

Current Status of Pepper Transplanting and Demand for Intelligent Transplanting Equipment: An Empirical Analysis of 813 Farmer Questionnaires from 15 Provinces in China

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Abstract: Transplanting is one of the most labor-intensive and quality-sensitive operations in pepper production. To understand the current state of transplanting among pepper growers and their demand for intelligent transplanting equipment, a questionnaire survey was conducted in September 2026, and 813 valid responses covering 15 provinces were obtained and analyzed through descriptive statistics and grouped cross-tabulation after IP deduplication and response-time screening. The results show that pepper transplanting is still dominated by manual labor: purely manual and mainly manual operations together account for 69.25%, while fully mechanical transplanting accounts for only 9.84%. The primary problem of manual transplanting is high labor intensity and difficulty in hiring workers (54.98%), and the prominent limitations of existing machinery are single functionality (58.92%), poor adaptability to complex terrain (46.86%) and low transplanting accuracy (42.56%), with terrain adaptability being a common concern across all terrain types. In total, 70.11% of the farmers are willing to adopt fully integrated equipment; this willingness is highest among medium-scale households (10-500 mu, 1 mu is approximately 666.7 square meters) and follows an inverted U-shaped pattern. The mainstream acceptable price is concentrated in the range of CNY 10,000-50,000 (55.59%), and equipment price (64.94%) and policy subsidies (50.31%) are the primary purchase factors. Accordingly, this paper identifies a triple mismatch in pepper transplanting mechanization - between labor dependence and machinery supply, between single functionality and the

demand for integration, and between the acceptable price and product cost - and proposes recommendations for the R&D and extension of intelligent transplanting equipment in terms of hilly-terrain adaptability, modular cost reduction and subsidy coordination.

Keywords: Pepper; Transplanting Mechanization; Intelligent Agricultural Equipment; Farmer Demand; Hilly and Mountainous Areas

1. Introduction

Pepper is the vegetable crop with the largest planting area in China. According to statistics from the China Agricultural Research System for Bulk Vegetables of the Ministry of Agriculture and Rural Affairs, the annual pepper planting area in China has remained stable at about 32 million mu (approximately 2.13 million hectares), accounting for 8%-10% of the total vegetable planting area and ranking first among all vegetables [1,2]. After nearly four decades of rapid growth, the pepper industry has become an important pillar of rural income growth in major producing regions such as Guizhou, Henan, Xinjiang and Inner Mongolia [2]. Nevertheless, the cost competitiveness of the industry is under growing pressure: in the international market, Indian dried chili peppers, backed by scale and cost advantages, are squeezing China's market position [3], which makes reducing production costs an increasingly urgent task.

Among all field operations, however, transplanting remains the least mechanized link in pepper production, and the low level of mechanization has been repeatedly identified as a major weakness in discussions of the industry [2]. Pepper transplanting is highly labor-

intensive. Pepper seedlings have fragile root systems and are sensitive to clamping force; row spacing, hill spacing and transplanting depth directly determine seedling survival and the uniformity of subsequent growth, so the agronomic requirements are strict. Transplanting is also concentrated within narrow spring and autumn work windows, when labor demand peaks and the shortage and cost of hired labor become most acute. Viewed from the vegetable sector as a whole, the comprehensive mechanization rate of vegetable production in China was only about 45% in 2024, far below the level of more than 90% achieved for the three main grain crops, and development across operations is uneven, with transplanting and harvesting lagging furthest behind [4]; regional studies likewise indicate clear gaps in operation coordination and equipment supply in vegetable production mechanization [5]. Labor costs already account for 58% of total vegetable production costs and continue to rise [4]. Conditions are even more difficult in hilly and mountainous areas. Such areas hold roughly one third of China's cultivated land and crop sowing area, about three quarters of their cropland lies on slopes steeper than 25 degrees, and machinery faces well-known barriers in field access and operation, so their mechanization level falls far behind that of plain areas [6]; surveys of the facility vegetable industry in the hilly areas of Chongqing reveal the same deep constraint imposed by terrain on production methods [7]; international experience in farmland construction likewise offers reference for improving mechanization in hilly and mountainous areas [8].

