CURRENT SITUATION AND PROSPECTS OF RENOVATION TECHNOLOGIES AND EQUIPMENT FOR AGING APPLE ORCHARDS
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老龄苹果园翻新技术与作业装备应用现状及展望

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ABSTRACT
Aging apple orchards in China are characterized by frequent pest and disease outbreaks, low suitability for mechanized operations, and an imbalance between production inputs and economic returns. In addition, orchard renovation is associated with high labor intensity, a lack of standardized operational procedures, and insufficient specialized equipment, which collectively constrain the green and high-quality development of the apple industry. This study aims to systematically review the technologies and equipment for the renovation of aging apple orchards and to establish a comprehensive technical framework to improve operational efficiency and standardization. Based on literature published between 1995 and 2025, a systematic and structured literature review was conducted with a focus on orchard renovation technologies and mechanized equipment. The results indicate that mechanized renovation technologies can improve operational efficiency by approximately 30%–60% while reducing labor demand by more than 40%. In addition, equipment systems significantly enhance process continuity and standardization. However, limitations remain in terms of adaptability to complex terrain, insufficient integration of technologies, and high operational costs. In conclusion, future development should prioritize intelligent, integrated, and adaptable equipment to support efficient and sustainable orchard renovation. This study provides a systematic reference for optimizing renovation practices and promoting the modernization and high-quality development of the apple industry.

摘要
中国老龄化苹果园存在病虫害多发、机械化生产困难、投入与经济效益不匹配的问题，且果园改造劳动力强度大、缺乏标准化操作流程、专业设备不足，严重制约了苹果产业的绿色和高质量发展。本研究旨在系统梳理针对老龄苹果园的翻新技术与设备，建立完整的技术和设备框架，为提升作业效率和标准化水平提供技术指导。本研究基于 1995 年至 2025 年间的文献资料，重点聚焦于果园改良技术与机械化设备，进行了结构化文献综述。结果显示，机械化翻新技术可将作业效率提升约 30%至 60%，并降低劳动力需求超过 40%，同时集成设备系统显著增强了流程的连续性和标准化程度。然而，设备对复杂地形的适应性、技术整合的不足以及高昂的运营成本等方面仍存在局限性。综上所述，未来应侧重发展智能化、集成化且具有适应性的装备，以支撑高效且可持续的果园翻新工作。本研究为优化改造实践并推动苹果产业现代化发展提供了系统性的参考依据。本研究为老龄果园翻新及促进苹果产业高质量发展提供了系统性的参考。

INTRODUCTION
China is the world's largest producer and consumer of apples, accounting for more than 50% of the global cultivation area and total output *(Yan, 2019; Chen et al., 2010; Shu & Chen, 2018)*. In 2024, apple orchards covered approximately 1.95 million hectares, with a total production of 51.29 million tons, making the apple industry a key pillar of rural economic development. However, a substantial proportion of orchards are aging and are characterized by declining yields, reduced fruit quality, and dense canopy structures (*Zhai et al., 2005*). These issues limit the applicability of mechanized operations, reduce management efficiency, and weaken economic returns. Therefore, the renovation of aging orchards and the establishment of modern, mechanization-compatible production systems are essential for improving productivity and ensuring sustainable development.

This study adopts a systematic and structured literature review approach based on publications from 1995 to 2025. Relevant studies were retrieved from databases including Web of Science and CNKI using keywords such as “apple orchard renovation”, “mechanization”, and “soil improvement”. The literature was selected according to predefined criteria, including relevance to orchard renovation, availability of technical data, and practical applicability.

Significant progress has been made in orchard renovation technologies and equipment. Existing studies mainly focus on newly established orchards or conventional transformation scenarios. Mature technical systems, such as column-type dwarf rootstock high-density planting and mechanization-oriented equipment, have been widely developed and applied (*Wen & Zhao, 2010; Yang, 2024; Yao & Yang, 2019*). Previous research has also examined machinery configurations throughout the orchard lifecycle, highlighting the coordination between agronomic practices and equipment development. However, key preliminary stages specific to aging orchards, including obstacle removal, root treatment, and field preparation, remain insufficiently investigated (*Cao, 2014*). For hilly and mountainous orchards, labor-saving construction models and integrated water–fertilizer management technologies have been proposed. Advances in field management and transportation equipment have improved operational feasibility under complex terrain conditions (*Zheng et al., 2020; Morinaga et al., 2005*). In addition, soil ecological restoration practices, such as the application of organic matter and compost, have been shown to alleviate replant disorders and promote tree growth (*Tristan et al., 2018; Vlad et al., 2023*). Despite these advances, existing technologies still exhibit limited adaptability to diverse orchard conditions and lack effective full-process integration.

This study aims to systematically review the key technologies and equipment used in the renovation of aging apple orchards. The review emphasizes the integration of key operational stages and equipment systems specific to aging orchard renovation. By comparing the field performance of manual labor and mechanized operations, the advantages of relevant equipment are evaluated. In addition, the study identifies the limitations of existing technologies and analyzes future development trends toward intelligent, integrated, and mechanization-oriented systems. This study provides a systematic framework linking renovation processes with corresponding technologies and equipment. The findings are expected to provide technical references for improving renovation efficiency and supporting the modernization of apple production systems.

DEMAND ANALYSIS AND TECHNICAL MODELS FOR APPLE ORCHARD RENOVATION

Demand for the Renovation of Aging Apple Orchards

In China, most aging apple orchards were established during the 1980s and 1990s. By 2016, orchards with tree ages exceeding 20 years covered an area of more than 667,000 hectares *(Pei, 2018)*. These aging orchards are typically characterized by excessive canopy closure, poor light penetration and ventilation, limited mechanization potential, cultivar senescence, and soil degradation. Together, these factors significantly constrain yield and fruit quality. Therefore, renovation is urgently needed, including the replacement of old trees with dwarf rootstock varieties, optimization of planting spacing, and improvement of soil conditions, so as to provide a foundation for mechanized and intelligent orchard management *(Wang et al., 2022; Wu et al., 2021)*.

At present, the apple industry is in urgent need of transformation toward modernization, intelligence, and mechanization *(Yang&Li, 2022)*. However, traditional orchards are poorly adapted to mechanized operations. Therefore, promoting the construction of high-standard, mechanization-oriented orchards has become an inevitable choice for the high-quality development of the apple industry. The renovation of aging orchards can not only improve production efficiency and reduce labor intensity, but also enhance fruit quality and economic returns. By adopting high-quality cultivars and mechanization-adapted dwarf and high-density planting systems, both fruit marketability and yield per unit area can be significantly increased.

Renovation Process and Technical Models for Aging Apple Orchards

The renovation of aging apple orchards can be divided into two main stages: removal of the old orchard and establishment of the new orchard. During the orchard removal stage, trees are felled and cleared using manual or mechanized equipment, while valuable timber is retained when appropriate. Root systems are removed using hydraulic excavators or specialized stump-removal devices. The topsoil and subsoil are separated and deeply tilled to a depth of 40–60 cm, accompanied by the application of soil conditioners and organic fertilizers. Stones are removed, and the land is levelled using a grader. In flood-prone areas, raised beds or sloped terrain are constructed to improve drainage. During the establishment of the new orchard, support systems are installed, planting pits or trenches are excavated and backfilled with improved soil, and seedlings are planted using mechanized transplanters. The renovation process follows the “four modernization principles”: standardized orchard removal, systematic soil restoration, strategic cultivar upgrading, and intelligent equipment integration *(Sun et al., 2021; Zhang et al., 2022)*. Compared with traditional planting methods, high-density dwarf planting systems achieve earlier fruiting and significantly higher yields.

