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Research Article

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Farmers' willingness to adopt a time-shifted silvopastoral agroforestry system (tree–mushroom–poultry) in sweet cherry orchards: extension of TPB with labour constraints and perceived risk

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Abstract

Integrating a second productive enterprise into mature fruit orchards can raise output without expanding area, but orchard–livestock systems face a recurrent spatial conflict: ranging poultry damage fruit during the vulnerable phenological window, and the arrangements that resolve it require permanent infrastructure or wholesale rotation, neither of which suits smallholders. We examine a spatio-temporal rotation that turns this conflict into a scheduling problem: two plots alternate mushroom cultivation and poultry rearing on a half-year phase shift, with a whole-orchard exclusion window during flowering and fruit set and a movable partition fence re-installed without specialised equipment. Drawing on an extended theory of planned behaviour, we analyse survey data from 300 sweet cherry growers in Tai'an, Shandong, a traditional open-field area of northern China, using ordered logit models. Attitude (β = 0.915), perceived behavioural control (0.806), subjective norms (0.531) and expected benefit (0.412) are positively associated with adoption willingness (all $p \leq 0.001$), and perceived risk negatively so (β = -0.410, $p <$ 0.01). Labour constraints are insignificant overall (β = -0.200, p = 0.109) but act conditionally on field type and grower age; mean willingness is moderate (3.377) and only 34.0% of growers are classified willing. Perceived behavioural control does not moderate the pathway (β = -0.006, p = 0.969). Three implications follow: because the design is reversible, the salient drivers are evaluative and efficacy-related rather than financial; labour constraints bite at changeover rather than in annual averages; and the pattern should hold in other deciduous orchards where the same phenological constraint binds.

Keywords: adoption willingness; agroforestry; edible fungi; free-range poultry; theory of planned behaviour; sweet cherry

1. Introduction

Orchard systems that integrate a second productive enterprise (ranging poultry, edible fungi, or cover crops) are widely proposed as a route to raise output without expanding land, but adoption is constrained by a spatial problem the literature has identified across continents. Ranging birds damage fruit while it is on the tree, so the timing of grazing is itself a variable growers must manage (Paut et al. 2021), and the arrangements that resolve the conflict fall into two patterns: co-located and synchronous, or partitioned by a permanent boundary (Garrett et al. 2004; Orefice et al. 2017; Hawke 1991; Peri et al. 2016). Neither separates the two activities in time. Whole-orchard rotation does, but it sacrifices half the orchard's productive capacity in any given year and is rarely observed in temperate smallholder systems (Paut et al. 2021). Missing from this evidence base is the arrangement examined here: a phase-shifted compartmental rotation in which the two activities share ground but exchange places on a fixed cycle, with the boundary carried by a movable, non-excavating fence unit.

The study uses a survey of 300 sweet cherry (*Prunus avium* L.) growers in Tai'an, Shandong, a traditional open-field production area of northern China that is representative of mature deciduous-fruit systems elsewhere where protected cultivation has not been taken up. China is the world's largest producer of sweet cherry, with 258,000 ha planted and 1.68 million tonnes harvested in 2024 (Liu et al. 2024; Chen et al. 2024). Shandong accounts for more than half of both national area and output, and Tai'an is the province's second largest production area after Yantai (Liu et al. 2024; Zhang et al. 2021). The two differ sharply in productivity: Fushan, in the Yantai region, averages about 12.3 t ha^{-1}, against roughly 6.0 t ha^{-1} in Tai'an. The gap is structural. Tai'an's orchards are predominantly open-field with little protected cultivation (Zhang et al. 2016), and planted area has plateaued near 13,300 ha since 2019 (Liu et al. 2024).

The 2026 growing season illustrated that vulnerability. Prolonged rainfall during ripening caused cracking rates above 20% in open-field orchards, and above 50% in some plots. Farm-gate prices for the early cultivar 'Hongdeng' fell from above 20 yuan kg^{-1} to 4–8 yuan kg^{-1}, while protected cultivation still returned 60–80 yuan kg^{-1}. For growers in

traditional areas the constraint is therefore not demand but an inability to raise income from a fixed, fully planted land base.

Integrating additional productive activities into existing orchards is one response, and the practice has a long history in China. Understory economies cover more than 40 million ha nationally, with an output value of 1.3 trillion yuan (Huang et al. 2014), and fruit trees combined with edible fungi or with poultry are both well documented: a cherry–*Stropharia rugosoannulata* intercrop has matured in the Yantai region, and free-range poultry is widely practised in orchards elsewhere (Dong and Li 2025; Zhu 2012; Liu et al. 2025). The two activities have rarely been combined within a single orchard, because they conflict in space. Poultry damage fruit by pecking, so growers keep birds confined year-round and forgo the benefits of ranging; mushroom beds occupy the inter-row space poultry would otherwise use. The arrangement examined here dissolves that conflict by converting it into a scheduling problem (Figure 1). The orchard is divided into two plots of equal productive capacity. In the first half-year plot A hosts mushroom beds while plot B carries poultry; in the following half-year the plots are exchanged. A whole-orchard exclusion window is maintained during flowering and fruit development, so no birds are present when fruit is at risk. Spent mushroom substrate and poultry manure are returned to the soil in situ (Zhang et al. 2026b; Ma et al. 2025; Zhou et al. 2026; Hong et al. 2022). The exchange requires a removable partition fence; the hardware component is protected by a utility model patent in China.

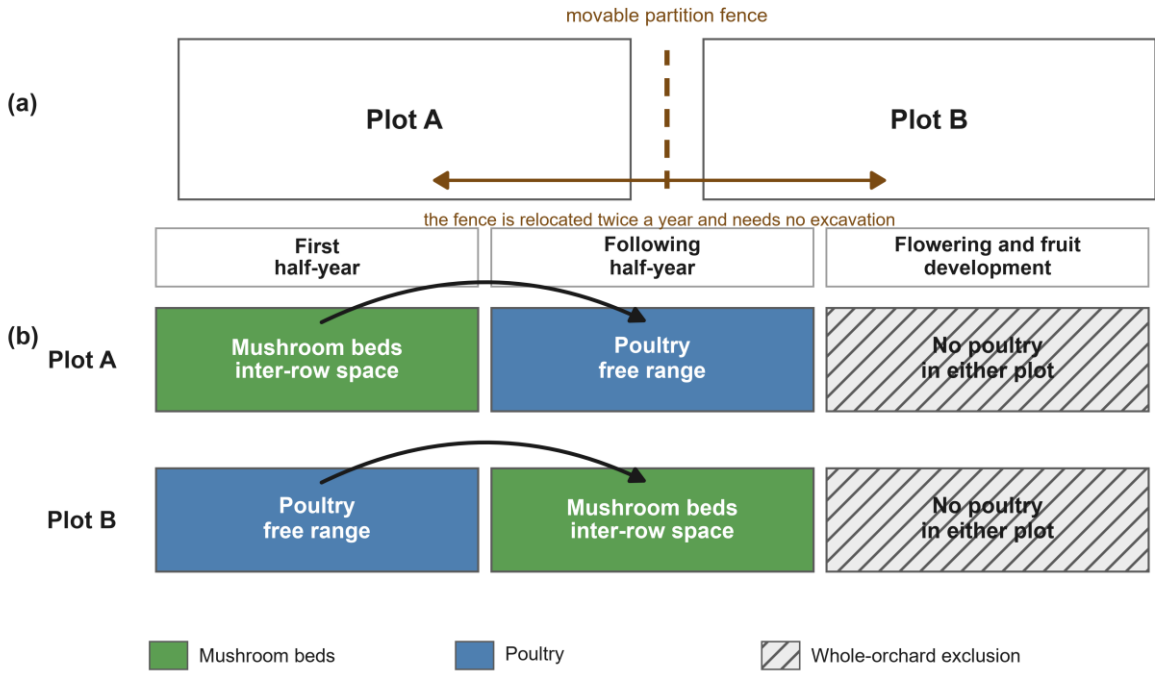


Figure 1. Schematic of the phase-shifted rotation in a mature orchard. (a) Plan view: the orchard is divided into two plots of equal productive capacity separated by a movable partition fence, which is relocated twice a year and requires no excavation. (b) Annual timetable: mushroom beds and free-range poultry exchange places between the two plots at each half-year boundary, and neither plot carries poultry during flowering and fruit development. Spent mushroom substrate and poultry manure are returned to the soil in situ.