Considerable research has been devoted to pepper and vegetable transplanting equipment at home and abroad. Review studies show that automatic vegetable transplanters have developed rapidly in recent years but that the field as a whole is still in transition from semi-automatic to fully automatic operation [9], and the technological trajectory abroad follows a similar path [10]; for the seedling-raising stage closely linked with transplanting, applied technologies such as grafting and transplanting equipment also made visible progress in recent years [11]. With respect to seedling pick-up and feeding, the automatic transplanter for pepper plug seedlings designed by Han et al. achieved a pick-up and feeding success rate of 97.07% at a planting frequency of 123 seedlings per minute

in field trials [12]; Hou et al. developed a linked clamping-inserting pick-up and feeding device to address low pick-up success rates and high damage rates [13]; the pick-up and feeding manipulator system built by Chen et al. attained an average single-point positioning error of 3.6 mm and a success rate of 96.0% [14]; Zhang et al. designed a seedling pick-up device combining pot ejection with stem clamping [15], and Chen et al. designed an ejection mechanism to solve the problems of uncontrolled seedling dropping trajectories [16], so the mechanisms for seedling pick-up continue to improve. These efforts demonstrate that fully automatic pick-up and feeding technology has achieved substantial breakthroughs, yet most devices remain at the prototype stage and have not entered large-scale application, leaving a clear gap between supply and demand. It should also be noted that most existing studies start from the equipment supply side and focus on the structural and control-system optimization of machinery, whereas studies that quantify the current state of pepper transplanting and the demand for intelligent equipment from the demand side, on the basis of large-sample farmer surveys, remain scarce. Farmers are the end users of agricultural machinery, and their judgments about operational pain points, functional priorities and acceptable price ranges are an important basis for choosing equipment development directions and designing extension policies.

Against this background, this study conducted a questionnaire survey of pepper growers nationwide and collected 813 valid responses covering 15 provinces, aiming to answer three questions: What is the current level of mechanization in pepper transplanting? What are the main pain points of manual transplanting and of the machinery currently available? And what characteristics do farmers' functional expectations, acceptable price ranges and purchase decision factors for intelligent transplanting equipment exhibit? In the analysis, the operational pain points, functional expectations and payment capacity on the farmer side are treated as demand-side variables, and the functional structure, terrain adaptability and price level of existing equipment as supply-side variables; the mismatch between the two sides is identified through comparison, structural differences in demand are examined through grouped cross-tabulation, and the development orientation and extension path of intelligent

transplanting equipment are discussed at the end.

2. Survey Design and Methods

2.1 Questionnaire Design

The questionnaire was designed around the survey objectives and consists of four parts with 16 questions in total. Part 1 collects basic information (Questions 1-3, single choice) on planting scale, years of cultivation and local topography, and is used to characterize the sample structure. Part 2 covers the current state and main problems of pepper seedling transplanting (Questions 4-8), including the current transplanting mode, the main problems of manual transplanting (multiple choice, up to 3 options), familiarity with or use of pepper transplanting machinery, the main limitations of existing transplanting machinery (multiple choice, up to 3 options), and the indicators farmers value most in transplanting. Part 3 addresses demand for and expectations of intelligent transplanting equipment (Questions 9-12), including the willingness to adopt a device that completes rotary tillage, ridging, film mulching, transplanting and intelligent irrigation in one pass, the functions expected of such a device (multiple choice, up to 4 options), the acceptable price range under the premise of multiplied efficiency and a survival rate above 95%, and the main factors affecting purchase (multiple choice). Part 4 elicits contextualized evaluations of the intelligent transplanter developed in this project (Questions 13-16), covering the most prominent advantages perceived, the core problems the device could solve (multiple choice), expectations about its diffusion prospects, and improvement suggestions collected through an open-ended question. The questionnaire contains 10 single-choice questions, 5 multiple-choice questions and 1 open-ended question.