In recent years, mechanized dwarf planting systems, organic ecological production models, and digital intelligent orchards have been increasingly adopted, reshaping orchard production by improving efficiency, sustainability, and precision. The advancement of mechanized and intelligent orchard systems enhances the sustainability and competitiveness of the apple industry, laying a foundation for high-quality development *(Gao et al., 2023; Yang, 2022)*. Based on the renovation process of aging, low-efficiency apple orchards, this study reviews the research progress and application of key technologies and equipment across major renovation stages (Fig. 1) and provides recommendations for future improvement.

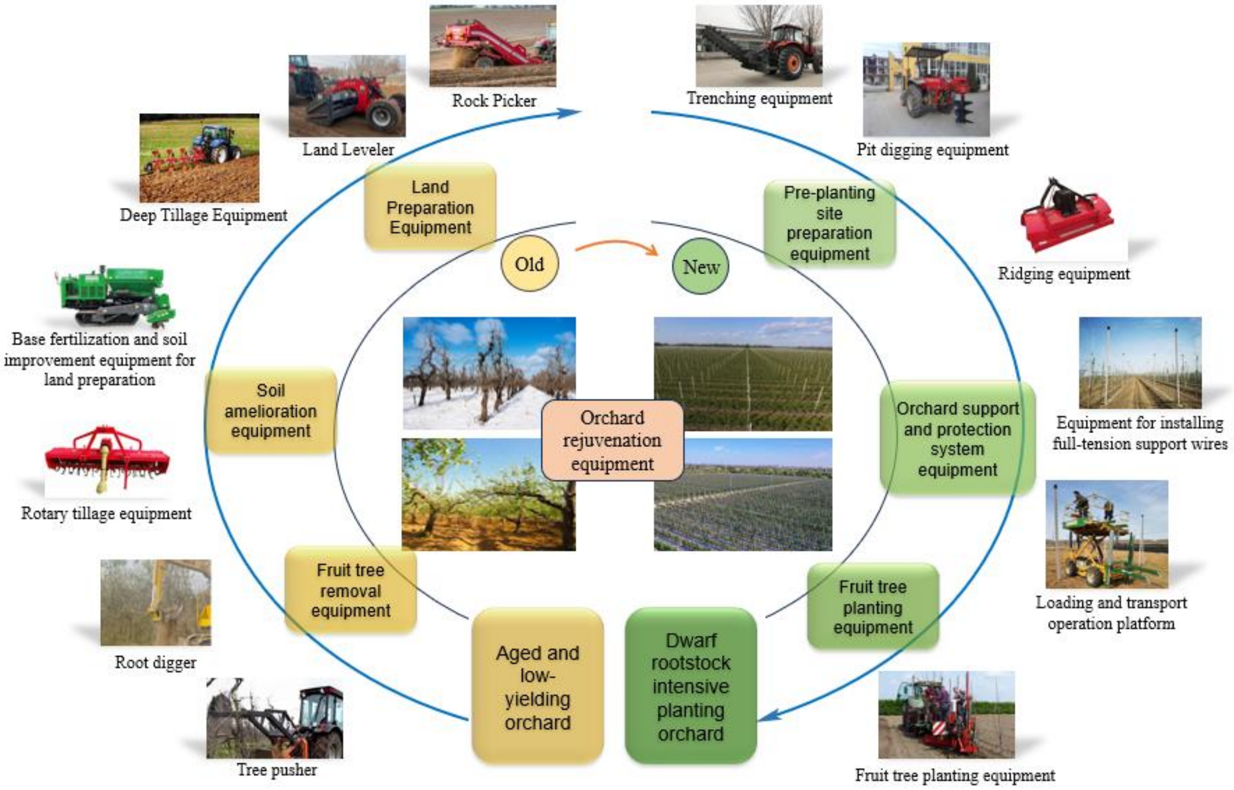


Fig. 1 - Equipment for renovating old apple orchards

CLASSIFICATION AND FUNCTIONAL ANALYSIS OF EQUIPMENT FOR AGING APPLE ORCHARD RENOVATION

Equipment for the Removal of Old Apple Trees

Apple tree trunks have certain economic value and are commonly used as fuelwood or timber; therefore, the trunks are usually retained during tree removal to improve resource utilization. Currently, tree removal is typically carried out by felling with chainsaws, followed by root extraction using excavators or specialized equipment. Existing equipment for orchard tree removal can be broadly categorized into two types: tree-pushing equipment and root-extraction equipment.

(1) Tree Pushing Equipment

Tree-pushing devices are specialized attachments mounted on high-power machinery and widely used in forestry clearing, land reclamation, and orchard renewal as key equipment for removing aging fruit trees. Their use creates favorable conditions for subsequent trunk removal and root excavation. In China, bulldozers commonly serve as the main power source; for example, the device developed by Shantui Construction Machinery Co., Ltd. (Fig. 2a) uses a toothed head that grips the trunk securely, with serrations preventing slippage and ensuring stable pushing and toppling. Baumalight has introduced a tractor-mounted hydraulic pushing and felling device (Fig. 2b), actuated by dual hydraulic cylinders that drive vertical movement of the pushing frame. As the frame descends, it lowers the trunk’s angle relative to the ground, lifting one side of the root system and creating a soil–root gap to facilitate removal. A bottom-mounted saw then cuts the trunk, and the pushing frame guides the fall direction, enhancing operational safety. This configuration enables rapid and efficient removal of aging fruit trees.

(2) Root Excavation Equipment

Residual roots in aging orchards serve as important habitats for soil-borne pathogens such as root rot fungi and nematodes. If not thoroughly removed, these pathogens can adversely affect the growth of newly planted trees *(Rumberger et al., 2007; Bai et al., 2009; Browne et al., 2006; Sheng et al., 2020)*. Currently, in China, root removal is mainly carried out using excavators or excavators equipped with specialized root-removal attachments.

Ma Biao (2015) designed a root-extraction machine (Fig. 2c) featuring a clamping structure composed of a main digging plate and an auxiliary digging plate, enabling effective extraction of root systems. In addition, Guangdong Yuantian Engineering Co., Ltd. developed a mechanical tree-root gripper (Fig. 2d) *(Lai et al., 2014)*, consisting of two semi-circular claws that can be mounted on an excavator boom to directly perform stump removal. Internationally, McLAREN INDUSTRIES has manufactured a hydraulic shear-and-pull tree remover (Fig. 2e), which uses bidirectional hydraulic clamping and a lifting frame to extract fences, roots, and seedlings. Savannah Agricultural Machinery Company developed a stump extractor (Fig. 2f) equipped with two counter-rotating cutting discs and a hydraulic lifting frame. Driven by large traction machinery, the two discs form a "V"-shaped structure that grips the tree stump and rotates while lifting it, enabling continuous stump removal operations.