Whether such a system can be promoted at scale depends on whether growers are willing to adopt it (Dong and Li 2025). That question has not been addressed empirically for rotational agroforestry in mature orchards, and the adoption literature for agroforestry and integrated crop–livestock systems offers only partial guidance (Pattanayak et al. 2003; Mercer 2004; Meijer et al. 2015; Baker et al. 2025), because the present technology differs from conventional agroforestry in two respects. It requires no permanent change to the orchard, being reversible and mobile, so land tenure and irreversibility do not dominate the decision. It is also labour-intensive at specific points in the annual cycle, which makes household labour endowment salient in a sector where the average grower is ageing.

This paper makes three contributions. Empirically, it provides, to our knowledge, the first quantitative evidence on growers' willingness to adopt a spatio-temporal rotation system in Chinese sweet cherry orchards. Theoretically, it extends the theory of planned behaviour (Ajzen 1991, 2002; Armitage and Conner 2001) with three constructs (perceived risk, labour constraints, and expected benefit) that are specific to the

technology's design, and tests a moderation pathway in which perceived behavioural control buffers the negative influence of labour constraints. Practically, it identifies where extension effort should be concentrated.

Section 2 develops the hypotheses, Section 3 the sampling, measurement and empirical model, Section 4 the results, and Section 5 the implications and limitations.

2. Literature review and hypotheses

2.1 The theory of planned behaviour in agricultural technology adoption

The theory of planned behaviour (TPB) holds that behaviour is proximally determined by intention, which is in turn shaped by attitudes toward the behaviour, subjective norms, and perceived behavioural control (Ajzen 1991, 2002). The framework has been applied extensively to agricultural technology adoption, including conservation tillage, organic certification and agroforestry (Baumgart-Getz et al. 2012; Prokopy et al. 2008; Dessart et al. 2019; Wauters et al. 2010; Van Dijk et al. 2016; Liu et al. 2018). Its appeal lies in parsimony and in the ease with which domain-specific constructs can be appended.

For the technology examined here, attitude captures the grower's evaluation of mushroom–poultry integration as beneficial and worthwhile; subjective norms capture the influence of peers, extension agents and family; and perceived behavioural control captures the assessment of whether the required skills, labour and capital are within reach (Ajzen 2002).

H1. Attitude is positively associated with willingness to adopt.

H2. Subjective norms are positively associated with willingness to adopt.

H3. Perceived behavioural control is positively associated with willingness to adopt.

2.2 Perceived risk

Adoption of a new orchard enterprise involves upfront expenditure on spawn, fencing and poultry stock, together with output price uncertainty, and the 2026 price collapse made revenue risk particularly salient in Tai'an. Perceived risk repeatedly depresses adoption of unfamiliar practices (Marra et al. 2003; Abadi Ghadim et al. 2005; Fahad and Wang 2018; Zhang 2018), and the TPB's core constructs do not capture it, because they measure evaluation rather than uncertainty.

H4. Perceived risk is negatively associated with willingness to adopt.

2.3 Labour constraints

The rotational system concentrates labour demand at two points: mushroom bed preparation and harvest, and fence relocation between plots. Chinese orchard growers are ageing, and household labour availability is a binding constraint in many fruit-producing regions (Zou et al. 2018; Li et al. 2026; Shang et al. 2026). Where labour is short, practices that add seasonal peaks are less likely to be taken up even when returns are favourable.

H5. Labour constraints are negatively associated with willingness to adopt.

2.4 Expected benefit

Expected benefit captures the grower's assessment of the economic return from the additional enterprises. It is the principal instrumental motivation for adoption (Baumgart-Getz et al. 2012; Prokopy et al. 2008; Dessart et al. 2019) and is expected to operate alongside, rather than through, attitude.

H6. Expected benefit is positively associated with willingness to adopt.

2.5 The moderating role of perceived behavioural control

The influence of labour constraints should not be uniform across growers. Where growers judge themselves able to mobilise labour, through household members, hired seasonal workers or cooperative arrangements, the negative association with willingness should weaken. Perceived behavioural control is therefore expected to moderate this pathway (Ajzen 2002; Armitage and Conner 2001). The hypothesis is the paper's main theoretical addition: it identifies a boundary condition on a constraint otherwise treated as fixed.

H7. Perceived behavioural control weakens the negative association between labour constraints and willingness to adopt.

3. Materials and methods

3.1 Study area

The survey was conducted in Tai'an Municipality, Shandong Province, the province's second largest sweet cherry production area, with approximately 13,300 ha under cultivation (Liu et al. 2024). Fieldwork was concentrated in Daiyue District, Taishan District and Tianbao Town. Tianbao, known as "China's leading sweet cherry

town", cultivates about 3,300 ha for an output of 20,000 t worth 400 million yuan, but its average yield of roughly 6.0 t ha^{-1} is half that of the Yantai region (Zhang et al. 2021). Tai'an's fruit also ripens 15 to 20 days earlier than the coastal region, an advantage offset by greater exposure to rain-induced cracking.

In this paper the administrative-division convention is applied consistently: Tianbao Town is administered by Xintai Municipality and counted under it, Shengzhuang Town under Taishan District, and Xiazhuang and Dawenkou Towns under Daiyue District.

3.2 Sampling and data collection

A stratified design was used. Townships were stratified by sweet cherry production scale, villages were selected within each stratum, and households were sampled at random from village registers. In practice the survey covered 3 county-level units, 4 townships and 9 main producing villages, yielding 31–38 valid questionnaires per village and 300 valid responses in total, the upper bound of the design target (250–300).

The sampling plan was adjusted during fieldwork. The original plan covered 10–12 villages with a quota of 25–30 questionnaires each. Because village registers were incomplete in places and the spring work window was short, the design was adjusted to 9 villages with a relaxed per-village quota; the valid sample still reached the upper bound of the target, so precision was not materially affected. By county-level unit: Daiyue 162 (54.0%), Xintai 73 (24.3%), Taishan 65 (21.7%).

Enumerators worked in pairs, one asking questions and one recording, and a five-point response card helped respondents express intensity judgements. Face-to-face administration was deliberate: the grower population is predominantly middle-aged and older, and self-administered digital questionnaires would have produced substantial non-response and comprehension error (Zou et al. 2018). Interviews took place at the respondent's home in 73.7% of cases, in the orchard in 22.0% and elsewhere in 4.3%, and lasted 10.5 minutes on average.

Of 350 questionnaires distributed and returned, 300 were complete and used, a valid response rate of 85.7%. Of the 50 invalid returns, 25 were void (16 refusals, 9 terminations) and 25 were partially incomplete with whole blocks of items unanswered, precluding computation of construct scores. Sample characteristics are reported in Online Resource 1 (Tables B1–B2).

3.3 Measurement

All latent constructs used five-point Likert scales (1 = strongly disagree to 5 = strongly agree); item wording is given in Online Resource 1 (Table A1). Attitude, subjective norms and perceived behavioural control used three, three and four items respectively. Perceived risk used four items on output market risk, damage to fruit, management complexity and capital recovery. Labour constraints used two items on seasonal labour shortage and physical capacity. Expected benefit used two items on income gain per unit area and payback period. Willingness to adopt, the dependent variable, used four items on willingness to trial on a small plot, to scale up, to recommend to peers and to join a village-level programme.

Construct scores are the mean of the constituent items. Internal consistency was assessed with Cronbach's alpha (Cronbach 1951) and construct validity through exploratory factor analysis with varimax rotation (Kaiser 1974); the outcomes are reported in Section 4.2.

3.4 Empirical strategy

Because the dependent variable is measured on a five-point ordinal scale, the main model is an ordered logit:

$$Pr(Y_i \leq j) = \Lambda(\theta_j - X_i'\beta), \; j = 1, \ldots, 4$$

where Y_i is grower i's willingness category, θ_j are cut-points, X_i contains the six construct scores, and $\Lambda(\cdot)$ is the logistic cumulative distribution function. Standard errors are robust to heteroskedasticity.

To test H7, perceived behavioural control and labour constraints were mean-centred and their product added to the specification. Moderation is supported if the interaction coefficient is positive and significant, indicating that the negative slope of labour constraints flattens as perceived behavioural control rises.