2.2 Data Collection

The survey was distributed online through a questionnaire platform in late September 2026, targeting pepper growers, cooperatives and farm operators on an anonymous basis, and 813 valid questionnaires were obtained after completeness screening. Quality checks show that the 813 questionnaires correspond to 792 unique IP addresses; the 21 questionnaires with duplicate IP addresses were verified to come from different respondents, and no single IP account

submitted more than two questionnaires. Response times range from 61 to 209 seconds with a median of 105 seconds, and no questionnaire was completed in under 60 seconds; all 813 questionnaires contain complete answers to all 16 questions. The sample covers 15 provinces (autonomous regions and municipalities), namely Jiangsu, Fujian, Anhui, Shandong, Guangdong, Zhejiang, Liaoning, Hebei, Sichuan, Hubei, Jiangxi, Guangxi, Hainan, Chongqing and Henan. Jiangsu (241 questionnaires), Fujian (114), Anhui (108), Shandong (72), Guangdong (63) and Zhejiang (59) together account for 80.81% of the sample, and the sample distribution is geographically consistent with the location of major pepper production areas along the eastern coast and in central China.

2.3 Analytical Methods

Descriptive statistics are used to characterize the distribution of single-choice questions by frequency and percentage; for multiple-choice questions, the response rate, defined as the number of respondents selecting an option divided by the number of valid responses, is used for ranking and comparison. In addition, items within the questionnaire are cross-validated against each other (for example, the manual pain points in Question 5 against the machinery limitations in Question 7, and the functional expectations in Question 10 against the advantage perceptions in Question 13) to reduce the bias of interpreting any single item in isolation. All statistics were aggregated automatically by the survey platform and cross-checked after export.

3. Results and Analysis

3.1 Basic Characteristics of the Sample

The basic characteristics of the sample are shown in Table 1. In terms of planting scale, the sample covers the full gradient from smallholders to large-scale operators, with the two middle brackets of 10-50 mu and 50-500 mu jointly accounting for 60.15%, consistent with the current pattern in which medium-scale households form the main force of pepper cultivation. In terms of years of cultivation, respondents with more than five years of experience account for 49.33%, so the sample is dominated by experienced growers whose judgments about the difficulties of transplanting

have a practical basis. In terms of topography, hills and mountains together account for 49.08%; nearly half of the sample farms operate under terrain conditions that are clearly unfavorable for machinery access and operation, and this sample structure provides the basis for the discussion of terrain constraints later in the paper.

Table 1. Basic Characteristics of the Sample (n = 813)

Dimension	Category	Frequency	Share (%)
Planting scale	Below 10 mu	170	20.91
	10-50 mu	250	30.75
	50-500 mu	239	29.40
	Above 500 mu	154	18.94
Years of cultivation	Below 3 years	169	20.79
	3-5 years	243	29.89
	6-10 years	236	29.03
	Above 10 years	165	20.30
Topography	Plain/basin	247	30.38
	Hills	237	29.15
	Mountains	162	19.93
	Plain-hill mixture	167	20.54

3.2 Transplanting Modes and Labor Dependence

According to Question 4, 31.37% of the respondents currently transplant pepper seedlings entirely by hand, 37.88% rely mainly on manual labor with mechanical assistance, 20.91% rely mainly on machinery with manual supplementation, and only 9.84% transplant entirely by machine. Combining the first two categories, 69.25% of the households still depend primarily on manual labor; even among the machinery-oriented categories, manual supplementation is common. The results of Question 6 form a contrast with this picture: 55.23% of the respondents have used pepper transplanting machinery, 30.14% know of such machinery but have not used it, and only 14.64% are unfamiliar with it. In other words, most farmers are not unfamiliar with transplanting machinery, yet fewer than one in ten operate fully mechanically, presenting a semi-mechanized standoff of "having touched machines but being unable to do without manual labor". This indicates that the main factor constraining the mechanization of pepper transplanting is no longer the diffusion of awareness, but that existing machinery, in terms of functionality, terrain adaptability and overall cost-effectiveness, does not yet constitute a genuine substitute for manual labor.

