ENGINEERING Agriculture

Engineering Journals

RESEARCH ARTICLE

2026 / Volume 13 / Issue 6 / 26699

Can intercropping increase farmers' income? Evidence from maize-soybean strip intercropping in China

Yuying YANG[1], Kaixuan MA[1], Yan YANG[2], Wei SI (✉)[3]

1 School of Economics and Management, Ningxia University, Yinchuan 750021, China.
2 School of Agriculture, Ningxia University, Yinchuan 750021, China.
3 College of Economics and Management, China Agricultural University, Beijing 100083, China.

KEYWORDS

Diversified agriculture, farmers' income, maize-soybean strip intercropping, income structure, subsidy

HIGHLIGHTS

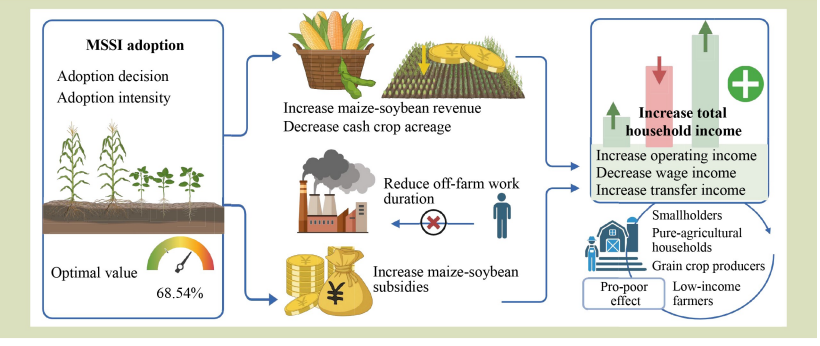
- Intercropping adoption increases total household income by boosting operating and transfer income, despite lowering wage income.
- Policy subsidies are indispensable, as intercropping no longer raises income when transfer income is excluded.
- Intercropping adoption intensity follows an inverted-U relationship with income, with an optimal ratio of 68.54%.
- Intercropping adoption influences household income through yield, factor reallocation, and subsidy effects.
- Intercropping adoption significantly raises incomes of smallholders, full-time and non-cash-crop households, with a clear pro-poor effect.

Received January 31, 2026;
Accepted June 24, 2026.

Correspondence: siwei@cau.edu.cn

Special Issue: Building Resilient Agrifood Systems

GRAPHICAL ABSTRACT



ABSTRACT

Intercropping is widely considered an effective strategy for increasing yields and economic returns per unit of land. However, its effect on household income remains insufficiently understood. From an income structure perspective, this study uses survey data from 1034 households in China's primary maize-soybean producing areas and conceptualizes maize-soybean strip intercropping (MSSI) adoption in terms of adoption decision and adoption intensity to examine its impact on household income. The results indicate that although MSSI adoption reduces wage income, it increases agricultural operating income and transfer income, leading to a significant increase in total household income. Notably, this effect becomes insignificant when transfer income is excluded, highlighting the role of policy support. An inverted U-shaped relationship exists between adoption intensity and household income, with an optimal adoption ratio of 68.54%. Mechanism analysis shows that MSSI adoption influences income through the yield effect, factor allocation effect, and subsidy effect. Heterogeneity analysis demonstrates that income benefits vary by opportunity cost and income level. Specifically, MSSI adoption yields significant income-increasing effects for smallholders, full-time farmers and non-cash-crop farmers, exhibiting a distinct pro-poor effect. Therefore, to ensure income growth of MSSI adopters, the study suggests optimizing

subsidies for MSSI, expanding local income opportunities, and improving intercropping practices.

© The Author(s) 2026. Published by Higher Education Press. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0)

1 Introduction

Against the backdrop of intensifying global resource constraints and food security pressures, achieving synergy between yield enhancement and income growth through technological innovation has become a strategic priority worldwide[1]. Despite their robust performance under experimental conditions, the widespread adoption of many agricultural technologies at the farm level remains limited. This disconnect stems primarily from the tendency of extension programs to prioritize yields while underinvesting in farmers' economic returns and livelihood sustainability[2]. Considering that income growth is the fundamental driver for mobilizing farmers' commitment to grain production, a systematic evaluation of how technology adoption affects household income is imperative for optimizing extension policies and reinforcing income support mechanisms.

China balances intensive agricultural demands with green development objectives, making it an ideal context for examining these dynamics. A central element of this endeavor is the large-scale promotion of maize-soybean strip intercropping (MSSI) technology. Since 2022, China has vigorously implemented MSSI across the Northwest, Southwest, and Huang–Huai–Hai regions to balance maize and soybean output and ensure national food security[3]. Rooted in traditional interplanting principles, MSSI represents a modern adaptation designed for highly intensive spatiotemporal production[4]. By optimizing the utilization of light and thermal resources, the system achieves a Land Equivalent Ratio of 1.29, securing an additional soybean harvest without compromising maize yield[5]. Furthermore, through biological nitrogen fixation and optimized canopy configuration, the system reduces reliance on chemical inputs, thereby fostering vital synergy between food production and environmental conservation[6].

Despite strong policy promotion and a solid agronomic foundation, the large-scale expansion of MSSI still faces several challenges, including low adoption rates, inadequate compliance with technical standards, and low retention[7]. According to our survey data, by 2023, 47.87% of intercropping farmers planned to reduce their planting area, while the proportion willing to continue adoption had declined by 17.16%. These challenges largely stem from extension efforts that emphasize technology diffusion but insufficiently consider farmers' cost-benefit evaluations and their core concern of achieving sustainable income growth[8].

Previous studies have consistently shown that intercropping adoption can improve yields and economic returns per unit of land[9,10]. Nevertheless, the literature remains inconclusive regarding whether intercropping can effectively enhance farm household income. Some studies argue that intercropping increases farmers' income primarily by generating economies of scope[11,12]. By contrast, others contend that its additional labor requirements crowd out off-farm employment and may ultimately reduce total household income[13]. These discrepancies likely arise from three methodological limitations. First, studies rely on inconsistent metrics, focusing on plot-level yields rather than household income structure. Meanwhile, they mainly examine adoption decision, with limited attention to adoption intensity, making it difficult to identify the optimal adoption ratio for maximizing total household income. Second, farmer heterogeneity has received insufficient attention, thereby overlooking how effects vary across households with different resource endowments. Third, studies have relied on localized datasets that lack national representativeness. Compared with existing studies, this paper makes three contributions. First, from a household income structure perspective, it extends the framework beyond yield or single-dimensional returns to better identify the income effects of MSSI adoption by distinguishing between adoption decision and adoption intensity, and further determines the optimal adoption ratio for increasing total household income. Second, using multiple models, it examines heterogeneity across farmers with different opportunity costs and income levels, revealing the pro-poor effect of MSSI adoption. Third, based on large-scale micro-level data from major promotion regions, it improves the representativeness and reliability of the results.

This study provides evidence for improving MSSI promotion and farmer income policies, and offers implications for coordinating food security, income growth, and agricultural sustainability in populous countries.