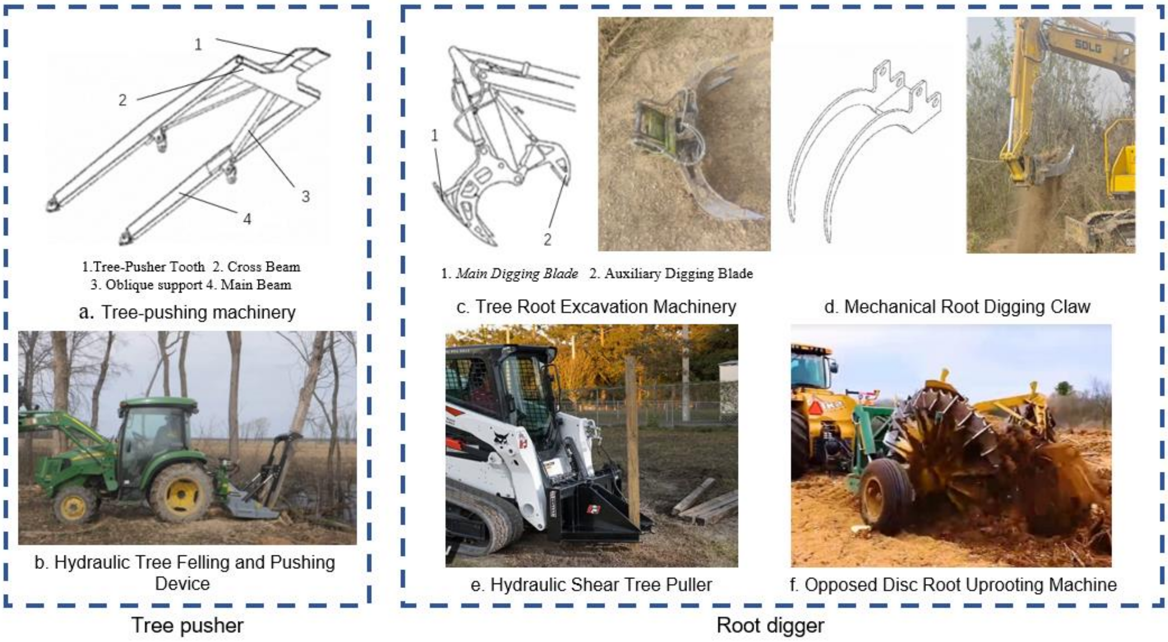


Fig. 2 - Aging Fruit Tree Removal Equipment

Soil Amendment Equipment

Before establishing a new orchard, the soil of the old apple orchard needs to be improved. Measures such as deep ploughing and sun exposure, as well as the application of pH-adjusting agents and organic fertilizers, are adopted to improve the soil's physicochemical properties and prevent continuous cropping obstacles. First, deep-tillage equipment is used to conduct deep ploughing and exposure of the soil to sunlight. Then, spreading equipment is employed to evenly apply organic fertilizer and soil amendments along the planting rows. Subsequently, a rotary tiller is used to level the field and incorporate the base fertilizer or soil amendments into the soil, thereby creating favorable conditions for the subsequent growth of fruit trees.

(1) Deep Tillage Equipment

Long-term cultivation often leads to soil compaction and reduced aeration and permeability, which restricts root development. Deep tillage can significantly improve soil porosity and structure by facilitating the exchange of topsoil and subsoil layers, while also bringing buried roots and stones to the surface *(Angelika et al., 2008; Deakin et al., 2019; Mazzola et al.,1998)*. When combined with soil sterilization, conditioning, and fertilization practices, deep tillage effectively reduces the risk of continuous cropping disorders. Deep soil improvement is considered a critical step in orchard renewal, and excavation machinery or deep ploughs are commonly used to turn over soil to a depth of approximately 30–45 cm *(Qiao, 2024; Mamatov et al., 2021; Mazzola et al., 2020)*.

Foreign research and development of reversible ploughs started earlier, and the corresponding equipment is generally characterized by large working widths and thorough soil inversion, making it suitable for large-scale operations. By contrast, domestic machinery places greater emphasis on structural compactness and operational adaptability, with most designs derived from improved traditional ploughs and localized modifications of imported models, which are more suitable for small- and medium-sized fields and complex terrain. In recent years, a variety of representative machines integrating shallow inversion and deep loosening, soil layer replacement, and hydraulic reversing functions have been successively developed in China, showing progress in improving operational efficiency and soil structure *(Gan, 2008; Zeng, 2017; Gao et al., 2013)*. Typical models of reversible ploughs and their technical parameters are presented in Table 1.

Table 1

Representative Models and Technical Parameters of Reversible Plows

Brand	Country	Picture	Operation Depth)	Supporting power	Operation Features
Case New Holland (CNH) HRS 4180 AS	USA		25-45 cm	165 kW	Four-bar linkage mechanism with automatic return function, ensuring outstanding stability during deep tillage
LOVOL 1LF8-4450	CHN		25-40 cm	60-150 kW	Dual-cylinder balancing system; more than 80% of the machine components are made of high-strength steel, and the moldboard side plates are replaceable, resulting in a high overall cost-effectiveness
KUHN MULTMASTER 183	FRA		25-40 cm	80-160 kW	Equipped with 5–7 optional plough bodies, featuring rapid reversing technology and a foldable design, suitable for orchard and sloping land operations
John Deere Z5T-CN6	USA		30-50 cm	118-169 kW	Hydraulic quick-reversing system combined with a modular design, adaptable to different soil conditions, and equipped with standard safety shear bolts.
YTO 1LF-445	CHN		18-35 cm	50-150 kW	The working width can be selected according to soil specific resistance, with stable tillage depth performance and high cost-performance ratio.
AMAZONE Cayros XS	DEU		25-45 cm	145-190 kW	Multiple overload protection methods are provided, along with stepped or continuously variable hydraulic trench-width adjustment.
Shandong Jinyuan 1LF-245	CHN		25-45 cm	60 kW	Adopting a hydraulic reversing structure, the double-moldboard plough has a compact size and convenient reversal, making it suitable for deep tillage operations in small plots and hilly or terraced fields.

(2) Base Fertilizer and Soil Amendment Application Equipment

During orchard renovation, fertilizer and soil amendment equipment uniformly distributes materials along new planting rows and incorporates them via rotary tillage, improving soil structure, physicochemical properties, and fertility. To mitigate continuous-cropping effects, new rows should avoid original tree lines. Fertilizer spreaders are simple, efficient, and provide uniform application *(Sankpal, 2020; Osadare et al., 2020)*, and are mainly classified as centrifugal disc or screw types. Centrifugal disc spreaders (Fig. 3a) offer wide working widths and strong adaptability for large-scale operations *(Cui et al., 2020)*. Screw-type spreaders, in horizontal (Fig. 3b) or vertical configurations (Fig. 3c), use augers that partially crush materials during discharge, enhancing distribution uniformity and reducing energy consumption. Simulation and experimental studies have further optimized operational parameters, improving both uniformity and efficiency (*Liu et al., 2017; Sun, 2024*).

In addition, trench fertilizer applicators can deliver base fertilizers directly into the planting rows and mix them with the soil, thereby improving nutrient utilization efficiency. Recently developed two-row, vertical, and self-propelled trench applicators integrate trenching (Fig.3d; Fig.3e), fertilization, and soil covering functions, offering automation and high adaptability suitable for orchards with diverse terrain conditions *(Zhang, 2022; Chen et al., 2024; Wu, 2015)*.