3.3 Major Problems of Manual Transplanting

Question 5 is a multiple-choice question (up to 3

options). The pain points of manual transplanting rank as follows: high labor intensity and difficulty in hiring workers (54.98%) rank first, followed by low operation efficiency (48.46%), high labor cost (40.96%), unsatisfactory seedling survival (37.02%), unstable quality caused by uneven transplanting depth and row spacing (36.04%), and difficulty in meeting the tight seasonal schedule caused by concentrated labor demand (32.10%). Placing the first and last items together, difficulty in hiring workers and the seasonal labor peak actually point to the same underlying problem: the tightening supply of rural labor. Against the background of the outflow of young workers and the aging of the remaining workforce, "finding no one and being unable to afford hired hands" has moved ahead of "transplanting seedlings poorly" as the first constraint on pepper transplanting. This is consistent with the earlier industry judgment that the aging of vegetable-sector workers and the loss of young labor make mechanization an inevitable trend [4].

The relationship between labor constraints and mechanization deserves further discussion. Household-level research shows that agricultural population aging does not automatically translate into wider adoption of mechanization services; on the contrary, aging may suppress farmers' adoption of such services [17]. Research on farmland use presents a similar picture: population aging leads farming households to cultivate less land and leave more land idle, the shock is greater in mountainous areas than in plains, and agricultural mechanization can mitigate this negative effect [18]. In other words, the labor constraint does not dissolve simply because machines exist; whether machinery can genuinely substitute for labor depends on whether the equipment is easy to use and well adapted to local conditions. In hilly and mountainous areas, labor aging interacts with terrain constraints and places higher demands on the adaptability of equipment than in plain areas.

3.4 Limitations of Existing Transplanting Machinery and Farmer Evaluation Criteria

Question 7 is a multiple-choice question (up to 3 options). The main limitations of existing transplanting machinery rank as follows: single functionality, requiring multiple machines or manual intervention (58.92%), ranks first, followed by poor adaptability to complex terrain such as hills and mountains (46.86%), low

transplanting accuracy (42.56%), high failure rate and inconvenient maintenance (38.99%), high price and low cost-effectiveness (33.21%), and operational complexity with high skill requirements (30.38%). Question 8 (single choice) shows that the transplanting indicators farmers value most are operation efficiency (29.89%), row and hill spacing accuracy (25.58%), transplanting cost (19.93%), seedling survival (14.64%) and ease of operation (9.96%). That "single functionality" ranks first by a clear margin can be explained by Question 8: a single-operation machine requires several implements and several rounds of manual cooperation, and the transition losses between operations cancel out most of the single machine's efficiency advantage, while efficiency is precisely the indicator farmers value most. A grouped cross-tabulation of terrain adaptability shows that the selection rates in the plain/basin, hill, mountain and mixed-terrain groups are 48.2%, 43.0%, 48.1% and 49.1% respectively, with very small differences between groups. Poor terrain adaptability is therefore not a localized experience of farmers in hilly and mountainous areas but a cross-terrain common judgment; its causes include both the direct operational difficulties of complex terrain and factors such as the cross-regional movement of machinery and the need to take future operation scenarios into account at the time of purchase. Transplanting accuracy ranks third, echoing the agronomic sensitivity of pepper seedlings, for which even small deviations in depth affect survival. Reading Questions 5 and 7 together, the manual side reports low efficiency and high cost, while the machinery side reports single functionality, terrain limitations and insufficient accuracy; the two lists jointly sketch the type of equipment missing from the current market: an integrated machine that is efficient, passes terrain constraints and guarantees accuracy.

