enable farmers to understand the conditions of soil, climate and crops in real time, helping them to arrange planting plans more reasonably (Al-Emran and Griffy-Brown, 2023). The promotion of green technology can also help reduce greenhouse gas emissions and gradually move agriculture towards a low-carbon, circular and efficient development direction (Behera, 2023). Although new technologies have brought many benefits, they have also encountered some difficulties in the promotion process, such as high costs, insufficient farmers' knowledge, or insufficient institutional support (Yuan and Zhang, 2020; Al-Emran and Griffy-Brown, 2023). The government can invest in green technology, provide training, and formulate an incentive mechanism to promote technological innovation to better serve agriculture and drive the green and high-quality development of the potato industry (Yuan and Zhang, 2020; Al-Emran and Griffy-Brown, 2023; Behera, 2023; Adanma and Ogunbiyi, 2024).

7 Future Outlook and Recommendations

7.1 Strengthen the integration of sustainable practices through education and promotion

Many farmers are still not familiar with new technologies in sustainable agriculture, which makes it difficult for them to use methods such as organic fertilizers, cover crops and crop rotation. We can help farmers understand these methods through training courses, on-site demonstrations, and expert guidance (Morugán-Coronado et al., 2024; Zhang et al., 2024a). The agricultural department should also communicate more with farmers and give appropriate planting suggestions according to their specific circumstances (Maulidiyah et al., 2024; Morugán-Coronado et al., 2024).

As long as we persist in training and promotion, the technical level of farmers will improve and promotion will be smoother. The government and relevant departments should also invest more resources and establish various forms of training mechanisms (Waaswa et al., 2022; Zhang et al., 2024a).

7.2 Increase investment in the research and development of sustainable potato varieties

Now that extreme weather, pests and diseases, and soil degradation are becoming more and more serious, we need some potato varieties with strong resistance and high resource utilization (Waheed et al., 2023; Rajendran et al., 2024). Combining practices such as straw mulching and no-tillage with improved varieties can not only increase yields, but also improve soil and reduce the use of pesticides and fertilizers (Waheed et al., 2023; Dey et al., 2025).

It is recommended that the government and scientific research institutions increase financial and policy support for potato variety improvement, encourage interdisciplinary cooperation, promote the research and development of drought-tolerant, disease-resistant, and adapted varieties in different ecological zones, and strengthen field trials and promotion of new varieties (Rajendran et al., 2024; Dey et al., 2025).

7.3 Encourage digital tools and data analysis to optimize resource utilization

Regular monitoring of soil nutrients and moisture conditions can help farmers accurately apply fertilizers and irrigation, improve nitrogen fertilizer utilization efficiency, and reduce environmental pollution (Wang et al., 2021). Digital tools such as remote sensing and artificial intelligence can help farmers understand field conditions in real time, adjust management measures in a timely manner, reduce costs, and improve yields and quality (Tedesco et al., 2023; Rajendran et al., 2024).

To promote these tools, it is necessary to first improve farmers' digital technology level and provide simple and affordable technical solutions. Governments and companies can develop platforms suitable for farms of different sizes to make data-based planting more popular in potato production (Wang et al., 2021; Tedesco et al., 2023).

7.4 Strengthen farmer cooperatives and alliances to promote the sharing of best practices

If farmers can act together through cooperatives, such as sharing resources, exchanging experiences, and purchasing seeds and fertilizers, they can also face the challenges of the market and nature (Morugán-Coronado et al., 2024; Dey et al., 2025). Cooperatives can also help unify planting techniques and make farmers more competitive in the market (Dey et al., 2025).

It is recommended that the government and social organizations support cooperatives more, such as providing policy support or financial assistance. Cooperatives can also undertake tasks such as training farmers, transmitting information, and expanding markets, and can also communicate and cooperate with other cooperatives (Morugán-Coronado et al., 2024; Dey et al., 2025).

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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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