7.3 Limitations of current irrigation technologies

Although many water-saving technologies have been developed, there are still several difficulties in practical application. First, advanced irrigation equipment, such as intelligent irrigation systems, is expensive and difficult for small-scale farmers to adopt without policy support and financial subsidies. Second, natural resource conditions vary greatly among regions, and the same technology may produce different effects in different environments. Therefore, localized technical evaluation is necessary. In addition, agricultural information services and technology extension systems still need improvement. Limited farmer training and low acceptance of new technologies have slowed down the adoption process. For example, the deployment rate of intelligent irrigation systems remains low in some areas of North China, while traditional farming habits in arid regions of Northwest China also limit the promotion of improved cultivation practices. Finally, more accurate decision-support tools are still needed. Many existing AI models cannot fully simulate the complete growth process of wheat, and more practical and adaptable agronomic models should be further developed.

7.4 Future development directions of climate-smart wheat systems

In the future, the trends of "smart agriculture" and "low-carbon agriculture" will strongly influence winter wheat production systems. In smart agriculture, technologies such as 5G communication, edge computing, and artificial intelligence will be more widely applied, allowing the whole crop production process to become digitalized. Every stage, from sowing to harvesting, can be monitored through cloud-based systems. Drone pesticide spraying and automated agricultural robots may become common practices. At the same time, new sensors, such as miniature UAV multispectral sensors, will enable real-time monitoring of microclimate conditions and vegetation indicators.

Biotechnology will also contribute to water management. For example, engineered microorganisms may regulate rhizosphere environments and improve water absorption, while symbiotic microbes may enhance soil water retention capacity. Regenerative agricultural systems, including cover crop strip farming and mixed cropping, can improve soil structure and regional water cycles, thereby indirectly increasing WUE. In addition, under the background of greenhouse gas reduction, low-carbon agricultural practices will gradually be introduced into wheat production systems. Energy-saving irrigation methods, such as solar-powered pumps and drip or micro-sprinkler irrigation systems, can reduce fossil fuel consumption. Overall, future wheat production systems will integrate information technology, mechanization, and biotechnology, gradually developing toward climate-smart agriculture to achieve sustainable high yield and water-saving goals.

Author Contributions

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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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