3.5 Demand for Intelligent Transplanting Equipment and Willingness to Pay

According to Question 9, regarding a device that can complete rotary tillage, ridging, film mulching, transplanting and intelligent irrigation in one pass, 31.37% of the farmers say they are very willing to learn about or use it and 38.75% are somewhat willing, for a combined total of 70.11%; 20.17% hold a neutral attitude and only 9.72% are unwilling. This high willingness corresponds to the top-ranked limitation of

"single functionality" in Question 7, indicating that integrated operation is precisely the gap in current supply.

Question 10 is a multiple-choice question (up to 4 options). The functions farmers expect rank as follows: integrated rotary tillage, ridging and film mulching (51.54%) ranks first, followed by precision-spaced transplanting with a row-spacing error within 3 cm (46.37%), damage-free seedling picking to raise survival (38.75%), operation data monitoring and fault alerts (37.02%), automatic seedling tray supply and recovery (36.78%), soil-moisture-based automatic irrigation (34.32%), automatic film mulching for moisture retention (29.03%) and adaptability to hilly and mountainous terrain (24.23%). Notably, "operation data monitoring and fault alerts" is a soft intelligent function, yet its selection rate reaches 37.02%, ranking fourth among the eight options and above most single-operation functions such as automatic mulching and terrain adaptability. Farmers' expectations of intelligentization are thus not limited to replacing physical labor; they also include the visualization of operation quality and risk warning.

Question 11 shows that, if the device could multiply transplanting efficiency and raise the survival rate above 95%, the acceptable price ranges perceived by farmers would be: CNY 30,000-50,000 (30.01%), CNY 10,000-30,000 (25.58%), above CNY 50,000 (19.68%), below CNY 10,000 (14.64%), and "depending on government machinery purchase subsidies" (10.09%). The CNY 10,000-50,000 band jointly accounts for 55.59%, the most concentrated price expectation in this survey. Question 12 (multiple choice) shows the main factors affecting purchase: equipment price (64.94%) ranks first, followed by quality and operational stability (57.32%), after-sales service (50.68%), policy subsidy intensity (50.31%), ease of operation (40.96%) and brand reputation (34.07%). With price first and subsidies close to half, this decision structure is consistent with the general finding of studies on farmers' machinery adoption that government support and household income significantly influence adoption behavior [19,20].

Grouped cross-tabulation further reveals clear stratification of demand by scale. In terms of adoption willingness, the proportions of farmers willing to learn about or use the fully integrated device are 61.8%, 74.8%, 76.2% and 62.3% in

the below-10 mu, 10-50 mu, 50-500 mu and above-500 mu groups respectively; medium-scale households show the highest willingness, forming an inverted U-shaped distribution. Current mechanization presents a different pattern: the combined share of machinery-mainly and fully mechanical transplanting is roughly equal in the below-10 mu and above-500 mu groups (37.0% versus 37.6%), while the two medium-scale groups are lower (24.0% and 28.8%); the fully mechanical share is highest in the above-500 mu group (13.6%) and stands at 8.8% in the below-10 mu group. Putting the two sets of figures together, medium-scale households are precisely positioned where willingness is highest while current mechanization is relatively low; the combination of labor pressure and payment capacity makes their demand for integrated equipment the most pressing, and they constitute the core target group. In terms of price expectations, the below-10 mu group shows the highest proportion choosing "below CNY 10,000" (20.6%), and the above-500 mu group ranks first in choosing "depending on government machinery purchase subsidies" (17.5%), so the stratification of payment capacity and subsidy dependence is consistently reflected in price expectations. It should of course be borne in mind that stated willingness usually exceeds actual purchase behavior, and market judgments based on the 70.11% figure should account for this hypothetical bias.