2 Theoretical analysis and research hypotheses

Assuming that farmers are rational economic agents who maximize utility, household income Y comprises agricultural income Y_a, wage income Y_b, transfer income Y_c, and property income Y_d. Since MSSI adoption is not assumed to directly affect property income, Y_d is treated as a constant and credit constraints are not considered. The farm household model is specified as follows:

$$\begin{cases} \text{Max } U = u(c, L_i) \\ \text{s.t.} c \leqslant Y = Y_a + Y_b + Y_c + Y_d \\ T = L_a + L_b + L_l \\ Y_a = P_a Q(L_a, M, K_r, Z) - C(L_a, M, K_r, Z) \\ Y_b = wL_b \\ Y_c = y_{c1}(M, Z) + y_{c2} \end{cases} \tag{1}$$

where U represents the utility derived from market consumption c and leisure L_l. T denotes the total time endowment, which is allocated to agricultural production labor L_a, off-farm employment labor L_b, and leisure L_l, P_a, Q, and C are the price, output, and cost of maize-soybean, with output and cost being functions of technology adoption M, which includes both adoption decision and adoption intensity, labor L_a, capital K_r, and other characteristics Z. w is the exogenous wage rate. y_{c1} denotes the subsidy associated with the adoption level, and y_{c2} represents other transfer income. Accordingly, total household income can be expressed as follows:

$$Y = P_a Q(L_a, M, K_r, Z) - C(L_a, M, K_r, Z) + wL_b + y_{c1}(M, Z) + y_{c2} + Y_d \tag{2}$$

Taking the partial derivative of Eq. (2) with respect to MSSI adoption M, holding other inputs and characteristics constant, yields:

$$\frac{\partial Y}{\partial M} = P_a \frac{\partial Q}{\partial M} - \frac{\partial C}{\partial M} + w\frac{\partial L_b}{\partial M} + \frac{\partial y_{c1}}{\partial M} \tag{3}$$

Equation (3) shows that the effect of MSSI adoption on household income operates through different income components, including agricultural income $\left(P_a \frac{\partial Q}{\partial M} - \frac{\partial C}{\partial M}\right)$, wage income $\left(w\frac{\partial L_b}{\partial M}\right)$, and transfer income $\left(\frac{\partial y_{c1}}{\partial M}\right)$.

2.1 Impact analysis of MSSI adoption on farm household income

The above analysis indicates that MSSI adoption, reflected in both adoption decision and adoption intensity, primarily affects farm household income through three income channels.

First, under land endowment constraints, the yield and land resource allocation effects jointly shape agricultural operating income. Compared with maize or soybean monocultures, MSSI enhances land productivity, thereby incentivizing adopters to expand maize and soybean cultivation and boost their income from these staple crops[14,15]. However, given finite land constraints, this expansion requires reducing the area allocated to alternative cash crops. Cash crops typically generate higher returns; therefore, under comparable levels of adoption, the reduction in cash crop income may be greater than the increase in maize and soybean production[7]. These two effects may offset each other, implying that the overall impact of MSSI adoption on agricultural operating income may be limited or not statistically significant.

Second, under labor supply constraints, the labor resource reallocation effect influences farmers' wage income. Although MSSI negligibly increases the total effective labor input, the proliferation of production stages and intensified field management requirements increase fragmented time investments. This hinders farmers' decisions regarding long-distance labor migration and curtails short-distance off-farm working hours, thereby reducing wage income[16].

Third, the subsidy effect driven by policy incentives affects farmers' transfer income. Financial support for maize and soybean producers primarily includes planting subsidies, subsidies for purchasing or upgrading specialized machinery, agricultural insurance premium subsidy and related project subsidies. Specifically, MSSI support comprises a producer subsidy ranging from 2250 to 6225 yuan·ha^{-1} and a machinery subsidy covering over 30% of specialized equipment purchases or modification costs. In the surveyed regions, subsidies for intercropping are generally higher than those for monoculture or crop rotation. Consequently, MSSI adoption can significantly increase farming households' transfer income.

According to the theory of economies of scope, the increased plot-level profits from MSSI are derived from economies of scope. However, farm household income effect varies with adoption intensity. The income effect of agricultural green

technology adoption may vary with adoption intensity, and a higher degree of adoption can generate a more pronounced income-enhancing effect[17]. Nevertheless, adoption intensity is not necessarily better at higher levels. Exceeding a certain threshold significantly increases management complexity and costs. Furthermore, technical immaturity and excessive adoption can hinder risk-sharing, leading to suboptimal outcomes. Consequently, the impact of MSSI adoption intensity on household income may exhibit an inverted U-shaped relationship, with the income-enhancing effect weakening as adoption intensity continues to increase. Accordingly, the following hypotheses are proposed:

H1: MSSI adoption affects household income.

H2: MSSI adoption affects household income structure by increasing agricultural operating income, decreasing wage income, and increasing transfer income.

H3: MSSI adoption intensity has an inverted U-shaped relationship with household income, such that the income-enhancing effect weakens after adoption intensity exceeds a certain level.

H4: MSSI adoption affects household income through higher maize-soybean revenue, reduced cash crop acreage, decreased off-farm work duration, and increased maize-soybean subsidies.

2.2 Heterogeneity analysis of the income-enhancing effects of MSSI adoption across farm households

Farmers with different opportunity costs exhibit significant disparities in risk tolerance, factor inputs, and human capital investment. Since opportunity costs mainly reflect farmers' participation decisions regarding MSSI adoption, the heterogeneity analysis focuses on the adoption decision. Regarding household type, compared with new agricultural business entities, smallholders face tighter constraints in capital, land, and off-farm employment, leaving them with fewer high-return alternatives. Thus, the opportunity income forgone from adopting intercropping is lower, resulting in a smaller adoption opportunity cost[18]. Regarding part-time farming status, full-time farmers often allocate more time and production factors to MSSI, which helps increase soybean and maize income[19]. Since full-time farmers rely more on agricultural income, MSSI adoption may increase their total household income through higher intercropping efficiency[20]. In terms of crop types, for farmers who grow only grain crops, MSSI adoption decision increases maize-soybean and agricultural subsidy incomes, thereby promoting agricultural operating and transfer incomes[21]. Conversely, for farmers accustomed to cash crops, cash crop income decreases because of land allocation effects. However, considering the compensation from MSSI subsidies, the change in total income is negligible.

Household income level is a comprehensive reflection of human, social, and physical capital[22]. From both the adoption decision and adoption intensity perspectives, household income level may affect the income-enhancing effects of MSSI adoption. Generally, low-income households tend to have limited human capital and lower levels of market participation, which restrict their access to employment opportunities. As a result, some households engage in farming primarily to satisfy their own consumption needs rather than to respond to market supply and demand[23]. Adopting MSSI can promote income growth by effectively increasing grain output and maize-soybean subsidies for low-income households. Furthermore, their weak economic foundation leads to the income-enhancing effect of MSSI, accounting for a relatively high proportion of their household income[24]. Therefore, low-income households benefit from the yield effects of MSSI more easily than high-income households do. Accordingly, the following hypothesis is proposed:

H5: The income-enhancing effect of MSSI adoption varies across farmers' opportunity costs, proxied by farm type, part-time farming status, and crop type, as well as income levels.

Figure 1 illustrates the impact mechanism through which MSSI adoption influences farmers' income.

3 Materials and methods

3.1 Data

Data were collected through field surveys conducted by the research team from November 2022 to February 2023 in villages promoting MSSI across China's three main soybean and maize production regions: the Southwest, Northwest, and Huang–Huai–Hai. Sichuan and Shaanxi were selected as representative provinces for the Southwest and Northwest,

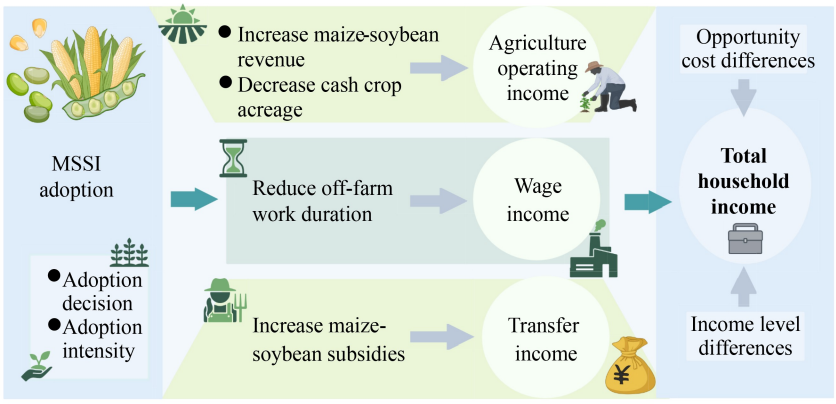


Fig. 1 Mechanism of the impact of MSSI adoption on farm household income.

respectively, because of their leading MSSI extension areas, whereas Shandong, Hebei, Henan, and Jiangsu were included to ensure adequate coverage of the Huang–Huai–Hai region.