Three robustness checks were performed: the dependent variable was dichotomised at the scale midpoint (mean ≥ 4 coded as willing) and estimated by binary logit; growers aged 60 and above were excluded, to test whether results are driven by the oldest cohort; and the sample was split by cultivation type. Common method bias was assessed with Harman's single-factor test (Podsakoff et al. 2003; Aguirre-Urreta and Hu 2019), and multicollinearity with variance inflation factors (Fornell and Larcker 1981).

3.5 Ethical considerations

Participation was voluntary and based on informed consent. Enumerators explained the purpose of the study and the intended use of the data before each interview, and respondents were told they could decline any question or stop at any point. No personally identifying information was recorded in the analytical dataset, and photographs were taken only with explicit permission.

4. Results

4.1 Descriptive statistics

Table 1 presents means, standard deviations and distributional statistics for the seven constructs. Construct means fall in the narrow band 3.00–3.55, between "neither agree nor disagree" and "somewhat agree", so growers evaluate mushroom–poultry integration as mildly positive rather than either clearly favourable or clearly averse.

Attitude (3.519), subjective norms (3.546) and perceived risk (3.528) all sit slightly above the scale midpoint, indicating that growers accept the practice while recognising its uncertainty. Perceived behavioural control averages exactly 3.000, the lowest of the seven constructs; its item PBC1 ("my household has enough labour to manage mushrooms and poultry") averages only 2.72, the lowest of all 22 items, so labour availability is the weakest element in growers' self-assessment. Expected benefit (3.187) is also low: growers expect modest income gains and a long payback period.

Willingness to adopt has a mean of 3.377 (SD 0.982), a moderate level. Being the mean of four five-point items, it can only take multiples of 0.25; the rounded means distribute as follows: 12 respondents (4.0%) in category 1, 31 (10.3%) in category 2, 108 (36.0%) at the midpoint, 92 (30.7%) in category 4 and 57 (19.0%) in category 5. Dichotomised on the unrounded mean (≥ 4.0), 102 respondents (34.0%) are classified as willing; the counts differ because rounding assigns means of 3.50–3.99 to category 4, whereas the split requires at least 4.00. Growers are therefore not averse, but not eager, and that fact frames the discussion below.

Table 1. Descriptive statistics for the seven constructs ($N = 300$)

Construct	Mean	SD	Min	Max	Skewness	Kurtosis
Attitude (ATT)	3.519	0.986	1.000	5.000	-0.490	-0.251
Subjective norms (SN)	3.546	0.924	1.333	5.000	-0.275	-0.681
Perceived behavioural control (PBC)	3.000	0.829	1.000	5.000	0.156	-0.391
Perceived risk (PR)	3.528	0.960	1.250	5.000	-0.330	-0.701
Labour constraints (LC)	3.430	0.962	1.000	5.000	-0.226	-0.494
Expected benefit (EB)	3.187	1.033	1.000	5.000	-0.149	-0.711
Willingness to adopt (WI)	3.377	0.982	1.000	5.000	-0.234	-0.548

Note: all |skewness| < 1 and all |kurtosis| < 1, indicating near-normal distributions appropriate for parametric methods.

4.2 Reliability and validity

Table 2 reports Cronbach's alpha for each construct. Attitude (0.830), subjective norms (0.743), perceived risk (0.870) and willingness to adopt (0.868) all exceed the conventional 0.70 threshold (Cronbach 1951), the last of these being the dependent variable, so the scales provide a sound basis for hypothesis testing. Three fall below: perceived behavioural control (0.675), expected benefit (0.650) and labour constraints (0.606).

Expected benefit and labour constraints each comprise only two items, and alpha is sensitive to item count (Cronbach 1951): for a given average inter-item correlation it declines as the item count falls, so two-item scales occupy the lower range by construction. Their low alphas therefore reflect scale length rather than poor content validity, and their inter-item correlations, 0.482 and 0.435, imply acceptable reliability in the Spearman–Brown sense.

Perceived behavioural control presents a different problem. Item diagnostics (Table 3) show that its fourth item, PBC4 ("I can afford the upfront costs of spawn, fencing and chicks"), has a corrected item–total correlation of only 0.252, below the conventional 0.30 threshold, and deleting it raises the construct alpha from 0.675 to 0.740. PBC4 evidently measures capital availability, whereas the remaining three items measure skill confidence, labour and access to help. Section 4.6 reports the re-estimated model with PBC4 removed.

Table 4 shows a KMO of 0.773, above the 0.6 threshold (Kaiser 1974), and a significant Bartlett test ($\chi^2 = 1752.82$, $p < 0.001$), so the correlation matrix is factorable. Principal axis factoring with varimax rotation (Table 5) extracted six factors with eigenvalues above one, explaining 54.8% of the total variance, and after rotation the six map essentially one-to-one onto the constructs. Two qualifications apply. PBC4 loads only

0.287 on its own factor, corroborating the reliability diagnosis. The expected-benefit factor is unstable, its two items loading at 0.423 and 0.976, a spread characteristic of a near-Heywood solution in which a two-item factor is empirically ill-defined; the same instability recurs in the reliability analysis ($\alpha = 0.650$) and is a reason to treat the expected-benefit coefficient with caution.

Table 2. Reliability analysis ($N = 300$)

Construct	Items	Cronbach's α	$\alpha \geq 0.70$
Attitude (ATT)	3	0.830	Yes
Subjective norms (SN)	3	0.743	Yes
Perceived behavioural control (PBC)	4	0.675	No
Perceived risk (PR)	4	0.870	Yes
Labour constraints (LC)	2	0.606	No
Expected benefit (EB)	2	0.650	No
Willingness to adopt (WI)	4	0.868	Yes

Note: Cronbach's α depends on item count and falls as items are added to a scale, so two-item scales score low by construction; the corresponding inter-item correlations are given in Section 4.2.

Table 3. Item-level reliability diagnostics (selected items)

Construct	Item	CITC	Construct α	α if item deleted	Decision
Attitude	ATT1 / ATT2 / ATT3	0.719 / 0.691 / 0.659	0.830	0.739 / 0.762 / 0.794	Retain
Subjective norms	SN1 / SN2 / SN3	0.595 / 0.589 / 0.528	0.743	0.626 / 0.640 / 0.708	Retain
Perceived behavioural control	PBC1 / PBC2 / PBC3	0.543 / 0.580 / 0.483	0.675	0.551 / 0.523 / 0.592	Retain
Perceived behavioural control	**PBC4**	**0.252**	0.675	**0.740**	**Consider deleting (CITC < 0.30)**
Perceived risk	PR1–PR4	0.751 / 0.721 / 0.700 / 0.725	0.870	0.825 / 0.835 / 0.844 / 0.833	Retain
Labour constraints	LC1 / LC2	0.435 / 0.435	0.606	— (two-item scale)	Retain
Expected benefit	EB1 / EB2	0.482 / 0.482	0.650	— (two-item scale)	Retain
Willingness to adopt	WI1–WI4	0.707 / 0.753 / 0.701 / 0.715	0.868	0.836 / 0.817 / 0.838 / 0.832	Retain

Note: the bold row marks the item whose corrected item–total correlation falls below the 0.30 threshold.

Table 4. Validity assessment

Statistic	Value	Criterion
KMO measure of sampling adequacy	0.773	> 0.6
Bartlett's test of sphericity χ^2	1752.822	—
Bartlett's test p-value	< 0.001	< 0.05
Factors with eigenvalue > 1	6	—
Cumulative variance explained	54.8%	> 50%

Table 5. Exploratory factor analysis with varimax rotation (18 items of the six predictors)

Item	F1 (PR)	F2 (ATT)	F3 (PBC)	F4 (SN)	F5 (EB)	F6 (LC)
ATT1	0.033	**0.800**	0.128	0.160	0.104	-0.036
ATT2	-0.056	**0.759**	0.141	0.154	0.111	0.074
ATT3	0.047	**0.705**	0.126	0.175	0.065	0.023
SN1	0.010	0.088	0.151	**0.732**	0.117	0.106
SN2	0.025	0.154	0.174	**0.692**	0.049	0.013
SN3	-0.011	0.232	0.041	**0.601**	0.003	0.017
PBC1	-0.089	0.037	**0.674**	0.230	0.028	-0.057
PBC2	-0.020	0.108	**0.760**	0.033	0.040	-0.039
PBC3	0.084	0.082	**0.617**	0.044	0.135	-0.099
PBC4	0.009	0.144	0.287	0.070	0.031	0.049
PR1	**0.819**	0.040	-0.024	0.033	-0.016	0.120
PR2	**0.780**	0.071	0.077	-0.051	0.011	0.085
PR3	**0.751**	-0.021	-0.004	0.005	0.019	0.113
PR4	**0.801**	-0.065	-0.047	0.034	0.058	0.082
LC1	0.096	0.041	-0.018	0.065	-0.003	**0.686**
LC2	0.222	0.016	-0.082	0.036	0.027	**0.595**
EB1	-0.015	0.324	0.170	0.105	**0.423**	0.074
EB2	0.079	0.121	0.123	0.086	**0.976**	-0.024

Note: bold indicates the primary loading. EFA uses the 300 respondents with complete data on all 22 items, matching the main analysis sample.