(3) Rotary tillage equipment

Rotary tillage equipment is primarily used to incorporate fertilizers and soil amendments into the soil while levelling the deep-tilled surface, creating favorable conditions for tree planting. Current research focuses on structural optimization, drag reduction, energy efficiency, and operational performance. Studies involving dual-axis counter-rotation, tool parameter optimization, and coating modifications have significantly improved soil pulverization and reduced energy consumption *(Guan, 2021; Xia et al., 2025).* In practice, various deep rotary tillers with reinforced transmission systems and optimized tool shaft movement achieve stable operation and desired tillage depth (Fig.3f; Fig.3g). A single pass can accomplish deep tillage, soil pulverization, and surface levelling, meeting the requirements for mechanized orchard establishment.

Base Fertilizer and Soil Amendment Application Equipment

Rotary Cultivation Equipment

Fig. 3 - Soil Amelioration Equipment

Soil Improvement Equipment

Stone pickers are used to remove stones and residual roots that have been turned up, while land levelers are applied to finish and smooth the land surface. Subsequently, trenchers or pit diggers are used to excavate planting furrows or planting pits, facilitating seedling transplantation. For ridge planting patterns, ridging equipment is used to form ridges along the preset planting rows, and planting furrows or pits are then excavated on the ridges using appropriate machinery.

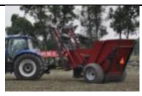
(1) Stone Pickers

During orchard renovation, the timely removal of stones from the field helps improve the soil environment, prevents mechanical damage, and facilitates subsequent operations such as land leveling, pit digging, and planting. After deep tillage, the soil often contains impurities such as stones and residual roots, which can be effectively removed using stone pickers. Stone pickers generally consist of three main parts: a front collecting blade for gathering stones, an intermediate screening system for separating soil from stones, and a rear collection bin for stone storage and transport. The operational efficiency of these machines is influenced by the quantity and size of the stones present in the soil. Typical models and their parameters are listed in Table 2.

Table 2

Representative Models and Technical Parameters of Stone Pickers

Name	Picture	Operation parameters	Supporting power (kW)
GRIMME CS150		150–170 cm working width; 20 cm working depth	75-90 kW

Name	Picture	Operation parameters	Supporting power (kW)
Case New Holland KONGSKILDE SB5200		2.8–20 cm stone diameter; 7 cm working depth	45-75 kW
Tasias MX-15		Adjustable grid adopted; 3–20 cm stone diameter; 10 cm working depth	40-60 kW
LUZHOU 4UJS-120		120 cm working width; 3–40 cm stone diameter	>50 kW
BAOHUA JS-3		5–40 cm stone diameter; 5–40 cm working depth	>45 kW

(2) Land Levelers

To satisfy the requirements of modern orchard construction and subsequent mechanized management, slope-to-terrace conversion and land leveling are generally carried out on sites with gentle terrain and good drainage. At present, laser-controlled and GNSS-based land levelers are mainly adopted, which can effectively improve land flatness and optimize drainage conditions. In laser land levelers, the scraper blade height is adjusted in real time through a laser transmitter, receiver, and hydraulic control system *(Meng, 2023)* whereas in GNSS-based levelers, the blade elevation is regulated according to positioning and elevation data, showing stronger adaptability to complex field conditions.

In recent years, a variety of land leveler models and control systems have been developed. The PDJ-4 large-curved-beam satellite land leveler produced by Shandong Ningjin Honghui Agricultural Machinery Co., Ltd., equipped with a side-lifting rear wheel has been applied to terrace reconstruction and land leveling (Fig. 4a). A suspended, multi-wheel-supported laser land leveler was designed by *Hu Lian et al. (2019)* (Fig. 4b), and the JPD-360 laser land leveler featuring automatic adjustment and vibration suppression was developed by *Yao et al. (2017)* (Fig. 4c). In addition, a dual-antenna GNSS precision leveling system was proposed by *Liang et al. (2020)*, and the 12PW-350W satellite land leveler with automatic elevation maintenance was developed by Qingdao Smart Beidou Agricultural Technology Co., Ltd. (Fig. 4d).

a. PDJ-4 Large Curved-Beam Satellite Land Leveler

c. JPD-360 Laser-Controlled Land Leveler

b. Mounted Multi-Wheel Supported Dryland Laser-Controlled Land Leveler

d. 12PW-350W Satellite Land Leveler

Fig. 4 - Soil Amelioration Equipment Land Leveler

Basic Equipment for Pre-Planting Operations

Before fruit tree planting, it is necessary to dig planting trenches or planting pits. In regions with heavy rainfall or a high risk of waterlogging, drainage systems should be improved, and ridge planting should be adopted when necessary to enhance drainage conditions and reduce the risk of root submergence.

(1) Trenching Equipment

Before planting, trenches or pits must be excavated and adequate organic fertilizer applied to promote root establishment *(Wu et al., 2015)*. Typically, trenches are oriented north–south with a row spacing of 3.5–4 m, a width of 70–100 cm, and a depth of 50–80 cm. For ridge planting, trench depth can be reduced, and residual roots should be removed promptly. Excavators and trenching machines are currently the primary tools for these operations in new orchards.

Trenching machines are generally classified into moldboard, rotary, and chain types, with rotary and chain trenchers being the most widely used. Rotary trenchers produce regular trench profiles, low resistance, and effective soil crushing, though their operational efficiency is relatively low *(Shao et al.,2019)*. The 1KS-22 dual-shaft vertical trencher developed by *Zhang et al.* (2005) employs counter-rotating spiral cutters, offering stable operation and strong adaptability, while the 1KL-100 vertical spiral trencher by *Han et al.* (2000) performs well in hard soils. Rotary disc-type trenchers currently dominate the market; for example, the remote-controlled self-propelled model produced by Hongchuan Machinery (Fig. 5a) demonstrates strong adaptability, with a trench width of 25 cm and a cutter disc speed of 350 r/min. Chain-type trenchers can achieve greater depths and produce uniform trench shapes but suffer from rapid tool wear and high energy consumption *(Alvarez & Verhoef, 1999)*. A mounted chain trencher (Fig. 5b), jointly developed by the Chinese Academy of Agricultural Mechanization Sciences and other institutions, offers a trench depth of 500–1,200 mm and a width of 200–400 mm, achieving high trench quality and efficiency. The orchard chain trencher designed by *Wang (2010)* enables remote-controlled operation in orchards with narrow row spacing and low canopies.

(2) Ridge-Making Equipment

In areas prone to frequent waterlogging, ridge planting is commonly adopted in newly established orchards. The ridge surface is usually in an arched or inverted trapezoidal shape, with a width of 1.4–1.8 m and a height of 20–40 cm. An operation passage of 1.8–2.0 m is reserved between the rows. If necessary, horticultural fabric can be laid to suppress weeds and prevent waterlogging (*Yang. 2024*). The single-side soil-throwing ridge-making machine manufactured by Hangyuan Machinery can achieve an adjustable ridge height of 10–50 cm. The rear-mounted double-side ridge-making machine produced by *Jialinuo* (Fig. 5c) has high operating efficiency, but the formed ridges are relatively loose. The rotary-tillage ridge-making machine of Haomin Machinery (Fig. 5d) shows strong adaptability and produces relatively flat ridge surfaces.