A multistage stratified random sampling method was used. Six provinces were initially selected, followed by two to eight cities in each province, based on geographical location, natural conditions, and cropping traditions. Within each city, one to four townships and then one to two villages were chosen at random. Finally, 12–24 maize-soybean farming households were sampled from each village according to the local distribution of smallholders and large-scale producers.

The final sample comprises 1034 valid household observations from 71 villages, with an effective response rate of 99.33%. Data were collected through face–to–face interviews using household and village questionnaires. The household survey covered farmer characteristics, production and management, technology adoption, plot characteristics, and social capital, while the village survey collected information on local demographics, land conditions, extension services, public services, and environmental factors.

3.2 Model

3.2.1 Propensity score matching

Technology adoption is not random, as farmers' decisions to adopt MSSI may depend on their observable characteristics and resource endowments. Therefore, directly comparing outcomes between MSSI adopters and non-adopters may produce biased estimates because of self-selection. Following Rosenbaum and Rubin[25], we employ propensity score matching (PSM) to address this issue. Specifically, we use a logit model to estimate the propensity score, defined as the conditional probability that a farmer adopts MSSI, based on a set of observed covariates:

$$P(X_i) = Pr(M_i = 1|X_i) = \frac{\exp(\alpha X_i)}{1+\exp(\alpha X_i)} \quad (4)$$

where $M_i = 1$ denotes that the i-th household belongs to the treatment group (adopters), whereas $M_i = 0$ represents the control group (non-adopters). The vector X_i represents the covariates influencing adoption, and α is the vector of parameters to be estimated.

Based on estimated propensity scores, we match adopters and non-adopters within the common support region using four matching algorithms: nearest neighbor matching, radius matching, nearest neighbor caliper matching and kernel matching, then calculate the average treatment effect on the treated (ATT):

$$ATT = E[Y_{1i}|M_i = 1] - E[Y_{0i}|M_i = 1] \quad (5)$$

In this specification, $E[Y_{1i}|M_i = 1]$ is the average actual income of adopters, which can be directly obtained from survey data; $E[Y_{0i}|M_i = 1]$ is the unobservable counterfactual average income of adopters assuming they do not adopt MSSI. We approximate this counterfactual outcome using income data from non-adopter households matched by similar propensity scores. The difference between the two terms captures the net income effect of MSSI adoption on adopters.

3.2.2 Multiple linear regression

Although PSM identifies the binary impact of an adoption

decision, evaluating adoption intensity and its subsequent effect on income is equally important. Therefore, we use Multiple linear regression (MLR) to examine how the degree of technological integration influences economic outcomes. In accordance with H3, we test for this potential inverted U-shaped relationship and identify the optimal adoption level by incorporating a quadratic term for adoption intensity into the model:

$$Y_i = \alpha + \beta_1 X_i + \gamma_i Z_i + \varepsilon_i \quad (6)$$

$$Y_i = \alpha + \beta_1 X_i + \beta_2 X_i^2 + \gamma_i Z_i + \varepsilon_i \quad (7)$$

where Y_i denotes household income, X_i denotes MSSI adoption intensity, Z_i is a vector of control variables, α is the constant term, β_1 and β_2 are the coefficients of the linear and quadratic terms of adoption intensity, respectively, γ_i denotes the parameter to be estimated for each control variable, and ε_i is the error term.

Theoretical analysis suggests that farmers' MSSI adoption may affect household income through several mechanism variables (M_i), including maize-soybean revenue, cash crop planting area, maize and soybean planting subsidies, and time spent in off-farm employment. Therefore, holding other factors constant, the following model is specified to examine these mechanisms:

$$M_i = \alpha + \beta_1 X_i + \gamma_i Z_i + \varepsilon_i \quad (8)$$

3.2.3 Quantile regression

Recognizing that farmers with different baseline wealth levels vary in their factor endowments and risk tolerance, this study employs a quantile regression (QR) framework. Unlike ordinary least squares (OLS), which focuses on mean effects, the QR approach allows us to investigate the heterogeneous impact of technology adoption across income distributions, thereby capturing its nuanced distributional features. The model is specified as follows:

$$Q_q(Y_i|X_i, Z_i) = \alpha_q + \beta_q X_i + \gamma_q Z_i \quad (9)$$

where $Q_q(Y_i X_i, Z_i)$ denotes the conditional q-th quantile of household income given the explanatory variables, where $0 < q < 1$. The parameters α_q, β_q and γ_q are estimated at quantile q. Other variables are defined as above.

3.3 Variables

3.3.1 Dependent variables

Following Fluhrer & Kraehnert[26], the logarithms of farm household, agricultural operating, wage, and transfer income are selected as dependent variables. Household income is the difference between total income and expenditure, agricultural operating income is the difference between operational income and inputs, wage income is the net income from household members' off-farm employment, and transfer income is the total amount of subsidies, such as agricultural subsidies, insurance indemnities, and relief funds. Household net income, excluding transfer income, is also examined to verify the subsidy effect. The variables were log-transformed to reduce the influence of extreme values and mitigate right-skewness.

3.3.2 Core explanatory variables

The key explanatory variables are MSSI adoption decision and adoption intensity. Adoption decision is assigned a value of 1 if the household adopted MSSI in 2022 and 0 otherwise. To eliminate the impact of land endowment, adoption intensity is measured as the proportion of the MSSI area to the total operated area.

3.3.3 Control variables

Referring to Yang & Si[27] and Ma & Wang[28], the control variables are selected from four levels: Farmer, household, village, and area characteristics. Farmer characteristics include age, education, health status, and agricultural technical training. Household characteristics include land endowment, agricultural income share, organizational involvement, and disaster status. Village characteristics include planting subsidy, demonstration programs, and soybean market. MSSI depends heavily on regional conditions; therefore, this study also controls for the Southwest, Northwest, and Huang–Huai–Hai regions. All of the aforementioned control variables were included in the subsequent regression analyses.

3.3.4 Mechanism variables

Based on the theoretical analysis, maize-soybean revenue, cash crop area, off-farm work duration, and maize-soybean subsidies are selected to test the impact paths of MSSI adoption on household income. Maize-soybean revenue refers to income generated from maize and soybean cultivation, off-farm work duration is the number of days of off-farm work per agricultural laborer, and maize-soybean subsidies are government subsidies for maize and soybean production.