4.3 Correlation analysis

Table 6 reports pairwise correlations. Willingness to adopt correlates positively with attitude ($r = 0.579$, $p < 0.01$), perceived behavioural control (0.447, $p < 0.01$), expected benefit (0.414, $p < 0.01$) and subjective norms (0.404, $p < 0.01$), and negatively with perceived risk (-0.192, $p < 0.01$) and labour constraints (-0.121, $p < 0.05$). All six take the sign predicted by the hypotheses.

The largest absolute correlation among the predictors is 0.356, far below the 0.8 threshold, and variance inflation factors range from 1.076 to 1.290, well below 5; multicollinearity is not a concern.

One correlation merits comment: labour constraints and perceived behavioural control correlate at only -0.074 ($p = 0.198$), essentially orthogonal, a point taken up in

Section 4.5. Labour constraints do correlate with perceived risk (0.262, $p < 0.01$), suggesting that the two jointly reflect growers' broader sense of operational uncertainty.

Table 6. Correlation matrix of constructs ($N = 300$)

Construct	ATT	SN	PBC	PR	LC	EB	WI
Attitude (ATT)	1						
Subjective norms (SN)	0.356***	1					
Perceived behavioural control (PBC)	0.271***	0.258***	1				
Perceived risk (PR)	0.019	0.023	-0.006	1			
Labour constraints (LC)	0.057	0.091	-0.074	0.262***	1		
Expected benefit (EB)	0.356***	0.227***	0.254***	0.059	0.043	1	
Willingness to adopt (WI)	0.579***	0.404***	0.447***	-0.192***	-0.121**	0.414***	1

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

4.4 Determinants of adoption willingness

Table 7 reports the ordered logit estimates. The model is significant overall (likelihood-ratio $\chi^2 = 178.72$, df = 6, $p < 0.001$), with a log-likelihood of -333.37 and a pseudo-R^2 of 0.211, a level typical of cross-sectional adoption studies.

Attitude (H1) carries the largest coefficient in the model (+0.915, $p < 0.001$; exp(β) = 2.498), so a one-point increase in attitude multiplies the cumulative odds of a higher willingness category by about 2.5. Perceived behavioural control (H3) follows at +0.806 ($p < 0.001$; exp(β) = 2.238), second only to attitude, so growers weigh capability no less heavily than worth; subjective norms (H2) reach +0.531 ($p < 0.001$; exp(β) = 1.701) and expected benefit (H6) +0.412 ($p = 0.001$; exp(β) = 1.509). Perceived risk (H4) is negative and significant (-0.410, $p = 0.001$; exp(β) = 0.664) but the smallest of the five significant predictors, so risk concerns are real without being dominant. Labour constraints (H5) carry the expected sign (-0.200) but fall short of significance ($p = 0.109$); Section 4.6 shows the variable becoming significant in several subsamples.

Five of the six main-effect hypotheses (H1–H4 and H6) are therefore supported; H7 is tested in Section 4.5. Ranked by absolute coefficient, the determinants are attitude, perceived behavioural control, subjective norms, expected benefit and perceived risk, in that order. Estimated cut-points are 2.245, 4.167, 6.809 and 8.902.

Table 7. Main model: ordered logit estimates (dependent variable: willingness to adopt, 1–5; $N = 300$)

Variable	Coef.	SE	z	p	exp(β)	Sig.	Hypothesis	Conclusion
Attitude (ATT)	0.915	0.139	6.587	< 0.001	2.498	***	H1 (+)	Supported
Subjective norms (SN)	0.531	0.136	3.893	< 0.001	1.701	***	H2 (+)	Supported
Perceived behavioural control (PBC)	0.806	0.154	5.239	< 0.001	2.238	***	H3 (+)	Supported
Perceived risk (PR)	-0.410	0.124	-3.293	0.001	0.664	***	H4 (-)	Supported
Labour constraints (LC)	-0.200	0.124	-1.604	0.109	0.819		H5 (-)	Not supported
Expected benefit (EB)	0.412	0.121	3.403	0.001	1.509	***	H6 (+)	Supported

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Log-likelihood = -333.37; pseudo-R^2 = 0.211; LR $\chi^2(6) = 178.72$, $p < 0.001$. Cut-points θ_1–θ_4 = 2.245, 4.167, 6.809, 8.902.

4.5 Moderation analysis

Table 8 adds the interaction between perceived behavioural control and labour constraints, both mean-centred. The interaction is negative and not significant ($\beta = -0.006$, $p = 0.969$); H7 is not supported. The pseudo-R^2 remains 0.211, identical to the main model, and the main-effect coefficients are essentially unchanged, indicating a stable specification.

Simple slopes reinforce this. At perceived behavioural control one standard deviation below its mean, at the mean and one standard deviation above, the slope of labour constraints is -0.195, -0.200 and -0.204, statistically indistinguishable; whatever a grower's self-assessed capability, labour constraints exert the same negligible influence.

The correlation reported in Section 4.3 points to the same mismatch. Only one of the four perceived-behavioural-control items (PBC1) concerns labour; the other three measure skill confidence, access to help and capital availability, so the construct as measured does not capture the *capacity to mobilise labour* that a moderator of labour constraints would have to represent. The two constructs are also nearly orthogonal ($r = -0.074$, $p = 0.198$), so nothing in the measurement system links the supposed buffer to the constraint it is meant to buffer. Re-estimating after deleting PBC4 leaves the interaction at +0.005 ($p = 0.970$), so the conclusion is unchanged.

Table 8. Moderation analysis (H7; variables mean-centred)

Variable	Coef.	SE	*p*	Sig.
Attitude (ATT)	0.915	0.139	< 0.001	***
Subjective norms (SN)	0.531	0.136	< 0.001	***
Perceived behavioural control (PBC)	0.806	0.156	< 0.001	***
Perceived risk (PR)	-0.410	0.124	0.001	***
Labour constraints (LC)	-0.200	0.125	0.109	
Expected benefit (EB)	0.412	0.122	0.001	***
PBC × LC (interaction)	-0.006	0.143	0.969	

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Pseudo-$R^2 = 0.211$, identical to the main model. Simple slopes (PBC at -1 SD / mean / +1 SD): LC slope = -0.195 / -0.200 / -0.204.

4.6 Robustness checks

Table 9 reports the re-estimations behind checks (a), (b), (c), (e) and (f); check (d) is a diagnostic on the item pool and is reported in the text only.

(a) Binary logit (dependent variable dichotomised at the scale midpoint, WI ≥ 4 coded as willing; 102 growers, 34.0%). All six coefficients take the same sign as in the main model: attitude (1.544), perceived behavioural control (0.902), expected benefit (0.638) and subjective norms (0.514) are significantly positive, perceived risk significantly negative (-0.682), and labour constraints become significantly negative (-0.371, p = 0.047). Pseudo-$R^2 = 0.396$.

(b) Excluding growers aged 60 and above ($N = 212$). All coefficients retain their signs and significance levels; labour constraints are significantly negative (-0.326, p = 0.025).

(c) Split by cultivation type. In the open-field subsample ($N = 201$) labour constraints are significantly negative (-0.405, $p = 0.010$) and the other constructs match the main model. In the protected subsample ($N = 99$) labour constraints are positive and insignificant (+0.173, $p = 0.422$), while the remaining five retain their signs and significance.

All three checks support the robustness of H1–H4 and H6. H5 follows a consistent pattern: insignificant in the full sample and the protected subsample, significantly negative under the binary specification, in the younger subsample and in the open-field subsample. Labour constraints are thus a conditional rather than universal constraint, tied to age structure and cultivation type, which is the empirical basis for Section 5.2.