(3) Pit-Digging Machines

Pit-digging machines mainly consist of a frame, a transmission box, and an auger bit. They are widely used in fruit tree planting and post installation operations, significantly improving efficiency and reducing labor intensity *(Ba 2024)*. Common types include handheld and rear-mounted models. The Huasheng Zhongtian 3WT-300 handheld pit digger (Fig. 5e) is lightweight and flexible, but requires high labor input. Zhang Fangyuan et al. *(2019)* designed a structural form of a mounted pit-digging machine. The Chifeng Tianfeng 3WH-60 mounted pit digger (Fig. 5f) adopts a double-spiral blade design, featuring high operating efficiency and convenient operation.

Fig. 5 - Pre-planting site preparation equipment

Support and Protection Systems and Equipment

Dwarfing apple rootstocks have shallow root systems and weak lodging resistance; therefore, support and protection systems composed of posts and steel wires are required to enhance wind resistance and overall stability of the orchard *(Lee et al., 2023)*. By limiting canopy expansion, improving light conditions, and enhancing mechanization adaptability, these systems can improve orchard management efficiency and reduce labor intensity *(Zhang et al., 2023)*. In modern standardized orchards, posts are installed along planting rows, ground anchors are embedded, and steel wires are tensioned to provide structural support for tree growth management and the installation of protective nets. As manual pit digging and post installation require intensive labor *(Feng et al., 2023)*, handheld or rear-mounted pit diggers combined with tractor-mounted hydraulic lifting devices are commonly used in practice to accomplish the installation of prestressed concrete posts.

(1) Posts and Auxiliary Equipment

The support and protection system consists primarily of prestressed concrete posts and standardized auxiliary components (Fig. 6). Together with ground anchors and steel wires, these elements form an integrated load-bearing structure that improves overall stability and adaptability. A settling-prevention plate at the post base increases the bearing area and reduces subsidence. Tensioners on end posts tighten in-row wires and prevent reverse rotation, while wire-fixing caps at the top secure longitudinal and transverse wires, enhancing wind resistance and facilitating the installation of protective nets.

Compared with traditional wooden posts, prestressed concrete posts offer superior corrosion and insect resistance, higher mechanical strength, and longer service life. Current systems typically employ C45 or C50 high-strength prestressed posts, whose durability generally matches the lifespan of apple orchards.

Table 3

Orchard Post Characteristics Comparison

Type	Tensile Strength	Service Life	Environmental Adaptability
Prestressed Concrete Post	Extremely high	Approx. 25–30 years	Corrosion-resistant and insect-resistant
Galvanized Steel Pipe	High	Approx. 15–20 years	Corrosion-prone but insect-resistant
Wooden Pole	Average	Approx. 5–10 years	Prone to mildew and insect infestation

Ground anchors can be classified into three main types: stake-type, concrete-type, and screw-type. Stake-type anchors are driven diagonally into the soil to a depth of approximately 1.2 m to increase pullout resistance. Concrete anchors consist of galvanized threaded steel bars combined with elongated concrete blocks; stability and bearing capacity are enhanced through deep burial, compaction, and water settlement, making them suitable for most orchards. Screw anchors rely on a spiral structure at the base to embed into the soil and provide strong pullout resistance.

(2) Multifunctional Protective Nets

Apple orchards are highly susceptible to extreme weather events, which can significantly reduce yield and fruit quality *(Wang et al., 2025)*. Protective nets can effectively mitigate hail, frost, sunburn, and bird damage, greatly enhancing orchard resilience *(Li, 2025)*. High-quality nets generally have a service life of 8–10 years. The most commonly used types are diamond-shaped and crescent-shaped nets. Diamond nets typically feature an 8-mm mesh and require a steel-wire framework. Crescent nets offer greater flatness and lower deformation, allowing hailstones to slide off easily; they are usually connected using snap-fastening structures for convenient installation, although their cost is relatively higher.

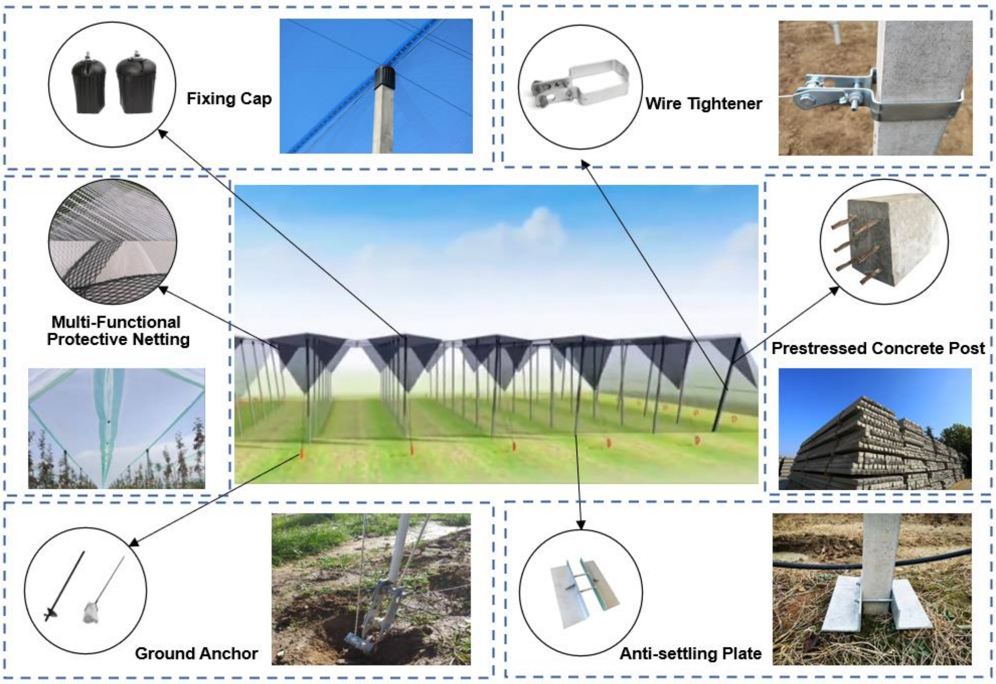


Fig. 6 - Installation Diagram of Support and Protection System Accessories

(3) Supporting Work Platforms

Self-propelled work platforms are widely used in operations such as steel wire installation, protective net deployment, and fruit harvesting, effectively overcoming the low efficiency and poor safety associated with traditional ladder-based work. These platforms are mainly classified into tracked and wheeled types, with scissor-type or mast-type lifting mechanisms. The lifting height generally ranges from 0.7 to 3 m, and the load capacity is typically 3–6 operators. The lifting system is powered by electric or hydraulic drives, and some models are equipped with functions such as automatic leveling, obstacle avoidance, and slope alarms, further improving operational safety and intelligence. Representative domestic self-propelled work platforms and their technical parameters are listed in Table 4