Table 1 presents the definitions and descriptive statistics of the

Table 1 Variable definitions and descriptive statistics

Variables		Variable definition and assignment	MSSI	Monoculture	Difference
Income variables	Household income	Total net household income (10,000 yuan, log-transformed)	1.317	1.124	0.193***
	Household income (without subsidies)	Net household income excluding transfer income (10,000 yuan, log-transformed)	1.125	1.113	0.012
	Agricultural operating income	Net agricultural operating income (10,000 yuan, log-transformed)	0.811	0.672	0.139**
	Wage income	Net household income from off-farm employment (10,000 yuan, log-transformed)	0.573	0.747	–0.174***
	Transfer income	All subsidies received (10,000 yuan, log-transformed)	0.472	0.204	0.268***
Explanatory variables	Adoption decision	Whether the farmer adopts MSSI (1 = Yes; 0 = No)	1.000	0.000	1.000***
	Adoption intensity	Ratio of MSSI area to total operated land area	0.597	0.000	0.597***
Farmer characteristics	Age	Actual age of the decision-maker (year)	56.897	57.222	–0.325
	Education	Years of formal education (year)	7.263	6.933	0.330
	Technical training	Whether the farmer received MSSI technical training (1 = Yes; 0 = No)	0.440	0.231	0.209***
Household characteristics	Land endowment	Ratio of operated area to agricultural labor count (hectare per person)	0.515	0.422	0.093***
	Agricultural income share	Ratio of agricultural income to total household income	0.436	0.456	–0.020
	Organizational involvement	Whether the farmer is a cooperative member (1 = Yes; 0 = No)	0.212	0.108	0.104***
	Disaster status	Whether the soybean/maize plots suffered natural disasters (1 = Yes; 0 = No)	0.543	0.456	0.087***
Village characteristics	Planting subsidy	MSSI planting subsidy amount (10,000 yuan per hectare)	0.229	0.182	0.047***
	Demonstration programs	Presence of MSSI demonstration bases in the village (1 = Yes; 0 = No)	0.613	0.320	0.293***
	Soybean market	Whether there are soybean purchasing entities in this village (1 = Yes; 0 = No)	0.692	0.540	0.152
Area characteristics	Southwest China	Whether it is in Sichuan Province (1 = Yes; 0 = No)	0.303	0.391	-0.088***
	Northwest China	Whether it is in Shaanxi Province (1 = Yes; 0 = No)	0.503	0.156	0.347***
	Huang–Huai–Hai region	Whether it is in Shandong, Hebei, Henan, or Jiangsu Province (1 = Yes; 0 = No)	0.194	0.454	–0.260***
Mechanism variables	Maize-soybean revenue	Total production revenue from soybean and maize (10,000 yuan, log-transformed)	0.792	0.676	0.116***
	Cash crop area	Household cash crop planting area (hectare)	0.253	0.222	0.031
	Off-farm work duration	Number of days of household off-farm employment (day)	29.767	37.458	–7.691*
	Maize-soybean subsidies	Subsidies for maize and soybean (10,000 yuan, log-transformed)	0.377	0.182	0.195***

Note: ***, ** and * denote that the mean differences are statistically significant at the 1%, 5% and 10% levels, respectively. In the survey sample, 9.19% of the new agricultural business entities reported unusually high agricultural operating income and subsidy income, and although the standard deviation was less than one-third of the mean after log transformation, these observations still substantially raised the overall mean level. Variables are log-transformed with one added to address zero-value issues. All control variables listed in the table, covering farmer, household, village, and area characteristics, were included in the subsequent regression analyses.

main variables. The results indicate that, compared to monoculture farmers, MSSI adopters exhibit significantly higher levels of household income, agricultural operating income, transfer income, technical training, land endowment, organizational involvement, disaster status, planting subsidies, demonstration programs, maize-soybean revenue, and maize-soybean subsidies. Conversely, they show significantly lower levels of wage income and off-farm work duration.

4 Results

4.1 Impact of the MSSI adoption decision on household income

4.1.1 Estimation of the adoption decision equation for MSSI

This study distinguishes between the adoption decision and adoption intensity to comprehensively evaluate the income effects of MSSI. A Logit model to estimate the probability of farmers' MSSI adoption decision. The results reported in Table 2 indicate that technical training, land endowment, planting subsidies, and demonstration programs all significantly increase the likelihood of MSSI adoption.

Among these factors, technical training exerts the strongest promoting effect, suggesting that knowledge acquisition and technical awareness are essential prerequisites for farmers to adopt MSSI[29]. Farmers with greater land endowment possess more flexibility for operational adjustments and experimentation, as well as the capacity for large-scale farming, making them more likely to adopt MSSI[30]. The significantly positive effects of planting subsidies and demonstration programs further indicate that government incentives and demonstration-based extension services play a crucial role in reducing adoption costs and alleviating cognitive uncertainty[19]. In addition, the share of agricultural income has a significantly negative effect on MSSI adoption. This may be because, on the one hand, 2022 was the first year of large-scale MSSI promotion, and households with a higher share of agricultural income were less willing to try MSSI due to their lower risk tolerance. On the other hand, part-time farm households were more likely to adopt MSSI through land trusteeship or subsidy incentives[31].

The results for the regional variables indicate that farmers in Northwest China are more likely to adopt MSSI, whereas those in the Huang–Huai–Hai region exhibit a significantly lower probability of adoption. This finding suggests that the promotion of MSSI demonstrates clear regional heterogeneity, which is closely associated with interregional differences in resource endowments, cropping systems, technological suitability, and policy environments. These factors also help explain, to some extent, why some farmers remain reluctant to adopt MSSI.

Table 2 Logit model estimation of the MSSI adoption decision equation

Item	Coefficient	Std. Err.	Z-statistic
Age	0.011	0.007	1.43
Education	0.023	0.023	1.00
Technical training	1.063***	0.190	5.58
Land endowment	0.669***	0.213	3.14
Agricultural income share	–0.585**	0.240	–2.44
Organizational involvement	0.347	0.263	1.32
Disaster status	0.194	0.154	1.26
Planting subsidy	1.124*	0.618	1.82
Demonstration programs	0.352**	0.179	1.97
Soybean market	0.104	0.177	0.59
Northwest China	1.157***	0.200	5.78
Huang–Huai–Hai region	–1.372***	0.246	–5.56
Constant	–1.515***	0.547	–2.77
LR statistic		287.81***	
Pseudo R^2		0.202	
N		1034	

Note: ***, ** and * denote statistical significance at the 1%, 5% and 10% levels, respectively.

4.1.2 ATT of MSSI adoption decision on household income

The validity of PSM must be tested before calculating the ATT to ensure that the PSM estimates are reliable. Taking the kernel density curves constructed using kernel matching as an example, Fig. 2 shows that the propensity score distributions of the treated and control groups differ substantially before matching, whereas after matching, the difference narrows markedly, and the two curves exhibit broadly similar patterns. Thus, the matching results satisfy the common support assumption. As Table 3 shows, after matching, the pseudo R^2 and LR chi^2 decrease significantly, while the mean and median biases decline from 25.3% and 23.0%, respectively, to below 6%. These results suggest that PSM substantially reduced the systematic differences between samples and achieved a good covariate balance.

Table 4 presents the results of estimating the ATT of MSSI adoption decision on household income. The ATT values are all positive, and significant across the four matching methods. For analytical convenience, the mean ATT across methods is used to represent the impact. The results indicate that under the counterfactual estimation of PSM, the average net effect of MSSI adoption on the logarithm of household income is 0.189. However, the income-increasing effect is not significant when transfer income is excluded. These results suggest that the significant impact of MSSI adoption on household income depends on transfer income. These results provide preliminary evidence for H1.

4.1.3 Impact of MSSI adoption decision on the structure of household income

This study employs PSM to estimate the treatment effects (ATT) on agricultural operating income, wage income, and transfer income. As Table 5 shows, the impact of MSSI adoption on agricultural operating income is not significant. This may be related to the resource allocation effect of MSSI, which reduces cash crop income, consistent with expectations. MSSI adoption has a negative impact on wage income. Although the labor input of MSSI is similar to that of monoculture, the increased production steps lead to fragmented labor, thereby reducing off-farm work duration

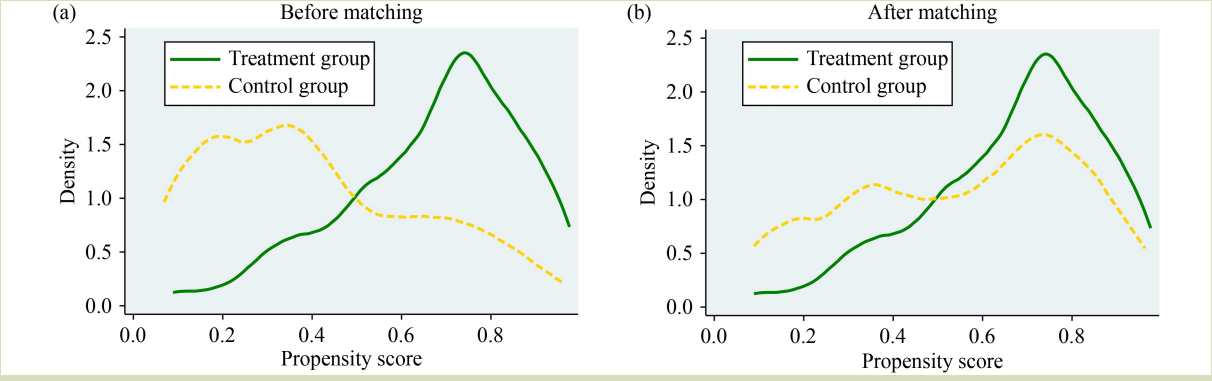


Fig. 2 Probability density of propensity scores for MSSI adopters and monoculture practitioners. (a) Before matching; (b) after matching.