3.6 Perceptions of Integrated Intelligent Transplanting Equipment and Diffusion Prospects

Before answering Questions 13-16, respondents were shown a brief description of the device developed in this project (integrating rotary tillage, ridging, film mulching, seedling supply, transplanting and intelligent irrigation, electrically powered, and adaptable to hilly and mountainous terrain); the results are therefore contextualized evaluations and may be affected by social desirability bias, and they should be interpreted with caution. Question 13 shows that, compared with existing transplanting machinery, farmers regard the most prominent advantages of the project device to be strong adaptability to complex terrain (29.89%), intelligent automatic adjustment of operating parameters (25.34%), environmentally friendly electric drive (19.56%), integrated full-process operation that saves time

and labor (15.25%), and "cannot say" (9.96%). This forms an intriguing contrast with Question 10: while 51.54% of the farmers list integrated operation as an expected function, only 15.25% regard "integration" as the most prominent advantage, and nearly 30% choose "adaptability to complex terrain". In farmers' decision framework, integration is closer to a necessary condition than a selling point; whether the device can operate stably on hilly and mountainous land is the primary criterion by which they judge its quality.

Question 14 (multiple choice) shows the core problems farmers believe integrated intelligent equipment can solve, in descending order of endorsement: heavy labor demand and recruitment difficulties in manual transplanting (57.69%), excessive labor costs (54.49%), low operation efficiency and tight production schedules (41.70%), aging of the agricultural workforce during busy seasons (39.98%), single functionality of existing equipment that cannot complete multiple operations in one pass (38.25%), irregular row and hill spacing and low precision (33.58%), and unstable tillage depth control with poor soil preparation (30.63%). Compared with Question 5, the combined endorsement of the three labor-related problems - recruitment difficulty, high cost and aging - is significantly higher than that of quality- and technology-related problems, confirming that the main driving force of demand is still the constraint of labor factors.

Question 15 shows farmers' expectations for the diffusion of intelligent transplanting equipment in the pepper industry: 30.50% are very confident (gradual diffusion within 3-5 years) and 37.88% are fairly confident but expect it to take time, for a combined 68.39%; 20.54% hold a wait-and-see attitude and 11.07% are pessimistic. Overall expectations are positive yet rational: most farmers endorse the direction while reserving judgment on timing, which is consistent with the "price plus subsidy" decision structure described above.

3.7 Responses to the Open-Ended Question

The responses to the open-ended Question 16 require specific explanation: of the 813 questionnaires, 812 answered "none" or left the item blank, and only one gave a substantive suggestion ("more intelligent"). This result is reported as it is, without reconstruction. The low participation rate in the open question is partly

attributable to response fatigue in online questionnaires, as respondents are more accustomed to expressing themselves within structured options; at the same time, the coexistence of 70.11% high willingness with nearly zero open expression indicates that farmers hold clear demand tendencies toward intelligent transplanting but lack concrete knowledge of the technical path and are unable to articulate specific suggestions. This state of "having demand but being unable to say what is wanted" carries policy implications of its own: at the current stage of intelligent agricultural machinery diffusion, demonstration and experiential training may be more effective than advertising.

4. Discussion and Countermeasures

4.1 The Triple Mismatch: Structural Obstacles to Pepper Transplanting Mechanization

Synthesizing the results in Section 3, this paper summarizes the obstacles to pepper transplanting mechanization as a triple mismatch.

The mismatch between labor dependence and machinery supply is the most fundamental. With 69.25% of households still relying mainly on manual transplanting and 55.23% having used transplanting machinery, the threshold of access to machinery is no longer the issue; the issue is that machinery has not yet formed a stable advantage over manual labor in efficiency, quality or overall cost.

The mismatch between single functionality and the demand for integration follows closely. A total of 58.92% of the farmers list "single functionality" as the primary limitation of existing machinery, 51.54% list "integrated rotary tillage, ridging and film mulching" as their primary functional expectation, and 70.11% are willing to adopt a fully integrated device. What farmers want is "one pass over the field for the whole operation", while the mainstay of current supply remains single-operation machinery; the gap between supply and demand is evident.

The mismatch between the acceptable price and product cost determines the pace of commercialization. A total of 55.59% of the farmers place the acceptable price within CNY 10,000-50,000, whereas fully automatic transplanting equipment is generally still at the prototype stage, the cost reductions of mass

production have not yet materialized [9,12-14], and low-cost fully automatic machines are virtually absent from the market. Price ranks first among purchase factors (64.94%), subsidies reach 50.31%, and 10.09% of the farmers directly make their price expectations contingent on subsidies; it is foreseeable that cost control and subsidy mechanisms will jointly determine the diffusion tempo of this type of equipment.