(d) Common method bias. Harman's single-factor test (Podsakoff et al. 2003; Aguirre-Urreta and Hu 2019) on all 22 items extracted six factors with eigenvalues above one, the first accounting for 25.5% of the variance, below the 50% threshold.

(e) Deleting PBC4. Re-estimating the main model with perceived behavioural control scored on PBC1–PBC3 leaves all six coefficients unchanged in sign and significance (attitude 0.932, subjective norms 0.533, perceived behavioural control 0.699, perceived risk -0.408, labour constraints -0.187 and insignificant, expected benefit 0.418; pseudo-R^2 = 0.210), and the interaction remains insignificant (+0.005, p = 0.970).

(f) Excluding low-discrimination questionnaires (35 respondents with a within-person response standard deviation below 0.5). Re-estimation on the remaining 265 leaves all signs unchanged, labour constraints at -0.250 (p = 0.050).

Table 9. Robustness checks

Specification	*N*	ATT	SN	PBC	PR	LC	EB
Main model (ordered logit)	300	0.915***	0.531***	0.806***	-0.410***	-0.200	0.412***
(a) Binary logit (WI ≥ 4)	300	1.544***	0.514**	0.902***	-0.682***	-0.371** †	0.638***
(b) Excluding age ≥ 60	212	0.944***	0.668***	0.722***	-0.426***	-0.326** †	0.420***
(c) Open-field subsample	201	0.987***	0.519***	0.762***	-0.309**	-0.405** †	0.434***
(c) Protected subsample	99	0.751***	0.529*	0.823***	-0.547**	+0.173	0.502**
(e) PBC4 deleted	300	0.932***	0.533***	0.699***	-0.408***	-0.187	0.418***
(f) Low-discrimination excluded	265	0.802***	0.424***	0.700***	-0.456***	-0.250** †	0.359***

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Coefficients reported. † marks specifications in which labour constraints are statistically significant. Harman's first factor = 25.5% (< 50%); VIF range 1.076–1.290 (< 5).

5. Discussion

5.1 Interpretation of findings

Consistent with mainstream TPB results (Ajzen 1991; Armitage and Conner 2001; Wauters et al. 2010; Van Dijk et al. 2016), attitude, subjective norms and perceived behavioural control are all significantly positively associated with willingness, and five of the seven hypotheses (H1–H4 and H6) are supported. Two features merit comparison with the literature.

First, attitude is the strongest predictor, in line with agroforestry adoption research (Pattanayak et al. 2003; Mercer 2004; Meijer et al. 2015; Zhou et al. 2018). The barrier is therefore not disapproval: mean attitude is 3.519 and its coefficient 0.915, so growers accept the idea at the level of evaluation. What requires explanation is the contrast with a mean willingness of only 3.377 and 34.0% classified as willing.

Second, perceived behavioural control is significant and second only to attitude (0.806), which differs from farmer studies where capability judgements are delegated to external service organisations and hence do not load significantly (Li et al. 2022; Yang and Wang 2024; Liu and Wang 2025). The explanation lies in the skill structure of this technology. In the sample 60.3% of growers have previously raised chickens and 28.0% keep them in their orchards, so the poultry component is familiar; although only 6.3% have grown mushrooms, mature technical support for cultivars such as *Stropharia rugosoannulata* already exists locally. What binds is therefore capital and labour rather than skill, which is why PBC1 (labour) averages only 2.72 and PBC4 (capital) is the low-quality item. Perceived behavioural control remains significant because it also captures skill confidence and access to help (PBC2, PBC3), on which respondents score relatively highly.

Subjective norms (0.531) have a specific structure of their own. Among its three items, SN2 ("I would feel more reassured if the extension agent or cooperative technician recommended it") has the highest mean (3.77), clearly above SN1 (village exemplars, 3.48) and SN3 (family opinion, 3.39). Institutionalised extension channels are thus more persuasive than personal networks in the Tai'an cherry district (Li et al. 2022; Yang and Wang 2024), with direct implications for extension design.

5.2 The role of risk and labour

Neither is the primary constraint. Perceived risk is significant (-0.410, $p = 0.001$) but the smallest of the five significant predictors, and labour constraints are simply insignificant in the full sample (-0.200, $p = 0.109$). Attitude and perceived behavioural control drive willingness.

Perceived risk is real but non-dominant. Its mean is high at 3.528 and its reliability the highest of the seven constructs ($\alpha = 0.870$), so growers genuinely worry. Among the four risk items, PR1 ("I worry the mushrooms cannot be sold", 3.64) and PR3 ("I worry the method is too troublesome to manage", 3.53) score highest, PR2 ("I worry the chickens will damage the cherries", 3.43) lowest. What growers fear most is not damage to their cherries but that output cannot be sold and the process cannot be managed (Fahad and Wang 2018; Zhang 2018). The rotation already resolves the fruit–poultry conflict technically, but market and management concerns remain, which points to an extension strategy combining guaranteed purchase or contract farming with a simplified workflow, rather than price assurances alone.

Labour constraints are conditional. Section 4.6 shows the variable insignificant in the full sample ($p = 0.109$) and the protected subsample (+0.173, $p = 0.422$), but significantly negative under the binary specification ($p = 0.047$), in the under-60 subsample ($p = 0.025$), in the open-field subsample ($p = 0.010$) and after excluding low-discrimination questionnaires ($p = 0.050$). With 59.7% of growers aged 50 or above, mean labour constraints of 3.430 and item LC2 ("I am getting older and find heavy work tiring") averaging 3.65 (Zou et al. 2018; Shang et al. 2026), labour constraints are real but operate through age and cultivation type rather than through overall willingness.

Open-field orchards lack the capital-intensive substitutes available under protected cultivation, so twice-yearly fence relocation and bed preparation must rely on manual labour, making labour a hard constraint. In protected orchards, where management is already labour-intensive and operators are younger (mean perceived behavioural control 2.907 and mean willingness 3.232, $N = 99$, both below 3.046 and 3.449 in the open-field subsample, $N = 201$), the labour factor is masked. Labour should therefore be addressed in a targeted way for open-field orchards rather than treated as a universal barrier.

5.3 The moderation result

H7 is not supported, and the evidence is consistent: the interaction coefficient is -0.006 ($p = 0.969$), simple slopes at ±1 SD almost coincide (-0.195 / -0.200 / -0.204), deleting the low-quality item leaves the interaction at +0.005 ($p = 0.970$), and the pseudo-R^2 does not improve.

This should not be read as "perceived behavioural control does not matter": it is one of the strongest predictors (0.806). A more reasonable explanation has three layers, and together they point to a methodological conclusion.

First, the moderator is construct-mismatched to the predictor. Only one of the four perceived-behavioural-control items (PBC1) concerns labour; the other three measure skill confidence, access to help and capital availability, so the construct as a whole does not operationalise the *capacity to mobilise labour* that H7 names. The two constructs are also nearly orthogonal ($r = -0.074$, $p = 0.198$), so nothing in the measurement system links the supposed buffer to the constraint it is meant to buffer.

Second, attenuation from measurement error. Labour constraints comprise only two items ($\alpha = 0.606$) and perceived behavioural control four, one of them of low quality ($\alpha = 0.675$), so both are measured with limited precision. An interaction is the product of two

error-laden variables (Fornell and Larcker 1981), and measurement error is amplified in the product, so the interaction is attenuated far more severely than the main effects.

Third, insufficient statistical power. A simulation based on the observed item-level distributions and the reliabilities in Table 2 shows that with 300 observations an interaction would need a true magnitude of about 0.50 to be detected at the 5% level; purifying perceived behavioural control to three items and expanding labour constraints to four would lower the threshold to about 0.36, and doubling the sample to 600 to about 0.25. Against typical moderation effect sizes of around 0.20, the present non-significance is better read as "not detected" than "non-existent".

The practical implication is clear: training programmes or model-farmer demonstration cannot be expected to raise self-efficacy and thereby relieve labour constraints as a side effect. Where labour binds, it can only be addressed through external substitution such as socialised services and organised seasonal labour, which corroborates Section 5.2.

5.4 Policy and extension implications

Sections 4.4–4.6 imply that extension resources should be allocated in the order cognition first, capability second, with risk and labour addressed in a targeted way.