Table 3 Covariate balancing test results before and after matching

Matching method	Pseudo R^2	LR statistic	p-value	Mean bias	Median bias	B	R
Before matching	0.103	147.16	0.00	25.3	23.0	79.6*	1.01
Nearest neighbor matching (K = 5)	0.007	10.97	0.360	5.8	5.2	19.7	0.84
Radius matching (caliper = 0.05)	0.008	12.68	0.242	5.3	5.1	21.1	0.88
Nearest neighbor caliper matching	0.007	11.62	0.311	5.9	5.4	20.2	0.86
Kernel matching	0.008	12.27	0.267	5.3	5.1	20.8	0.87

Note: All matching results reported below are based on K = 5 and a caliper width of 0.05. *Denotes that the mean difference is statistically significant at the 10% level.

Table 4 Estimated ATT of MSSI adoption decision on household income

Dependent variable	Matching method	Treated	Controls	ATT	*T*-statistic
Farm household income	Before matching	1.317	1.124	0.193***	3.03
	Nearest neighbor matching	1.307	1.129	0.178**	2.06
	Radius matching	1.317	1.120	0.197**	2.44
	Nearest neighbor caliper matching	1.317	1.129	0.188**	2.17
	Kernel matching	1.307	1.119	0.188**	2.33
	Mean	1.313	1.124	0.189	–
Farm household income (Excluding subsidies)	Before matching	1.125	1.113	0.012	0.20
	Nearest neighbor matching	1.115	1.092	0.023	0.28
	Radius matching	1.125	1.086	0.039	0.49
	Nearest neighbor caliper matching	1.125	1.089	0.036	0.43
	Kernel matching	1.115	1.087	0.028	0.36
	Mean	1.121	1.094	0.028	–

Note: *** and ** Denote statistical significance at the 1% and 5% levels, respectively. Standard errors were obtained using the bootstrap method with 500 replications. – Indicate that the statistic is not applicable.

Table 5 ATT of MSSI adoption decision on household income structure

Dependent variable	Matching method	Treated	Controls	ATT	*T*-statistic
Agricultural operating income	Nearest neighbor matching	0.806	0.743	0.063	0.66
	Radius matching	0.811	0.772	0.039	0.45
	Nearest neighbor caliper matching	0.811	0.747	0.064	0.67
	Kernel matching	0.806	0.770	0.036	0.41
Wage income	Nearest neighbor matching	0.575	0.587	−0.012	−0.16
	Radius matching	0.573	0.586	−0.013	−0.18
	Nearest neighbor caliper matching	0.573	0.583	−0.010	−0.13
	Kernel matching	0.575	0.587	−0.012	−0.16
Transfer income	Nearest neighbor matching	0.465	0.302	0.163***	3.55
	Radius matching	0.472	0.292	0.180***	4.17
	Nearest neighbor caliper matching	0.472	0.307	0.165***	3.57
	Kernel matching	0.465	0.288	0.177***	4.12

Note: *** Denotes statistical significance at the 1% level. Standard errors were obtained using the bootstrap method with 500 replications.

and subsequently lowering non-farm income. However, this effect is not significant. Conversely, MSSI adoption has a significant positive treatment effect on transfer income. On average, if MSSI adopters had not adopted the technology, the log of transfer income would have decreased by 0.171. This indicates that only MSSI support policies significantly promote household income growth. These results provide preliminary evidence for H2.

4.2 Impact of MSSI adoption intensity on farm household income

4.2.1 Impact of MSSI adoption intensity on farm household income

Although the PSM results reveal the average treatment effects of MSSI adoption decision, they cannot capture the impact of varying adoption intensity on income. Therefore, OLS

regressions are performed on Eqs. (6) and (7) to analyze the marginal effects of adoption intensity and determine the optimal adoption ratio. The variance inflation factor values are below 3, with a mean of 1.56, indicating no multicollinearity. Robust standard errors are used to address heteroscedasticity, and Table 6 presents the estimation results.

Column (1) presents the results without the quadratic term. The coefficient of MSSI adoption intensity on household income is positive and significant at the 1% level. However, when transfer income is excluded, the coefficient fails to reject the null hypothesis of zero. This indicates that MSSI adoption intensity promotes household income growth only when transfer income is considered. These results provide further evidence supporting H1.

This study further examines the optimal adoption ratio for MSSI among farm households. Column (3) of Table 6 shows that both the linear and quadratic terms for the adoption ratio are significant at the 5% level. The positive linear and negative quadratic terms indicate the existence of a maximum value. Based on the first-order condition, the optimal adoption ratio is calculated as 68.54%. This confirms the robust inverted U-shaped relationship between adoption intensity and household income, with net household income peaking at an adoption ratio of 68.54%. This can be explained by the fact that when the ratio is below 68.54%, expanding the MSSI area increases subsidies and soybean returns, thereby raising transfer income and agricultural operating income. Beyond 68.54%, however, the MSSI's demand for refined management becomes harder to meet as management difficulty rises. Combined with reduced off-farm labor supply and higher production risk, this leads to a decline in wage income and diminishing marginal returns on operating income. Although net household income continues to grow, the growth rate decelerates markedly, exhibiting an overall pattern of diminishing marginal returns. Overall, these results are consistent with H3.

4.2.2 Impact of MSSI adoption intensity on the structure of farm household income

Table 7 presents the estimated impact of MSSI adoption intensity on household income structure. The impact of

Table 6 Estimation results of the impact of MSSI adoption intensity on farm household income

Item	Farm household income	Farm household income (Excl. subsidies)	Household income
Adoption intensity	0.226*** (0.082)	0.033 (0.084)	0.738*** (0.257)
Adoption intensity squared	–	–	−0.538** (0.262)
Control variables	Yes	Yes	Yes
Constant	1.725*** (0.168)	1.883*** (0.171)	1.707*** (0.169)
R^2	0.399	0.353	0.402
Sample size	1034	1034	1034

Note: *** and ** Denote statistical significance at the 1% and 5% levels, respectively. Coefficient estimates are reported outside the parentheses, and robust standard errors are reported in parentheses. – Indicate that the statistic is not applicable.

Table 7 Estimation results of the impact of MSSI adoption intensity on the structure of farm household income

Item	Agricultural operating income	Wage income	Transfer income
Adoption intensity	0.064 (0.066)	−0.164** (0.071)	0.333*** (0.042)
Control variables	Yes	Yes	Yes
Constant	0.515** (0.131)	2.279*** (0.157)	−0.315*** (0.087)
R^2	0.612	0.328	0.551
Sample size	1034	1034	1034

Note: *** and ** Denote statistical significance at the 1% and 5% levels, respectively. Coefficient estimates are reported outside parentheses, and robust standard errors are reported in parentheses.

adoption intensity on agricultural operating income is not significant. However, increased adoption intensity significantly reduces wage income and increases transfer income. Furthermore, the marginal effect of the increase in transfer income exceeds that of the decrease in wage income. These findings are broadly consistent with the PSM estimation results for adoption decision. These findings provide further evidence for H2.

4.3 Mechanism analysis

To elucidate the mechanisms through which MSSI adoption influences farm household income, this study conducts separate OLS regressions using adoption decision and adoption intensity as independent variables respectively, and characterizes the transmission mechanisms of MSSI adoption on farm household agricultural operating income, wage income, and transfer income through four mediating variables, namely maize-soybean revenue, cash crop acreage, off-farm work duration, and maize-soybean subsidies.