The terrain constraint deserves separate emphasis. Hills and mountains account for 49.08% of the sample, and farmers in all terrain groups list "poor adaptability to complex terrain such as hills and mountains" among the main limitations of existing machinery (selection rates 43.0%-49.1%, with no significant difference between groups), while also regarding "strong adaptability to complex terrain" as the most prominent advantage of the integrated device (29.89%). Terrain adaptability is therefore not a localized demand of farmers in hilly areas but a cross-terrain consensus, and it should serve as a precondition of the whole-machine design of intelligent transplanting equipment rather than an optional add-on.

4.2 Mapping of Demand-Side Evidence onto Equipment Design

This section compares the questionnaire results with the design parameters of the device under development in this project. Two caveats are in order. The questionnaire was distributed by the project team and Questions 13-16 contain project-specific context, so the comparison serves only as a design check and carries the inherent limitations of a stakeholder survey; moreover, the mapping is based mainly on Questions 9-12, which address generic issues, while the results of Questions 13-16 serve only as auxiliary reference.

The directional results of the comparison are consistent. The device integrates six functions - rotary tillage, ridging, film mulching, seedling supply, transplanting and intelligent irrigation - corresponding to the top-ranked expectation of integrated operation in Question 10 (51.54%); precision transplanting based on machine vision and stepper control (positioning accuracy of plus or minus 1.5 cm) corresponds to the expectation of precision-spaced transplanting (46.37%); the flexible-gripper damage-free seedling pick-up design corresponds to the expectation of damage-free picking to raise survival (38.75%); intelligent irrigation with soil-moisture feedback

corresponds to the expectation of automatic watering based on soil moisture (34.32%); the electric drive corresponds to the 19.56% endorsement of "environmentally friendly" in Question 13; and the whole-machine architecture oriented toward hilly and mountainous land responds to the top-ranked "adaptability to complex terrain" in Question 13 (29.89%). For development work, the value of this comparison lies in grounding the trade-offs among design indicators in a quantitative survey of farmers rather than in the intuition of developers, and the core target group of medium-scale households identified through cross-tabulation also provides a direct basis for the cost positioning and target market selection of the device.

4.3 Countermeasures and Suggestions

In terms of R&D, priority should be given to adaptability to hilly and mountainous terrain, following a cost-control route of "sufficient rather than excessive intelligence". Terrain passability should be the first constraint of whole-machine design, together with lightweight chassis and adaptive leveling mechanisms; the configuration of intelligent functions should prioritize precision spacing, damage-free picking and data monitoring, for which farmer expectations are high, avoiding cost escalation for the sake of intelligence itself; modular design should be used to spread manufacturing costs, anchoring the complete machine within the CNY 10,000-50,000 mainstream price band, and the functional and cost positioning should target the medium-scale households (10-500 mu) with the highest willingness.

In terms of policy, purchase subsidies and extension mechanisms should become more precise. Integrated transplanting equipment for pepper and other vegetables that meets the operating conditions of hilly and mountainous areas should be included in the scope of agricultural machinery purchase and application subsidies, responding to the subsidy expectations of 50.31% of the farmers. Empirical research shows that machinery purchase subsidies significantly raise the probability that smallholders obtain mechanization services and expand the scale of services they obtain, but that the policy effect weakens markedly in areas with steep terrain and severe land fragmentation [21]; subsidies also indirectly raise farmers' income by promoting the development of mechanization services [22] and help improve the use efficiency

of agricultural machinery [23]; institutional arrangements such as farmland rights confirmation also affect farmers' choice of mechanized operations [24]. Subsidies should therefore tilt toward machinery adapted to hilly terrain and be combined with guidance toward moderately scaled operations.