(1) Agricultural extension agencies: the core task is to improve the comprehensibility and credibility of the practice. The coefficients on attitude and subjective norms (0.915 and 0.531) show that the cognition and evaluation channel carries the greatest weight, and among subjective-norm items technician recommendation is the most persuasive (SN2, mean 3.77). Classroom briefings should therefore give way to on-site demonstration. Mean willingness is lowest among growers who had never heard of the practice (3.108, n = 83) and higher among all groups with prior exposure, at 3.522 (n = 136), 3.380 (n = 69) and 3.583 (n = 12) for those who had heard of it, seen it and tried it respectively. The association is positive but not monotonic in depth of exposure, since passive observation scores below a verbal account, so demonstration should be participatory rather than observational (Meijer et al. 2015; Li et al. 2022). Fence relocation between plots should be shown visually, being the step growers find hardest to imagine and the one most consequential for labour input.

(2) Cooperatives: assume both a marketing and a labour-organisation function. To address PR1 ("I worry the mushrooms cannot be sold", mean 3.64, the highest risk item), cooperatives should provide centralised purchase or guaranteed prices that transfer price

risk from the grower to the organisation (Liu and Wang 2025). To address labour constraints, they should organise the concentrated tasks, twice-yearly fence relocation and bed preparation, into a single work team, substituting external services for household labour (Shang et al. 2026; Li et al. 2025; Zhang et al. 2026a). This is the direct solution for open-field orchards, and on the evidence of Section 5.3 the only feasible one.

(3) Lead firms and technical service providers: supply inputs and technical support, and design recoverable input schemes. The capital dimension of perceived behavioural control (PBC4) is a low-quality item, indicating that capital availability is a relatively distinct concern. If the upfront costs of spawn, fencing and chicks could be arranged through leasing, instalments or payment out of output, growers' assessment of affordability would improve directly (Yang and Wang 2024). Since the partition fence is removable and the investment recoverable, this should be communicated explicitly: it downgrades the decision from an irreversible modification to a revocable trial, lowering the psychological threshold.

(4) Government: prioritise pilots in open-field cherry districts, since Section 4.6 shows labour constraints significant in the open-field subsample (-0.405, $p = 0.010$) but not in the protected one. Subsidies should focus on upfront fixed investment such as the removable fence rather than output-side price support (Yang and Wang 2024; Xue et al. 2018), because growers' core concerns relate to whether the practice is worth doing and whether they can do it, and reducing upfront outlay improves both judgements at once.

5.5 Transferability and boundary conditions

The evidence comes from a single municipality in northern China. Before setting out the components that should transfer, the conditions under which the pattern should hold, and those under which it should not, need to be stated.

Three components should transfer to other deciduous orchard systems in which the same phenological constraint binds. First, the ordering of the drivers, evaluative and efficacy-related factors above financial ones, is consistent with TPB applications to other orchard and agroforestry technologies (Wauters et al. 2010; Van Dijk et al. 2016; Liu et al. 2018), and there is no reason to expect it to reverse in a temperate cherry, apple or pear orchard of comparable structure. Second, the sign of the perceived-risk coefficient should be stable: revenue risk is salient wherever output markets for the second enterprise are thin or volatile, and open-field Tai'an, where the 2026 price collapse made that risk visible, is at the high-risk end of the spectrum rather than an outlier. Third, the conditional nature of

the labour effect follows structurally from a technology that is labour-intensive at fixed moments rather than annually, and should reproduce wherever those moments coincide with other calendar-fixed operations (Fanchone et al. 2022; Pierotti et al. 2022).

Two components are likely to vary and need separate evidence. The first is the magnitude of the perceived-behavioural-control coefficient. PBC here includes a low-quality capital item that absorbs much of the variance, a profile specific to a setting in which upfront outlay is the most binding capital question; where capital is freely available through cooperatives or extension credit, the relative contribution of PBC should shrink (Gallardo and Sauer 2018). The second is the magnitude of the labour effect. In China household labour binds because the changeover moments fall inside the working day; where a service economy supplies hired workers at peak moments the constraint becomes financial rather than physical, with different policy implications (White et al. 2005). Both are also implicated by household composition and by the gendered distribution of farm labour (Pierotti et al. 2022), which a single-region survey cannot resolve.

Three Chinese-specific features should not be assumed elsewhere. First, smallholders fragmented across plots of less than one hectare make any labour-absorbing technology sensitive to household demographics; where orchards are owned or operated by corporations, labour constraints appear as a wage bill rather than a household availability constraint (Ajayi et al. 2009). Second, the regulatory environment for mushroom production and sale is comparatively permissive at village level (Li et al. 2025), which lowers PR1; a stricter setting would raise its cost and depress willingness even with identical coefficients. Third, the cooperative structure invoked in Section 5.4 presupposes a density of cooperatives that varies sharply across and within countries, and the implication holds more weakly where cooperatives are absent or commercialised.

The setting therefore has external validity where the technology's phenological constraint binds, the grower faces the same evaluative and efficacy questions, and revenue risk is visible; it requires separate evidence where capital is freely available, hired labour exists, regulatory frictions are tighter or cooperative organisation is absent. These boundaries are testable by repeating the survey in contrasting settings, for example an open-field cherry or apple region of southern Europe with developed cooperatives and accessible hired labour (Paut et al. 2021), and comparing coefficient magnitudes rather than signs.

5.6 Limitations and future research

First, the study measures stated willingness rather than observed behaviour, and intention–behaviour gaps are well documented (Wan et al. 2017). Second, the sample is confined to one municipality, which limits external validity, although Tai'an is representative of traditional open-field production in northern China. Third, cross-sectional data cannot establish causality, and reverse or joint determination between attitude and willingness cannot be ruled out. Fourth, the technology is at the pilot stage, so growers' judgements rest on description rather than experience, which may depress perceived behavioural control and expected benefit, precisely the two constructs with the lowest means (3.000 and 3.187).

Fifth, measurement precision. Labour constraints and expected benefit each comprise only two items (α = 0.606 and 0.650), and perceived behavioural control contains a low-quality item (PBC4, CITC = 0.252). Short scales and low reliability cause severe coefficient attenuation in interaction tests (Cronbach 1951), one important reason H7 was not detected (Section 5.3).

Sixth, the labour-constraint effect is inconsistent across subsamples, and the cross-sectional data cannot distinguish genuine group heterogeneity from differences in statistical power across subsamples.

Future research should proceed in three directions: track actual adoption among pilot participants, treating intention–behaviour conversion as the object of explanation; improve measurement by expanding labour constraints and expected benefit to four items each and deleting or rewording PBC4, and raise the sample to 600 or more for adequate power to test moderation; and extend the design to other fruit species and production regions.

6. Conclusion

Sweet cherry growers in the traditional open-field districts of northern China work a fixed and fully planted land base at roughly half the yield of protected systems, so additional income has to come from the same ground. Ranging poultry and cultivated edible fungi are both established understorey enterprises, but they compete for that ground, and the arrangements available to growers resolve the competition in space: a permanent boundary, or a whole-orchard rotation that idles half the area each year. The phase-shifted compartmental rotation examined here resolves it in time instead. Two plots of equal productive capacity exchange mushroom beds and poultry on a half-year cycle; a whole-orchard exclusion window keeps birds out while fruit is at risk; a removable,

excavation-free fence carries the boundary. Nothing in the orchard is permanently modified, so the decision is reversible, and reversibility is what separates this technology from those on which the agroforestry adoption literature rests. Ordered logit models on 300 face-to-face interviews in Tai'an show how that decision is made.

Evaluative and efficacy judgements dominate it. Attitude carries the largest coefficient (0.915) and perceived behavioural control the second largest (0.806), ahead of subjective norms (0.531) and expected benefit (0.412); perceived risk is significant and negative (-0.410) but the weakest of the five. Labour constraints are insignificant in the full sample (-0.200, $p = 0.109$) and become significant only under the binary specification, among growers under 60 and in open-field orchards, so they operate through age structure and cultivation type rather than as a general barrier. Willingness is moderate (3.377), 34.0% of growers are classified as willing, and perceived behavioural control has the lowest mean of the seven constructs (3.000). The constraint on diffusion is therefore not rejection of the practice but the distance between judging it worthwhile and judging oneself able to carry it out.