As shown in Table 8, regardless of whether MSSI adoption is measured by adoption decision or adoption intensity, it affects farm households' income structure through four variables. Specifically, in terms of agricultural operating income, MSSI adoption is associated with higher maize-soybean revenue and lower cash crop acreage, thereby affecting the composition of agricultural operating income. In terms of wage income, MSSI adoption reduces farmers' off-farm work duration, thereby decreasing wage income. The effect of adoption decision is negative but insignificant, whereas adoption intensity has a significantly negative effect. This difference likely arises because adoption decision only captures participation in MSSI production, while adoption intensity reflects the scale of participation and the associated labor reallocation. As MSSI cultivation expands, off-farm employment is increasingly crowded out, making its negative effect on wage income more pronounced. In terms of transfer income, MSSI adoption increases subsidy receipts and thereby raises transfer income.

Overall, the above results confirm that MSSI adoption, including both the adoption decision and adoption intensity, affects farm household income through higher maize-soybean revenue and subsidies, lower cash crop acreage, and reduced off-farm work duration, thereby supporting H4.

4.4 Endogeneity analysis

Reverse causality may exist between MSSI adoption and farm household income, as higher-income farmers may be more likely to adopt MSSI. To address this concern, we employ the neighborhood effect as an instrumental variable, defined as whether neighboring households have adopted MSSI. Given that MSSI adoption includes both adoption decision and adoption intensity, where the former is a binary variable and the latter is a continuous measure, the two equations may be jointly determined with correlated error terms. Therefore, the conditional mixed process (CMP) estimator is employed to jointly estimate the system of equations.

Before estimation, we first examined the validity of the instrumental variable using two-stage least squares. As reported in Table 9, the Kleibergen-Paap LM statistics are significant at the 1% level, rejecting the null hypothesis of under identification. The Cragg-Donald F statistics exceed the Stock-Yogo critical value, indicating that the instrumental variable is sufficiently strong. In addition, the Wald endogeneity test rejects the null hypothesis of exogeneity, confirming the presence of endogeneity and the necessity of instrumental variable estimation.

Table 8 Mechanism of the impact of MSSI adoption on farm household income

Item	Agricultural operating income		Wage income	Transfer income
	Maize-soybean revenue	Cash crop acreage	Off-farm work duration	Maize-soybean subsidies
Adoption decision	0.069*** (0.025)	−0.213* (0.116)	−5.313 (4.996)	0.164*** (0.019)
Adoption intensity	0.199*** (0.031)	−0.370*** (0.128)	−10.862* (6.467)	0.277*** (0.024)
Control variables	Yes	Yes	Yes	Yes
Sample size	1034	1034	1034	1034

Note: The effects of adoption decision and adoption intensity are estimated separately. *** and * Denote statistical significance at the 1% and 10% levels, respectively. Coefficient estimates are reported outside parentheses, and robust standard errors are reported in parentheses.

Table 9 Diagnostic Tests

Item	Adoption decision	Adoption intensity
Underidentification test (Kleibergen-Paap LM)	91.042***	61.617***
Weak identification test (Cragg-Donald Wald *F*)	141.208	78.392
Endogeneity test	5.017**	7.395***
Chi-sq (1) *p*-value	0.025	0.007

Notes: *** and ** Denote statistical significance at the 1% and 5% levels, respectively. The critical value for the Cragg-Donald *F* test at 10% maximal IV size is 16.38.

Table 10 reports the results. The significance of the Atanhrho parameters indicates correlated error terms across equations, supporting joint estimation under the CMP framework. After correcting for endogeneity, both MSSI adoption decision and adoption intensity are significantly and positively associated with farm household income at the 1% level. The results indicate that MSSI adoption contributes to income improvement. These findings are consistent with the baseline results and confirm the robustness of the estimated effects of MSSI adoption.

4.5 Robustness check

To verify the robustness of the baseline regression, this study further employs the Endogenous Switching Regression model to examine the impact of MSSI adoption decision on the logarithm of net household income. As shown in Table 11, the estimated coefficient for the adoption variable is significantly positive, confirming the reliability of the baseline conclusions.

However, considering that the sample includes 9.19% professional agricultural entities—characterized by higher income levels and larger operational scales—the resulting income stratification within the sample might lead to an upward bias in the ATT estimated by the ESR model. To prevent the estimation results of a single method from being skewed by sample heterogeneity, this study further utilizes RA, IPW, IPWRA, and AIPW methods for supplementary testing, as reported in Table 12. The results indicate that the estimates across all these methods remain significantly positive. This consistently demonstrates that the promoting effect of MSSI adoption on household income is highly robust.

Table 10 Estimation results of the CMP model for the impact of MSSI adoption on farm household income

Item	Adoption decision	Adoption intensity
First-stage dependent variable: farmers' MSSI adoption behavior		
Neighborhood effect	0.348*** (0.029)	0.207*** (0.023)
Control variables	Yes	Yes
Constant	0.092 (0.094)	0.027 (0.075)
Second-stage dependent variable: farm household income		
Adoption decision	0.581*** (0.166)	–
Adoption intensity	–	0.977*** (0.288)
Control variables	Yes	Yes
Constant	1.628*** (0.190)	1.655*** (0.194)
Atanhrho	–0.211** (0.089)	–0.325*** (0.116)
LR chi2	958.75***	860.63***
Sample size	1034	1034

Notes: *** and ** Denote statistical significance at the 1% and 5% levels, respectively. Coefficient estimates are reported outside parentheses, and robust standard errors are reported in parentheses. – Indicate that the statistic is not applicable.

Table 11 Robustness check of ESR estimates of MSSI adoption effects on farm household income

Group	Adoption decision		Treatment effect	
	MSSI	Monoculture	ATT	ATU
Adopters	1.317	0.776	0.541*** (0.040)	–
Non-adopters	1.582	1.125	–	0.457*** (0.037)

Notes: *** Denotes statistical significance at the 1% level. Standard errors are reported in parentheses. – Indicate that the statistic is not applicable.

Table 12 Robustness checks using RA, IPW, IPWRA, and AIPW estimators

Household income	RA	IPW	IPWRA	AIPW
Adoption decision	0.187*** (0.070)	0.236** (0.092)	0.236** (0.092)	0.253** (0.072)
POmean	1.130*** (0.067)	1.082*** (0.087)	1.082*** (0.087)	1.097*** (0.064)

Notes: *** and ** Denote statistical significance at the 1% and 5% levels, respectively. Coefficient estimates are reported outside parentheses, and standard errors are reported in parentheses.

4.6 Heterogeneity analysis

4.6.1 Heterogeneity analysis for farm households with different opportunity costs

As shown in Table 13, the PSM results by Household type indicate that MSSI adoption significantly increases smallholders' income, whereas its effect on new agricultural business entities is not statistically significant. This may be because smallholders have fewer high-return alternatives and thus lower opportunity costs of adoption, while new agricultural business entities often face higher upfront investments in machinery and related inputs.

PSM estimates by employment status show that MSSI adoption significantly improves the income of pure-agricultural households, but has no significant effect on part-time farming households. A plausible explanation is that pure-agricultural households depend mainly on farming for their livelihoods, so MSSI adoption more directly enhances agricultural operating income and total household income. By contrast, for part-time farming households, the potential gains from adoption may be offset by reduced off-farm labor time and wage income.

PSM estimates by cropping pattern show that MSSI adoption significantly increases the income of grain crop producers, while the effect for cash crop producers is not statistically significant. This finding implies that households specializing in grain production are more likely to translate MSSI adoption into higher total household income, mainly through increases in maize-soybean revenue and transfer income. These findings indicate that the income effects of MSSI adoption are heterogeneous across households with different opportunity costs, thereby supporting H5.