Table 4

Representative Models and Technical Parameters of Self-Propelled Work Platforms

Brand	Country	Picture	Operation Features
Holmac HBK3	ITA		The overall structure is elongated, with dimensions of approximately 315 cm × 110 cm and a total weight of around 1150 kg. The maximum lifting height reaches 290 cm. It is powered by a diesel engine, with a maximum travel speed of 4 km/h, featuring four-wheel drive and good passability.
COMPACT(CMA) Multi-01	ITA		Powered by an electric drive, it offers selectable two-wheel or four-wheel drive and steering, equipped with a longitudinal levelling system to adapt to mountainous terrain. The platform features retractable side supports and tilt guards, as well as a lifting mechanism capable of replacing a single 500 kg fruit crate.
Corbins HF 3000	ESP		This platform is equipped with a 24-horsepower diesel engine and a hydraulic lifting system, achieving a maximum lifting height of approximately 2.5 m. Hydraulic lifting devices and transport rollers are installed at both the front and rear for crate handling. A dual-speed transmission enables a maximum travel speed of 8 km/h.
NEWERAFRUIT Self-propelled picking platform	CHN		Driven by a diesel engine with a fully hydraulic system, it provides longitudinal and lateral tilt adjustment. The platform supports automatic movement, four-wheel drive, and four-wheel steering, with a small turning radius and high passability. Lifting rollers are installed at the front and rear for stable crate handling
Zoomye 4GP-1200	CHN		Available in electric or diesel versions, it provides a working area of approximately 3 m × 3 m, accommodating 6–8 personnel and two standard 500 kg fruit crates. The travel speed ranges from 0–1.94 m/s, with rated lifting speed of 50 mm/s and no-load lifting speed of 60 mm/s.

After the support and protection system is established, regular maintenance is essential, especially after rainfall. The condition of posts, ground anchors, and steel wires should be inspected in a timely manner and reinforced if necessary. If maintenance is not performed promptly, strong winds and other extreme events may cause partial collapse of the system, leading to seedling breakage. The overall stability of the system mainly depends on post strength and layout density, wire-tensioning methods, and the pullout resistance of ground anchors, which should be selected and designed according to local climatic conditions.

Orchard Planting Equipment

Mechanized orchard planting primarily uses two methods: hole digging and continuous trenching (Fig.8a). Small- and medium-scale orchards typically employ hole-digging machines similar to post-hole diggers, whereas large-scale orchards rely on continuous trenching planters. These tractor-mounted machines open continuous furrows, place seedlings at preset spacing, and complete soil covering and compaction with covering wheels.

Representative models include the ZS70-2 high-efficiency tree planter developed by Shihezi University and Yinfeng Technology *(Li et al., 2023)*, which integrates trenching, seedling placement, and soil covering, suitable for afforested desert lands. The suspended hydraulic planter from Tianfeng Agricultural Machinery (Fig. 8b), capable of planting at depths of 30–50 cm; the novel automatic tree planter designed by *Wang (2012)* (Fig. 8c), equipped with a mechanical arm and gripper for adjustable spacing and rapid automated planting.

The 2ZY-2 apple seedling transplanter developed by Hebei Agricultural University, which can automatically upright seedlings and perform soil covering, with adjustable planting distance and depth *(Pei, 2022)*. The DOMCON PL-30/80 series planter from the Netherlands (Fig. 8d), capable of trenching and hole digging, with GPS-assisted automated trenching, after which seedlings are manually inserted and mechanically covered. For ridge planting, the graft union of seedlings should be positioned 6–20 cm above the ridge surface to prevent loss of dwarfing effect and to promote root formation from the scion.

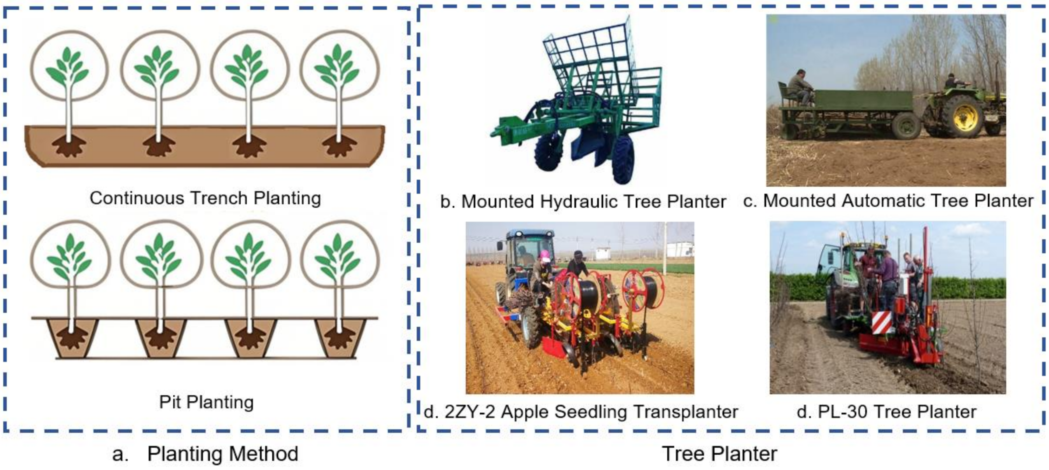


Fig. 7 - Fruit Tree Planting Methods and Equipment

Table 5

Comparison of Seedling Planting Methods

Type	Advantages	Disadvantages	Application Scenarios
Manual Planting	High flexibility, adaptable to complex terrains	High labor intensity, low efficiency	Small-scale or mountain orchards
Semi-mechanized Planter	Improves efficiency and reduces labor intensity	Relies on manual cooperation	Small and medium-sized orchards
Fully Automatic Planter (GNSS-assisted)	Good planting consistency, high standardization and high efficiency	High cost and high requirements for terrain conditions	Large-scale and modern high-standard orchards in plain areas

KEY TECHNOLOGIES FOR AGING APPLE ORCHARD RENOVATION

Renovation of aging apple orchards involves a systematic transformation process encompassing site planning, soil remediation, orchard reconstruction, intelligent management, and resource recycling. In recent years, significant progress has been achieved in these areas, driven by the integration of digital technologies, mechanization, and ecological management approaches. Through the promotion and application of machinery related to orchard construction, the costs of dismantling and establishing orchards have been significantly reduced, and operational efficiency has been improved. Using a trenching fertilizer applicator, 2.7-4 hectares of organic fertilizer can be applied per day, reducing labor by 30 people; using a wind-blown orchard sprayer, 10 to 13.3 hectares of orchard can be sprayed per day, reducing labor by 40 people, and saving 2-3 tons of pesticide per 6.7 hectares; using a multifunctional orchard work platform, 2-8 people can work at height simultaneously, improving operational efficiency 4-10 times compared with ordinary ladder frame operations *(Yang, 2024)*. These results demonstrate that mechanization is a critical driver for improving efficiency, reducing labor dependency, and enabling standardized large-scale orchard renovation. This section reviews the key technologies supporting orchard renovation from a full-process perspective.

Digital Orchard Planning and Autonomous Navigation Technologies

Digital technologies represented by Global Navigation Satellite Systems (GNSS) play a fundamental role in orchard renovation by enabling precise terrain mapping and intelligent machinery operation.