Three contributions follow. Empirically, this is, to our knowledge, the first quantitative evidence on willingness to adopt a temporal rather than a spatial form of orchard integration. Theoretically, reversibility changes what the adoption decision is about: a fence that can be moved turns a capital commitment into a trial, which is why self-assessed capability rather than expected return is the second strongest predictor, and why the barriers usually placed first in agroforestry adoption, insecure tenure and irreversibility, are designed out rather than overcome. Methodologically, the failure of H7 is informative in its own right. Perceived behavioural control as conventionally operationalised measures skill confidence, access to help and capital, of which only one item concerns labour; the two constructs are near-orthogonal ($r = -0.074$), the interaction is attenuated by two-item measurement, and a sample of 300 has little power against an interaction of the size moderation effects usually take. Perceived behavioural control is therefore not a generic buffer against labour constraints, and raising self-efficacy should not be expected to substitute for the organised supply of seasonal labour.

In practical terms, extension effort should begin with demonstration rather than with price assurance, because the step growers find hardest to picture is the twice-yearly relocation of the fence, and a technician's recommendation is more persuasive than village exemplars or family opinion. Where labour binds, in open-field orchards and not by age group, since the constraint survives removal of the oldest cohort, cooperative work teams

that take over bed preparation and fence relocation are the direct answer. The pattern should transfer to deciduous orchards elsewhere in which the same phenological window excludes birds during fruit development, and should not be expected to transfer where hired labour is available at peak moments, where capital is supplied through cooperatives or credit, or where the second enterprise faces a regulated market. Repeating the survey in such a setting and comparing coefficient magnitudes rather than signs would test those boundaries, and a positive interaction between perceived behavioural control and labour constraints there would count against the diagnosis offered in Section 5.3.

Supplementary Information

Online Resource 1 contains the wording of all 22 scale items (Table A1), the demographic and socio-economic characteristics of the sample (Table B1), and the orchard profile, marketing channels and prior experience of respondents (Tables B2–B4).

Statements and Declarations

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Competing interests

The authors have no financial or non-financial interests to disclose in relation to this work, with one exception. The authors are the named inventors on a pending Chinese utility model patent application covering the removable partition fence described in Section 1, filed on 15 September 2026. The application protects a hardware component of the system whose adoption willingness is analysed here; it had no influence on the design, analysis or interpretation of the study, and no commercial partner or licensee is involved.

Ethics approval

The study was approved by the institutional review process of Shandong Agricultural University for household survey research before fieldwork began, and was conducted in accordance with the ethical principles of the Declaration of Helsinki.

Consent to participate

All respondents took part voluntarily and gave verbal informed consent after the purpose of the study and the intended use of the data had been explained to them. No personally identifying information was recorded in the analytical dataset.

Data availability

The datasets generated and analysed during this study are available from the corresponding author on reasonable request.

Author contributions

Song Chenghao and Liang Mengru conceived and designed the study. Song Chenghao collected the field data and performed the statistical analysis. Liang Mengru drafted the manuscript. Both authors reviewed and approved the final version.

References

Abadi Ghadim AK, Pannell DJ, Burton MP (2005) Risk, uncertainty, and learning in adoption of a crop innovation. Agric Econ 33:1–9. https://doi.org/10.1111/j.1574-0862.2005.00433.x

Aguirre-Urreta MI, Hu J (2019) Detecting common method bias: performance of the Harman's single-factor test. SIGMIS Database 50:45–70. https://doi.org/10.1145/3330472.3330477

Ajayi OC, Akinnifesi FK, Sileshi GW et al (2009) Labour inputs and financial profitability of conventional and agroforestry-based soil fertility management practices in Zambia. Agrekon 48:276–292. https://doi.org/10.1080/03031853.2009.9523827

Ajzen I (1991) The theory of planned behavior. Organ Behav Hum Decis Process 50:179–211. https://doi.org/10.1016/0749-5978(91)90020-T

Ajzen I (2002) Perceived behavioral control, self-efficacy, locus of control, and the theory of planned behavior. J Appl Soc Psychol 32:665–683. https://doi.org/10.1111/j.1559-1816.2002.tb00236.x

Armitage CJ, Conner M (2001) Efficacy of the theory of planned behaviour: a meta-analytic review. Br J Soc Psychol 40:471–499. https://doi.org/10.1348/014466601164939

Baker TP, England JR, Brooks ST et al (2025) Effect of silvopasture, paddock trees and linear agroforestry systems on agricultural productivity: a global quantitative review. Agric Syst 224:104240. https://doi.org/10.1016/j.agsy.2024.104240

Baumgart-Getz A, Prokopy LS, Floress K (2012) Why farmers adopt best management practice in the United States: a meta-analysis of the adoption literature. J Environ Manage 96:17–25. https://doi.org/10.1016/j.jenvman.2011.10.006

Chen H, Duan XW, Li HB et al (2024) Global and domestic cherry production status and trends of cherry industry development in Beijing, China. Acta Hortic 1408:53–56. https://doi.org/10.17660/ActaHortic.2024.1408.7

Cronbach LJ (1951) Coefficient alpha and the internal structure of tests. Psychometrika 16:297–334. https://doi.org/10.1007/BF02310555

Dessart FJ, Barreiro-Hurlé J, Van Bavel R (2019) Behavioural factors affecting the adoption of sustainable farming practices: a policy-oriented review. Eur Rev Agric Econ 46:417–471. https://doi.org/10.1093/erae/jbz019

Dong P, Li BJ (2025) Determinants of new-technology adoption willingness among sweet cherry growers in Yantai, Shandong: evidence from a survey of 211 growers [in Chinese]. China Fruits 2025(9):130–135+143. https://doi.org/10.16626/j.cnki.issn1000-8047.2025.09.023

Fahad S, Wang J (2018) Farmers' risk perception, vulnerability, and adaptation to climate change in rural Pakistan. Land Use Policy 79:301–309. https://doi.org/10.1016/j.landusepol.2018.08.018

Fanchone A, Alexandre G, Hostiou N (2022) Work organization as a barrier to crop-livestock integration practices: a case study in Guadeloupe. Agron Sustain Dev 42:54. https://doi.org/10.1007/s13593-022-00782-8

Fornell C, Larcker DF (1981) Evaluating structural equation models with unobservable variables and measurement error. J Mark Res 18:39–50. https://doi.org/10.1177/002224378101800104

Gallardo RK, Sauer J (2018) Adoption of labor-saving technologies in agriculture. Annu Rev Resour Econ 10:185–206. https://doi.org/10.1146/annurev-resource-100517-023018

Garrett HE, Kerley MS, Ladyman KP et al (2004) Hardwood silvopasture management in North America. Agrofor Syst 61–62:21–33. https://doi.org/10.1023/b:agfo.0000028987.09206.6b

Hawke M (1991) Pasture production and animal performance under pine agroforestry in New Zealand. For Ecol Manage 45:109–118. https://doi.org/10.1016/0378-1127(91)90210-m