In terms of industrial layout and basic conditions, the window created by the pepper industry's concentration toward advantaged production areas should be seized to advance farmland suitability transformation in step. The westward relocation of processing pepper planting toward Xinjiang, Inner Mongolia and other regions is already visible [25]; the concentration of production areas and the consolidation of plots will markedly improve the conditions for mechanized operation. Farmland suitability transformation can directly improve the cost efficiency of agricultural mechanization - enlarging the farmland area per worker and improving field leveling both significantly reduce operating costs [26] - and should be advanced in an integrated manner together with high-standard farmland construction and suitability transformation in hilly and mountainous areas [6]. In addition, varieties and agronomic systems should be coordinated with equipment design, cultivating machinery-friendly specialized varieties and optimizing planting patterns around market demand [27], so that varieties and machinery do not constrain each other; demonstration sites should be established in major production areas to close farmers' perception gaps through field demonstration.

In terms of services, the county-level after-sales and training network should be improved. After-sales service carries a weight of 50.68%, ranking third among purchase factors; a rapid-response network can be built on the county agricultural machinery distribution and repair system. In view of the operational complexity reported by 30.38% of the farmers, simplified training oriented toward middle-aged and elderly operators should be provided to lower the technical threshold.

In terms of cognition, experiential demonstration and training should be strengthened. The open-ended question shows that farmers have demand but cannot articulate what they want; field days, hands-on equipment experience and visualized demonstrations of operational performance should be used to help farmers form concrete

perceptions of intelligent transplanting and convert latent demand into effective demand.

5. Conclusions

Based on 813 farmer questionnaires covering 15 provinces, this study quantified the current state of pepper transplanting and the demand for intelligent transplanting equipment. The main conclusions are as follows.

First, pepper transplanting is still dominated by manual labor: purely manual and mainly manual operations together account for 69.25%, while fully mechanical transplanting accounts for only 9.84%; hills and mountains make up 49.08% of the sampled planting areas, and terrain constraints compounded by labor shortage form the basic background of transplanting mechanization.

Second, the primary pain points of manual transplanting are high labor intensity and difficulty in hiring workers (54.98%), while the prominent limitations of existing machinery are single functionality (58.92%), poor adaptability to complex terrain (46.86%) and low transplanting accuracy (42.56%). The efficiency and cost problems on the manual side and the functionality and terrain problems on the machinery side correspond to each other, reflecting the absence from the market of integrated equipment that is efficient, terrain-adaptable and precise.

Third, farmers show explicit demand for fully integrated intelligent transplanting equipment: 70.11% are willing to learn about or use it, functional expectations are led by integrated operation (51.54%) and precision-spaced transplanting (46.37%), the mainstream acceptable price is concentrated in the CNY 10,000-50,000 band (55.59%), and equipment price (64.94%) and policy subsidies (50.31%) are the primary purchase factors; adoption willingness is highest among medium-scale households (10-500 mu).

Fourth, farmers have demand for intelligent transplanting but lack concrete knowledge of it, and the open-ended question yielded almost no substantive expression. The extension stage should simultaneously advance equipment R&D, subsidy precision, county-level service networks and experiential demonstration to convert latent demand into effective demand.

Although the demand data come from China's pepper-producing areas, the path they reveal - rising labor costs driving the mechanization of

individual production operations in smallholder agriculture - and the equipment positioning oriented toward hilly terrain and medium-scale households are also of reference value to other economies facing similar structural constraints.

This study has several limitations. The sample was collected through online channels, provinces in eastern China are overrepresented, and the coverage of some northwestern and southwestern production areas is limited; no grower-identity screening question was included, so the coverage of genuine planting entities relies on the targeted nature of the distribution channels, and online channels reach elderly and remote farmers less adequately; the analysis relies on descriptive statistics and grouped cross-tabulation and has not yet subjected the relationships of scale, terrain and other factors with demand willingness to econometric testing; and the open-ended question carries little information. Future research should expand the regional representativeness of the sample and introduce econometric models to further identify the factors influencing farmers' adoption willingness.

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