<u>(1) Orchard Planning Based on GNSS</u>

GNSS-RTK technology is widely used to acquire high-resolution spatial data for orchard planning *(Umstatter, 2011; Wei et al., 2023)*. By establishing control points and collecting real-time kinematic positioning data, detailed three-dimensional terrain models can be constructed and integrated into Geographic Information System (GIS) platforms (Fig. 8a). These digital models provide a scientific basis for the rational design of orchard infrastructure, including slope grading, road networks, drainage systems, irrigation facilities, and planting layouts. In particular, proper drainage design is essential for dwarf rootstock orchards due to their sensitivity to waterlogging. Engineering measures such as raised beds, ridge planting, and subsurface drainage pipelines are therefore commonly implemented. In addition, GNSS-based automatic land leveling systems enable real-time adjustment of leveling tools according to predefined terrain models, significantly improving land uniformity and operational precision.

(2) Autonomous Navigation of Orchard Machinery

High-precision GNSS positioning enables centimeter-level localization, forming the basis for autonomous orchard machinery. By integrating RTK modules with path-planning algorithms and automatic control systems, agricultural equipment can perform tasks with high accuracy and repeatability. Based on pre-established digital orchard maps, operation paths can be generated through GIS platforms (Fig. 8b). Furthermore, multi-sensor fusion technologies, such as machine vision and LiDAR, allow real-time perception of environmental conditions and dynamic path adjustment *(Zhang et al., 2020)*. This enables efficient execution of operations such as fertilization, spraying, and transportation, significantly improving management efficiency and reducing labor dependency *(Wang et al., 2024; Luo et al., 2025; Zhao et al.,2023)*. Overall, GNSS-based technologies enhance the digitalization, precision, and automation level of modern orchard systems *(Dou et al., 2024)*.

a. Orchard Layout Planning b. Machine Navigation

Fig. 8 - Application of GNSS Technology

Soil Remediation and Improvement Technologies

Soil degradation is a key constraint in aging orchards, often manifested as reduced organic matter, soil compaction, and accumulation of soil-borne pathogens. Effective soil remediation is therefore essential for successful orchard renovation.

(1) Physical and Chemical Improvement Measures

Mechanical deep ploughing is commonly applied to break compacted soil layers and improve aeration and water infiltration. Organic amendments, including well-decomposed manure, crop residues, and compost, are widely incorporated to enhance soil fertility and structure. In addition, microbial agents such as phosphate-solubilizing and potassium-solubilizing bacteria, as well as beneficial microorganisms (e.g., *Bacillus subtilis*), are used to activate soil nutrients and suppress pathogens. For acidified soils, amendments such as lime, wood ash, or organic fertilizers are applied to regulate soil pH and improve the root growth environment.

Table 6

Comparison of soil improvement methods

Type	Advantages	Disadvantages	Application Scenarios
Organic Matter Improvement (Straw/Compost)	Improves soil structure and increases organic matter content	Slow effect and long time-consuming	Soils with obvious continuous cropping obstacles and severe soil degradation
Chemical Improvement (Lime/Biological Agent)	Regulates pH value and improves soil environment quickly	Poor sustainability and reliance on repeated application	Acidified or salinized soils
Deep Plowing & Soil Loosening	Breaks through plow sole and improves soil permeability	High energy consumption and great disturbance	Soils with severe compaction
Bioremediation (Microorganisms/Green Manure)	Ecologically friendly and with long-term good effect	Long cycle and great impact of environmental factors	Green organic orchards

(2) Intelligent Soil Diagnosis and Precision Improvement

With the development of smart agriculture, soil management is increasingly supported by data-driven approaches. A systematic workflow of "sampling–testing–analysis–decision-making" is commonly adopted. Soil samples are collected at multiple locations and depths, and laboratory analyzes—such as near-infrared spectroscopy and ion chromatography—are conducted to determine key indicators, including nutrient content, organic matter, pH, enzyme activity, and pathogen levels. By integrating these data with terrain, climate, and cultivar information, targeted soil improvement strategies can be developed. These include optimized deep-ploughing depth, precise organic fertilizer application rates, and appropriate selection and dosage of microbial agents, thereby improving resource-use efficiency and reducing unnecessary inputs.

(3) Effects of Soil Remediation

Soil remediation significantly improves soil structure, porosity, and nutrient availability, creating favorable conditions for root growth. Enhanced soil quality increases the resilience of root systems to environmental stresses such as drought and waterlogging. In addition, the use of organic inputs contributes to long-term soil fertility and reduces dependence on chemical fertilizers, promoting sustainable orchard development.

Mechanization-Oriented Orchard Reconstruction

Reconstruction of orchard structure is a critical step in transitioning from traditional to modern, mechanization-compatible production systems.

(1) Planting Mode and Technical Advantages

Following the removal of old trees, dwarf rootstock seedlings are typically replanted using wide-row, high-density configurations. This planting pattern improves light distribution and ventilation within the canopy while providing sufficient space for mechanized operations. Studies have shown that renovated orchards adopting such systems exhibit significant improvements in yield and fruit quality, with notable increases in the proportion of high-grade fruit *(Technical Brief, 2023)*. These advantages highlight the effectiveness of mechanization-oriented planting systems.

(2) Canopy Structure Optimization

In the context of orchard renovation, canopy architecture optimization is essential for ensuring compatibility with mechanized operations and improving long-term productivity. Common canopy forms include trellis systems, central leader systems, and spindle-shaped structures. Trellis systems, such as V-shaped and multi-leader configurations, provide high light interception efficiency and are well suited for mechanized operations, although they require intensive early-stage training. Central leader systems are relatively simple to establish but may result in excessive canopy height and uneven light distribution *(Bu,2020)*. Spindle systems represent an optimized form, characterized by balanced branch distribution and moderate canopy size, making them more suitable for mechanized management *(Scalisi et al. 2024; Anthony & Minas 2025)*. Overall, appropriate canopy design contributes to improved light utilization, standardized tree architecture, and enhanced compatibility with mechanized operations.

Intelligent Pest and Disease Monitoring and Control

Effective pest and disease management is essential for ensuring the productivity and sustainability of newly established orchards.

(1) Intelligent Monitoring Technologies

Advanced sensing technologies have significantly improved early detection of pests and diseases. Unmanned aerial vehicles equipped with hyperspectral and thermal infrared sensors can identify subtle physiological changes in plants, enabling early warning of disease outbreaks *(Li et al., 2025)*. In addition, ground-based intelligent monitoring systems use image recognition and environmental data to track pest populations and predict outbreak trends, improving the timeliness and accuracy of pest control decisions.

(2) Precision Control Technologies

Precision agriculture technologies enable targeted pest and disease control, reducing pesticide use and environmental impact (Fig. 9). By integrating GNSS positioning with multispectral imaging, UAVs can generate spatial distribution maps of pest infestation. Variable-rate spraying systems further enhance control efficiency by adjusting application rates in real time based on canopy characteristics and pest distribution. Emerging technologies such as pheromone-based mating disruption also provide environmentally friendly alternatives for pest control *(Qi et al. 2022)*. These technologies collectively improve control effectiveness while minimizing resource waste and ecological impact.