729 Hong Q, Zhao Y, Chen MJ et al (2022) Effects of in situ *Stropharia rugosoannulata*
730 cultivation residue return on soil organic matter, enzyme activity and bacterial diversity
731 [in Chinese]. Acta Edulis Fung 29:27–35. https://doi.org/10.16488/j.cnki.1005-
732 9873.2022.01.004
733 Huang YH, Liu S, Tian C et al (2014) Study on the development of under-forestry
734 economy in mountain areas of Beijing [in Chinese]. Chin Agric Sci Bull 30:83–89.
735 https://doi.org/10.11924/j.issn.1000-6850.2013-1622
736 Kaiser HF (1974) An index of factorial simplicity. Psychometrika 39:31–36.
737 https://doi.org/10.1007/BF02291575
738 Li B, Zhuo N, Ji C et al (2022) Influence of smartphone-based digital extension
739 service on farmers' sustainable agricultural technology adoption in China. Int J Environ
740 Res Public Health 19:9639. https://doi.org/10.3390/ijerph19159639
741 Li TT, Chen JY, Liu HG (2026) Effects of agricultural labour force ageing on
742 farmers' crop diversification behaviour: a survey of main vegetable production areas in the
743 Beijing-Tianjin-Hebei region [in Chinese]. Chin J Agric Resour Reg Plan 47:103–115.
744 https://doi.org/10.7621/cjarrp.1005-9121.20260308
745 Li YH, Wang XY, Miao XK et al (2025) Effects of agricultural socialised services on
746 mushroom growers' adoption of new varieties [in Chinese]. North Hortic 2025(24):139–
747 148. https://doi.org/10.11937/bfyy.20250957
748 Liu B, Wang Y (2025) A study on the impact of farmers' adoption of productive
749 services: based on a survey of wheat growers in Shandong Province [in Chinese]. Chin
750 Agric Sci Bull 41:152–164. https://doi.org/10.11924/j.issn.1000-6850.casb2025-0337
751 Liu QZ, Qiao Q, Zhu DZ et al (2024) Sweet cherry industry in Shandong Province,
752 China. Acta Hortic 1408:37–44. https://doi.org/10.17660/ActaHortic.2024.1408.5
753 Liu RY, Wang YF, Tang B et al (2025) Survey and analysis of the under-forest
754 chicken industry in Hunan Province [in Chinese]. China Poultry 47:97–104.
755 https://doi.org/10.16372/j.issn.1004-6364.2025.08.013
756 Liu T, Bruins RJF, Heberling MT (2018) Factors influencing farmers' adoption of
757 best management practices: a review and synthesis. Sustainability 10:432.
758 https://doi.org/10.3390/su10020432
759 Ma X, Han F, Yang G et al (2025) Enhanced soil ecosystem multifunctionality and
760 microbial community shifts following spent mushroom substrate application. Appl Soil
761 Ecol 213:106230. https://doi.org/10.1016/j.apsoil.2025.106230

762 Marra M, Pannell DJ, Abadi Ghadim A (2003) The economics of risk, uncertainty
763 and learning in the adoption of new agricultural technologies: where are we on the
764 learning curve? Agric Syst 75:215–234. https://doi.org/10.1016/S0308-521X(02)00066-5
765 Meijer SS, Catacutan D, Ajayi OC et al (2015) The role of knowledge, attitudes and
766 perceptions in the uptake of agricultural and agroforestry innovations among smallholder
767 farmers in sub-Saharan Africa. Int J Agric Sustain 13:40–54.
768 https://doi.org/10.1080/14735903.2014.912493
769 Mercer DE (2004) Adoption of agroforestry innovations in the tropics: a review.
770 Agrofor Syst 61–62:311–328. https://doi.org/10.1023/B:AGFO.0000029007.85754.70
771 Orefice JN, Carroll JM, Conroy D et al (2017) Silvopasture practices and
772 perspectives in the Northeastern United States. Agrofor Syst 91:149–160.
773 https://doi.org/10.1007/s10457-016-9916-0
774 Pattanayak SK, Mercer DE, Sills E et al (2003) Taking stock of agroforestry adoption
775 studies. Agrofor Syst 57:173–186. https://doi.org/10.1023/A:1024809108210
776 Paut R, Dufils A, Derbez F et al (2021) Orchard grazing in France: multiple forms of
777 fruit tree–livestock integration in line with farmers' objectives and constraints. Forests
778 12:1339. https://doi.org/10.3390/f12101339
779 Peri PL, Bahamonde HA, Lencinas MV et al (2016) A review of silvopastoral
780 systems in native forests of Nothofagus antarctica in southern Patagonia, Argentina.
781 Agrofor Syst 90:933–960. https://doi.org/10.1007/s10457-016-9890-6
782 Pierotti RS, Friedson-Ridenour S, Olayiwola O (2022) Women farm what they can
783 manage: how time constraints affect the quantity and quality of labor for married women's
784 agricultural production in southwestern Nigeria. World Dev 152:105800.
785 https://doi.org/10.1016/j.worlddev.2021.105800
786 Podsakoff PM, MacKenzie SB, Lee JY et al (2003) Common method biases in
787 behavioral research: a critical review of the literature and recommended remedies. J Appl
788 Psychol 88:879–903. https://doi.org/10.1037/0021-9010.88.5.879
789 Prokopy LS, Floress K, Klotthor-Weinkauf D et al (2008) Determinants of
790 agricultural best management practice adoption: evidence from the literature. J Soil Water
791 Conserv 63:300–311. https://doi.org/10.2489/jswc.63.5.300
792 Shang GY, Chen LT, Yang X et al (2026) Effects of labour transfer on farmers'
793 continued adoption of conservation tillage technology: the moderating role of agricultural

794 socialised services [in Chinese]. Resour Sci 48:1193–1207.
795 https://doi.org/10.18402/resci.2026.05.11
796 Van Dijk WFA, Lokhorst AM, Berendse F et al (2016) Factors underlying farmers'
797 intentions to perform unsubsidised agri-environmental measures. Land Use Policy
798 59:207–216. https://doi.org/10.1016/j.landusepol.2016.09.003
799 Wan YS, Cheng JM, Wu JX et al (2017) Divergence between farmers' intention and
800 behaviour in rural homestead exit: an analysis based on the theory of planned behaviour
801 [in Chinese]. Resour Sci 39:1281–1290. https://doi.org/10.18402/resci.2017.07.06
802 Wauters E, Bielders C, Poesen J et al (2010) Adoption of soil conservation practices
803 in Belgium: an examination of the theory of planned behaviour in the agri-environmental
804 domain. Land Use Policy 27:86–94. https://doi.org/10.1016/j.landusepol.2009.02.009
805 White DS, Labarta R, Leguía EJ (2005) Technology adoption by resource-poor
806 farmers: considering the implications of peak-season labor costs. Agric Syst 85:183–201.
807 https://doi.org/10.1016/j.agsy.2004.07.018
808 Xue CX, Huang YX, Han WT (2018) Effects of government subsidies and adoption
809 outcomes on farmers' continued adoption of water-saving irrigation technology [in
810 Chinese]. Resour Sci 40:1418–1428. https://doi.org/10.18402/resci.2018.07.10
811 Yang Y, Wang Y (2024) The impact of government subsidies and quality
812 certification on farmers' adoption of green pest control technology. Agriculture 15:35.
813 https://doi.org/10.3390/agriculture15010035
814 Zhang C, Liu H, Xi DJ et al (2021) Comparative study on flower-bud contents and
815 flower-bud quality of sweet cherry at different developmental stages in Hangzhou and
816 Tai'an [in Chinese]. J Fruit Sci 38:1308–1318.
817 https://doi.org/10.13925/j.cnki.gsxb.20210106
818 Zhang L, Zhang ZX, Mu YY (2026a) Synergistic mechanisms of technical training
819 and social interaction: evidence from 1,040 farm households [in Chinese]. J Agrotech
820 Econ 2026(6):3–20. https://doi.org/10.13246/j.cnki.jae.2026.06.003
821 Zhang QJ, Zhao Y, Yu KH et al (2016) A model system for off-season sweet cherry
822 production in northern China. Acta Hortic 1130:179–184.
823 https://doi.org/10.17660/ActaHortic.2016.1130.26
824 Zhang S, Li H, Li K et al (2026b) Effects of *Stropharia rugosoannulata*–tomato
825 rotation coupled with spent mushroom substrate incorporation on soil properties.
826 Agronomy 16:1767. https://doi.org/10.3390/agronomy16181767

Zhang ZH (2018) Determinants of farmers' risk perception in the new round of the Grain for Green Programme: survey evidence from Aksu, Xinjiang [in Chinese]. Resour Sci 40:1387–1396. https://doi.org/10.18402/resci.2018.07.07

Zhou JP, Luo YL, Wei JJ et al (2026) A meta-analysis of the effects of spent mushroom substrate application on crop yield [in Chinese]. Soil Fert Sci China 2026(1):244–253. https://doi.org/10.11838/sfsc.1673-6257.25094

Zhou YX, Zhou JZ, Dai YC (2018) Influencing factors of farmers' behaviour of agroforestry based on a Probit-ISM model [in Chinese]. Chin Agric Sci Bull 34:153–159. https://doi.org/10.11924/j.issn.1000-6850.casb18040031

Zhu YF (2012) Study on economic efficiency of forest-chicken compound management patterns in the lower Yellow River [in Chinese]. Chin Agric Sci Bull 28:70–73. https://doi.org/10.11924/j.issn.1000-6850.2011-3219

Zou B, Mishra AK, Luo B (2018) Aging population, farm succession, and farmland usage: evidence from rural China. Land Use Policy 77:437–445. https://doi.org/10.1016/j.landusepol.2018.06.001

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