Table 13 Income effect heterogeneity of MSSI adoption decision across opportunity costs

Type		Treated	Controls	ATT	*T*-statistic
Household type	Smallholders	1.072	0.905	0.167**	2.12
	New agricultural business entities	3.144	2.530	0.614	1.14
Employment status	Pure-agricultural households	1.338	1.115	0.223**	2.18
	Part-time farming households	1.831	1.779	0.052	0.21
Primary crop type	Grain crop producers	1.329	1.125	0.204*	1.92
	Cash crop producers	1.340	1.147	0.193	1.43

Notes: **and * Denote statistical significance at the 5% and 10% levels, respectively.

4.6.2 Impact effect analysis for different income groups

A QR model is used to examine the heterogeneous income-enhancing effects of MSSI adoption across various income levels. The 0.25, 0.50, and 0.75 quantiles are selected to represent the low-, middle-, and high-income groups, respectively. Table 14 shows that MSSI adoption significantly influences income across all examined quantiles, although the magnitude of these effects varies. Figure 3 shows that the coefficients for MSSI adoption exhibit an overall downward trend as income levels increase. This suggests a "pro-poor effect", as MSSI adoption generates more pronounced relative income gains for low-income households and thus helps reduce the rural income gap. High-income households are mainly diversified part-time households or large-scale operators. For the former, adoption may reduce off-farm wage income, while for the latter, high upfront machinery investment can offset short-term gains from mechanization and subsidies. Therefore, the income-enhancing effect is weaker among high-income households, further supporting H5.

5 Conclusions and policy implications

5.1 Conclusions

Based on an income structure perspective, this study utilizes survey data from 1034 households in the MSSI promotion area.

Table 14 Impact of MSSI adoption on farm household income across different income levels

Item	Low income		Median income		High income	
	Decision model	Intensity model	Decision model	Intensity model	Decision model	Intensity model
Adoption decision	0.273***	–	0.174**	–	0.145*	–
	(0.068)		(0.075)		(0.075)	
Adoption intensity	–	0.301***	–	0.221**	–	0.137
		(0.090)		(0.107)		(0.104)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.961***	1.131***	1.676***	1.752***	2.310***	2.267***
	(0.232)	(0.204)	(0.233)	(0.225)	(0.222)	(0.223)
Sample size	1034	1034	1034	1034	1034	1034
R^2	0.173	0.169	0.244	0.243	0.301	0.300

Notes: ***, ** and * Denote statistical significance at the 1%, 5% and 10% levels, respectively. Coefficient estimates are reported outside parentheses, and standard errors are reported in parentheses. – Indicates that the variable is not included in the corresponding model.

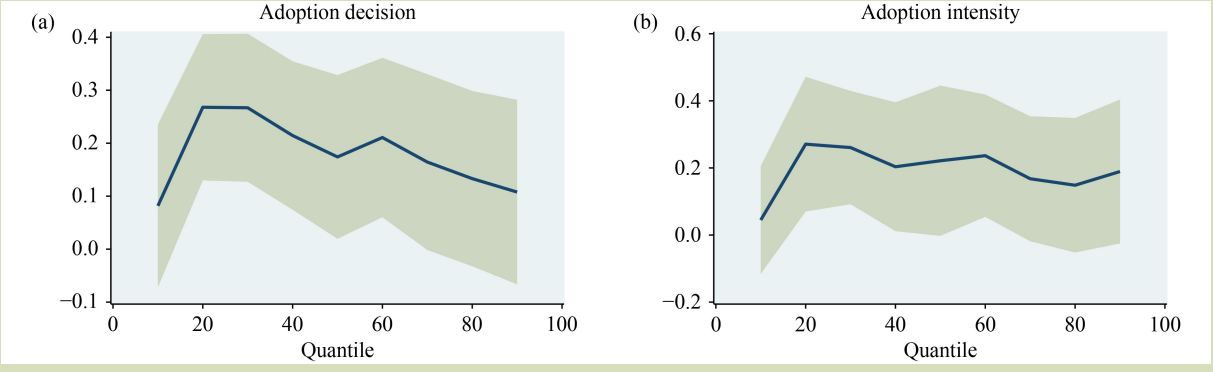


Fig. 3 Quantile regression of the impact of MSSI adoption on household income. (a) Effect of adoption decision; (b) effect of adoption intensity.

Employing PSM, MLR, and QR models, this study investigates the impact of farmers' MSSI adoption behavior on household income and its underlying mechanisms, while further analyzing the heterogeneity of the income-increasing effect. The conclusions are as follows:

(1) Farmers' decisions to select MSSI are significantly influenced by technical training, land endowment, the share of agricultural income, planting subsidy support, demonstration programs, and regional differences.

(2) MSSI adoption significantly increases total household income. This is primarily because the combined increase in agricultural operating income and transfer income generally exceeds the decrease in wage income. However, this positive effect is not significant when transfer income is excluded.

(3) MSSI adoption intensity has an inverted U-shaped relationship with household income, and the optimal adoption ratio is 68.54%.

(4) Path analysis of the income-increasing effect reveals that MSSI adoption affects agricultural operating, wage, and transfer income through yield, factor, and subsidy effects. Specifically, adoption leads to increased income from soybean and maize, reduced cash crop planting areas, decreased off-farm work time, and increased subsidies for soybeans and maize.

(5) Heterogeneity analysis indicates that MSSI adoption yields significant income-increasing effects for smallholders, full-time farmers, and farmers without a habit of planting cash crops, exhibiting a distinct "pro-poor effect". This also suggests that the income gains from MSSI adoption are significant only for certain groups, which may partly explain why some farmers gradually discontinue adoption.

5.2 Policy implications

Several policy implications to promote sustained income growth for MSSI farmers can be made based on the findings of this study.

Intercropping subsidy policies should be strengthened to enhance their stability and effectiveness. First, account for natural risks and market uncertainties, raise subsidy standards for producers, and announce subsidy plans before sowing to fully leverage their guiding role. Second, combine financial subsidies with in-kind subsidies, such as seeds, agricultural machinery, integrated pest management, and mechanized services, to reduce farmers' production costs according to local conditions, with particular attention paid to small-scale and grain-only farmers, who benefit more from diversified production.

Local income-generating channels should be broadened to reduce the opportunity cost of production. First, promote benefit-sharing mechanisms between agricultural operators and smallholder farmers, cultivate highly skilled professional farmers, and foster cooperative operations and shared income growth. Second, strengthen and expand the rural collective economy, develop modern agricultural parks, create local employment and entrepreneurial opportunities, and offset the reduction in wage income resulting from participation in diversified production.

Intercropping practices should be improved to unlock the income growth potential of MSSI. First, guide farmers to keep MSSI adoption within an optimal range to avoid diminishing marginal returns beyond the threshold. Second, strengthen technical training and demonstration programs through diversified training methods, stronger demonstration bases, field observation, and on-site guidance to improve the standardization of technology application. Third, promote the scale and organization of intercropping to capture economies of scale, enhance endogenous profitability, and reduce long-term dependence on policy subsidies.

This study systematically examines the impact of MSSI adoption on farmers' income，but several limitations should be acknowledged. MSSI-related inputs require upfront investment, and a majority of Chinese farmers adopted the technology for the first time in 2022. In addition, soybean market prices stayed high in 2022, yet the expanding domestic soybean supply has dragged down soybean prices since 2023, which weakens the income-increasing benefits of MSSI. As a result, its effect on overall household net income remains limited in the short term. Moreover, due to the use of cross-sectional data, this study is unable to capture the long-term income effects of sustained adoption. Although the analysis covers China's three major MSSI promotion regions, the findings are grounded in the specific institutional context of China's special subsidy policy for MSSI. Therefore, the income

effects identified here may differ in regions without comparable policy support, and the external validity of the conclusions requires further testing in other settings. Future research could draw on panel data or long-term tracking surveys to explore the dynamic income effects of sustained MSSI adoption under different policy and regional contexts.