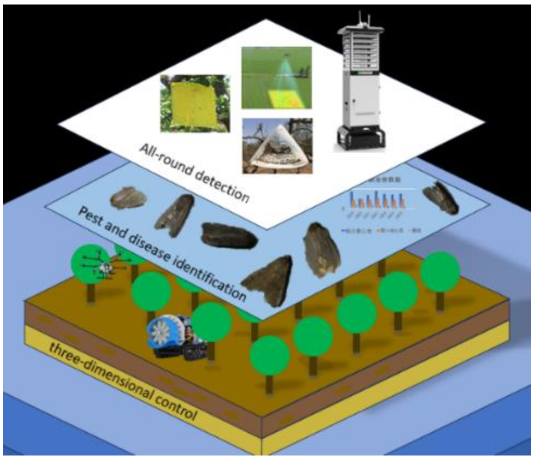


Fig. 9 - Pest and Disease Prediction and Control Technologies

Resource Recycling and Sustainable Utilization

The renovation process generates substantial biomass residues, including trunks, branches, and roots. Efficient utilization of these materials is essential for reducing waste and improving economic returns. Shredding branches and incorporating them into the soil can enhance organic matter content and improve soil structure. Root residues can be processed through composting or fermentation to produce organic fertilizers, facilitating nutrient recycling. In addition, apple wood possesses unique combustion properties and can be used as a high-quality fuel for specialty food processing, such as smoked meat and cheese production, thereby creating additional economic value. These resource utilization approaches contribute to reducing renovation costs, promoting circular agriculture, and supporting environmentally sustainable orchard management.

Challenges in Renovating Aging Apple Orchards

(1) Equipment-related Issues

Aging orchards commonly exhibit tree degradation, declining yields, low profitability, and poor adaptability to mechanized operations. Although renovation is essential, the availability of specialized, high-efficiency equipment remains limited. Critical operations, including old tree removal, support pillar installation, and wire stringing and fixing, still rely heavily on labor-intensive manual work, resulting in low operational efficiency. In addition, the overall level of automation and system integration remains inadequate. Key components often suffer from insufficient wear resistance and operational stability, making them prone to failure during prolonged use and thereby affecting construction progress. Therefore, the development of reliable, automated, and integrated equipment is crucial for improving renovation efficiency and supporting the modernization of orchard systems.

(2) Reasons for Lack of Supporting Equipment

Renovation involves multiple steps, terrains, and site-specific agronomic requirements, making equipment design complex. Market research and equipment development are mismatched, with poor technology transfer between universities and enterprises. Renovation equipment is mainly used by large orchards or professional companies; ordinary farmers have limited purchasing power, resulting in low incentive for enterprises to develop reliable, integrated supporting equipment.

(3) Operational Limitations in Orchard Refurbishment

Current workflows are largely independent, with frequent equipment switching and long waiting times. Soil improvement (deep ploughing, fertilization, rotary tillage) is performed by separate machines, requiring repeated setup. Support system installation is inefficient: each pillar excavation, lifting, levelling, and wire tensioning takes 30–40 min, with multiple vertical adjustments, creating redundant steps. Existing processes are designed for flat large-scale orchards and poorly suit hilly or small-scale orchards. Terracing is only applicable to gentle slopes, requiring location-specific process adjustments.

(4) High Initial Investment

Agricultural production involves high risks and long investment cycles, and orchard renovation is no exception. Establishing dwarfing, high-density orchards requires substantial upfront investment with a prolonged payback period. In the first two years, continuous expenditures on infrastructure, labor, fertilizers, and pesticides are necessary. Economic returns are influenced by cultivar selection, management practices, fruit quality, and market prices. Under optimal conditions, the initial investment is typically recovered within 4–

6 years; however, natural disasters, pest outbreaks, or market fluctuations can extend this period. Thus, the high capital requirement, long payback, and inherent uncertainties are critical considerations in planning orchard renovation.

Future Directions and Prospects

(1) Multi-party Collaboration and Standardized Orchard Systems

The establishment of mechanized and standardized orchards requires coordinated participation from governments, research institutions, enterprises, and farmers. Demonstration orchards have been shown to play a critical role in validating and disseminating mechanized renovation models under controlled conditions. Under conditions of standardized planting and unified management, such systems can improve operational efficiency and facilitate large-scale mechanization. However, their effectiveness is often constrained by regional differences in terrain, farm size, and management capacity. For example, smallholder-dominated regions or mountainous orchards may face difficulties in adopting large-scale mechanized systems. Future efforts should focus on developing region-specific demonstration models and improving the scalability of standardized orchard management systems.

(2) Integration of Agronomy and Mechanization, Development of Supporting Equipment

Renovation is a system integrating machinery and agronomy. Planting requires precise row and tree spacing, seedling uprightness, root spreading, soil compaction, and synchronized irrigation/fertilization. Future equipment should integrate trenching, seedling support, soil covering, and drip line installation. High-strength support systems and protective nets require modular, lightweight, and intelligent machinery. Current renovation equipment (tree removal, pillar installation, wire stringing, net installation/closure, integrated planting machines) is still lacking. R&D should align with agronomic standards to ensure standardized planting and management.

(3) Green and Eco-friendly Development

Promote branch shredding and organic fertilizer fermentation for residual biomass recycling, increasing soil organic matter, improving aeration, and reducing chemical fertilizer use. Develop environmentally friendly soil conditioners using biochar, microbial residues, and crop straw. Equipment should adopt electric or hybrid power to reduce energy consumption and emissions, supporting green and eco-friendly orchard development.

(4) Multi-technology Integration, Smart Orchard Construction

Renovated orchards should integrate multiple technologies for intelligent management. IoT sensors monitor temperature, humidity, wind, soil moisture, and nutrients. Pest lights, leaf image recognition, and machine learning enable early pest/disease detection, prediction, and dynamic control. Historical and meteorological data support risk modelling and alerts. Smart irrigation and fertilization systems adjust based on soil moisture, crop water needs, and weather. A cloud-based smart orchard platform integrates meteorology, soil, pest, and operation data to create a digital twin, supporting informed decision-making and full-cycle management. Inspection robots using GNSS positioning, environmental perception, and multi-source data processing can autonomously perform irrigation, fertilization, pruning, and harvesting, achieving full mechanization, intelligence, and unmanned operation, improving productivity and management.

CONCLUSIONS

(1) Aging orchard renovation requires a full-process technological system integrating planning, soil remediation, orchard reconstruction, intelligent management, and resource utilization. The transformation from traditional orchards to modern systems depends on the coordinated application of digital technologies, mechanization, and ecological management practices.

(2) GNSS-based digital planning and autonomous navigation technologies provide essential support for precision orchard construction and operation. These technologies enable high-accuracy terrain modelling and improve the efficiency and repeatability of mechanized operations, particularly under standardized orchard conditions.

(3) Soil remediation is a critical prerequisite for successful orchard renovation. Integrated approaches combining physical improvement, organic amendments, and microbial regulation can significantly enhance soil structure, fertility, and root growth environment, although their effectiveness depends on local soil conditions and management practices.

(4) Mechanization-oriented planting systems and optimized canopy structures are key to improving production efficiency and enabling large-scale operations. High-density planting and standardized tree architectures facilitate mechanized management.

(5) Intelligent pest and disease monitoring and precision control technologies contribute to improving management efficiency and reducing chemical inputs. The effectiveness of these technologies depends on data accuracy, system integration, and investment levels.

(6) Resource recycling and green development strategies play an important role in reducing environmental impact and enhancing sustainability.

(7) Despite significant technological progress, challenges remain in system integration, cost control, and adaptability to diverse orchard conditions. Future research should focus on the coordinated development of agronomy and machinery, reduction of technology costs, and improvement of intelligent system reliability to promote widespread adoption.

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