Acknowledgements

This research was supported by the Natural Science Foundation of Ningxia, China (2026AAC030017) and the China Agriculture Research System (CARS-04-04A). We are grateful for the opportunity to contribute to this field of study. We would also like to thank the editorial team and reviewers for their valuable comments and suggestions. Claude 4.6 (Anthropic) was used to assist with language polishing and expression refinement after the manuscript was completed. All AI-assisted text was then carefully reviewed and revised by the authors.

Compliance with ethics guidelines

Yuying Yang, Kaixuan Ma, Yan Yang, and Wei Si declare that they have no conflicts of interest or financial conflicts to disclose. This article does not contain any studies with human or animal subjects performed by any of the authors.

REFERENCES

1. Li G T, An L N, Yang W N, Yang L, Wei T, Shi J W, Wang J L, Doonan J H, Xie K B, Fernie A R, Lagudah E S, Wing R A, Gao C X. Integrated biotechnological and AI innovations for crop improvement. *Nature*, 2025, **643**(8073): 925–937
2. Ruzzante S, Labarta R, Bilton A. Adoption of agricultural technology in the developing world: a meta-analysis of the empirical literature. *World Development*, 2021, **146**: 105599
3. Yang W Y. *Maize-Soybean Strip Intercropping Technology*. Beijing: *Science Press*, 2021 (in Chinese)
4. Liu J, Yang W Y. Soybean maize strip intercropping: a solution for maintaining food security in China. *Journal of Integrative Agriculture*, 2024, **23**(7): 2503–2506
5. Li C J, Hoffland E, Kuyper T W, Yu Y, Zhang C C, Li H G, Zhang F S, van der Werf W. Syndromes of production in intercropping impact yield gains. *Nature Plants*, 2020, **6**(6): 653–660
6. Yang Y Y, Si W, Chen Z, Feng X L. Does relay strip intercropping technology improve agricultural environmental efficiency?: case study in the Southwest, Northwest, and Huang–Huai–Hai regions of China. *Journal of Arid Land Resources and Environment*, 2024, **38**(10): 166–176 (in Chinese)
7. Yang Y Y, Si W. Maize-soybean relay strip intercropping system: technical model, cost-benefit and subsidy policy. *Issues in Agricultural Economy*, 2023, (1): 49–63 (in Chinese)
8. Yang Y Y, Si W, Li J X. Maize-soybean strip intercropping subsidies: standard calculation and differentiated compensation—based on farmer survey data from southwest, northwest, and Huang–Huai–Hai regions. *Rural Economy*, 2024, (3): 64–74 (in Chinese)
9. Li X F, Wang Z G, Bao X G, Sun J H, Yang S C, Wang P, Wang C B, Wu J P, Liu X R, Tian X L, Wang Y, Li J P, Wang Y, Xia H Y, Mei P P, Wang X F, Zhao J H, Yu R P, Zhang W P, Che Z X, Gui L G, Callaway R M, Tilman D, Li L. Long-term increased grain yield and soil fertility from intercropping. *Nature Sustainability*, 2021, **4**(11): 943–950
10. Li X F, Yu R P, Li L. Intercropping sustainably increases yields and soil fertility. *Frontiers of Agricultural Science and Engineering*, 2021, **8**(4): 659–661
11. Huang J L, Wang L Q. Policy feasibility and effectiveness test of relaxing constraints of interplanting in returning farmland: based on a survey of farmers in Guizhou Province. *Resources Science*, 2021, **43**(9): 1863–1875 (in Chinese)
12. Rao F P, Shadike M, Abudikeranmu A. Effects of fruit farming on households' income: empirical evidence from county panel and household survey data. *Journal of Arid Land Resources and Environment*, 2021, **35**(3): 36–42 (in Chinese)
13. Dai X Q, Pu L J, Rao F P. Assessing the effect of a crop-tree intercropping program on smallholders' incomes in rural Xinjiang, China. *Sustainability*, 2017, **9**(9): 1542
14. Yang H, Zhang W P, Surigaoge S, Xu H S, Su Y, Callaway R M, Li L. Functional traits are plastic in response to intercropping, improving the stability of yield through temporal asynchrony. *Field Crops Research*, 2026, **340**: 110398
15. Schneider J M, Delzeit R, Neumann C, Heimann T, Seppelt R, Schuenemann F, Söder M, Mauser W, Zabel F. Effects of profit-driven cropland expansion and conservation policies. *Nature Sustainability*, 2024, **7**(10): 1335–1347
16. Kafle K, Fatema N, Kibriya S, Wang Y H, Twongyirwe R. "Too poor to migrate": a narrative of labor migration and land

fragmentation in Uganda. *Land Use Policy*, 2026, **160**: 107844
17. Liu Y Y, Chen R B, Chen Y F, Yu T L, Fu X H. Impact of the degree of agricultural green production technology adoption on income: evidence from Sichuan citrus growers. *Humanities and Social Sciences Communications*, 2024, **11**(1): 1160
18. Thierfelder C, Mhlanga B, Nyagumbo I, Kalala K, Simutowe E, Chiduwa M, MacLaren C, Silva J V, Ngoma H. Two crops are better than one for nutritional and economic outcomes of Zambian smallholder farms, but require more labour. *Agriculture, Ecosystems & Environment*, 2024, **361**: 108819
19. Yang Y Y, Si W, Zhou X S, Feng X L. Traditional practice and policy incentives: an analysis of farmers' adoption behavior of relay strip intercropping technology. *Journal of Agrotechnical Economics*, 2025, (6): 49–67 (in Chinese)
20. Hong Y, Heerink N, Zhao M J, van der Werf W. Intercropping contributes to a higher technical efficiency in smallholder farming: evidence from a case study in Gaotai County, China. *Agricultural Systems*, 2019, **173**: 317–324
21. Fan P F, Mishra A K, Feng S Y, Su M, Hirsch S. The impact of China's new agricultural subsidy policy on grain crop acreage. *Food Policy*, 2023, **118**: 102472
22. Wu X Q, Li L P, Shan T C. Adoption and multidimensional effects of socialized services for tea farmers. *ENGINEERING Agriculture*, 2026, **13**(4): 26670
23. Amankwah A, Gwatidzo T. Food security and poverty reduction effects of agricultural technologies adoption—A multinomial endogenous switching regression application in rural Zimbabwe. *Food Policy*, 2024, **125**: 102629
24. Zhang Z. Do agricultural subsidies raise the income of rural households effectively? Evidence from rural China. *Applied Economics Letters*, 2024, **31**(10): 958–966
25. Rosenbaum P R, Rubin D B. The central role of the propensity score in observational studies for causal effects. *Biometrika*, 1983, **70**(1): 41–55
26. Fluhrer S, Kraehnert K. Mobile phone network expansion and agricultural income: a panel study. *Agricultural Economics*, 2024, **55**(1): 54–85
27. Yang Y Y, Si W. Enhancement pathways and effect estimates of the production scale and farmers' adoption behaviors of returning straw to field technology: evidence from Heilongjiang Province. *Research of Agricultural Modernization*, 2022, **43**(4): 648–659 (in Chinese)
28. Ma W L, Wang X B. Internet use, sustainable agricultural practices and rural incomes: evidence from China. *Australian Journal of Agricultural and Resource Economics*, 2020, **64**(4): 1087–1112
29. Vaiknoras K, Larochelle C. Training and seed production spillovers and technology adoption: the case of seed producer groups in Nepal. *Agricultural Economics*, 2023, **54**(6): 921–942
30. Peng Y Y, Guo J Y, Liu Y D, Liao L C, Jiang S W, Tang Y H. Will land transfer improve grain farmers' adoption of agricultural green production technology? Evidence from Jiangxi Province, China. *Humanities and Social Sciences Communications*, 2025, **12**(1): 466
31. Patil V, Veettil P C. Farmers' risk attitude, agricultural technology adoption and impacts in eastern India. *Agriculture & Food Security*, 2024, **13**(1): 50