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Article — Published Version

## Land tenure, autonomy and crop choice: Institutional drivers of agricultural diversification in Uzbekistan

Agricultural Systems

**Provided in Cooperation with:**

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*Suggested Citation:* Bilal, Muhammad; Umirbekov, Pishenbay; Djanibekov, Nodir; Tadjiev, Abdusame; Mirkasimov, Bakhrom (2026) : Land tenure, autonomy and crop choice: Institutional drivers of agricultural diversification in Uzbekistan, *Agricultural Systems*, ISSN 1873-2267, Elsevier, Amsterdam, Vol. 233, pp. 1-11, <https://doi.org/10.1016/j.agsy.2025.104574> , <https://www.sciencedirect.com/science/article/pii/S0308521X25003142>

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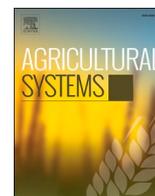
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## Research Paper

## Land tenure, autonomy and crop choice: Institutional drivers of agricultural diversification in Uzbekistan



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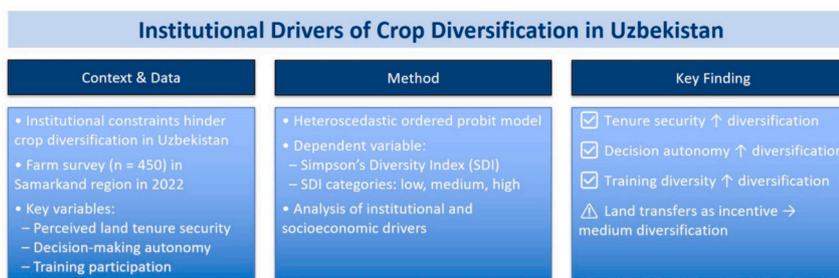
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## HIGHLIGHTS

- Link between perceived tenure security, autonomy and diversification understudied.
- Survey data from Uzbekistan analyzed using heteroscedastic ordered probit model.
- Secure land tenure is associated with more diverse cropping patterns.
- Greater decision-making autonomy corresponds with higher crop diversification.
- Higher training diversity is linked to increased likelihood of diversification.

## GRAPHICAL ABSTRACT



## ARTICLE INFO

Editor: James Alan Turner

## Keywords:

Crop diversification  
Decision-making autonomy  
Institutional factors  
Land tenure security  
Heteroscedastic ordered probit

## ABSTRACT

**CONTEXT:** Crop diversification can improve income stability, reduce environmental risks, and make farming more resilient. Uzbekistan is one such country, where agriculture is shifting from a state-controlled cotton and wheat system towards a more market-oriented approach. This study explores how crop diversification is linked to institutional factors, such as farmers' sense of land security and their ability to make independent decisions.

**OBJECTIVE:** The study aims to understand how the variety of crops grown by farmers is related to their perceptions of land tenure security and decision-making autonomy. It also considers how training, information sources, and farm characteristics are associated with diversification outcomes.

**METHODS:** Using survey data from 450 farms in the Samarkand province collected in 2022, the study measures crop diversification with Simpson's Diversity Index and groups farms into low, medium, and high diversification levels. A heteroscedastic ordered probit model is applied to examine how institutional, geographic, and socioeconomic factors are associated with these outcomes.

**RESULTS AND CONCLUSIONS:** Farmers who feel confident about keeping their land and who report greater freedom in deciding what to grow are more likely to have diversified crop portfolios. Attending more training programs and using land as an incentive for farm workers are also positively linked to diversification. In contrast, relying on media for agronomic information and having formal agricultural education focused on traditional

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crops are associated with lower diversification. Larger farms tend to avoid monoculture but are not necessarily more likely to achieve high diversification.

**SIGNIFICANCE:** These findings suggest that improving land tenure security, expanding farmer autonomy, increasing access to diverse training, and providing better-targeted farming advice can help support the shift towards more diverse and sustainable farming. This has important implications not only for Uzbekistan, but also for other countries undergoing agricultural reform.

## 1. Introduction

Crop diversification is important in ensuring the sustainability and resilience of agricultural systems. By reducing reliance on a single crop, diversification helps farmers mitigate risks associated with climate variability, market shocks, and pest outbreaks. It contributes to soil health, enhances biodiversity, and stabilises farm incomes while improving household food security and nutrition (Makate et al., 2023; Snapp et al., 2019; Vu and Rammohan, 2022; Shively and Sununtnasuk, 2015). Diversified farming systems support agroecosystem well-being, enabling farmers to adapt to environmental, economic, and institutional changes and improving resilience to stresses like land degradation, water scarcity, and climate variability (Chavas et al., 2022; Liebenehm et al., 2023; Schmitt et al., 2024; Vernooij, 2022; Maggio and Sitko, 2021; Ahmadzai and Morrissey, 2025).

Understanding the determinants of crop diversification can contribute to the design of effective agricultural policies. Key factors include access to markets, irrigation, and infrastructure, as farmers in remote areas often face limited resources and opportunities, resulting in lower levels of diversification (McCord et al., 2015; Bogado et al., 2024). Agro-environmental conditions, such as soil fertility and climatic variability, also play significant roles, with farmers in drought-prone or degraded areas adopting diversification as a risk management strategy (Snapp et al., 2019). Socioeconomic factors like education, income, and gender shape crop diversification decisions. Educated farmers are more likely to adopt diverse cropping systems due to better knowledge of benefits, while gender differences often lead women to prioritise food crops and men to focus on market-oriented cash crops (Makate et al., 2023; Tilinti et al., 2024; Zachariou et al., 2025). Institutional frameworks like access to credit, tenure security, and cooperative membership also play a role in crop diversification decisions. Secure land tenure encourages long-term investments via a diversified crop portfolio, while credit access enables investment in inputs for a diverse crop portfolio (Tanti et al., 2022; Binswanger and Rosenzweig, 1986). Market incentives like output prices and access to high-value crops promote crop diversification, although market imperfections like price volatility and poor storage facilities act as constraints (Buisson and Balasubramanya, 2019; Kumar et al., 2022).

Despite growing research, gaps remain in understanding how institutional factors shape crop diversification. Land tenure security, land transactions, and decision-making autonomy of farmers are often assumed to impact farmers uniformly, overlooking how institutional settings influence behaviour. For example, tenure security enables long-term investments and increases farmers' willingness to diversify. Unlike previous studies that primarily consider observable land rights or participation in cooperatives as institutional variables (e.g., Buisson and Balasubramanya, 2019; Tanti et al., 2022), our analysis introduces farmers' subjective perceptions of land tenure security and decision-making autonomy among the key determinants of crop diversification decisions. The role of these institutional factors remain poorly understood. These research gaps are especially relevant in transition economies where institutional reforms and their outcomes evolve unevenly across regions and farm types.

Geographical and economic contexts in studies of crop diversification also lack representation of economies transiting from centrally planned to market-oriented systems. Due to ongoing reforms and structural changes, institutional factors often play an important role in

such settings. Transition economies are characterised by changing land ownership, market liberalisation processes, and governance shifts, influencing farmers' decision-making. Similarly, uncertainty from frequent land redistributions or weak governance during the transition period can discourage diversification, even when its economic or environmental benefits are evident.

Addressing these gaps, we investigate how institutional factors relate to crop diversification outcomes among farmers using the case of Uzbekistan, a transition economy of, until recently, cotton monoculture and a highly regulated agricultural sector. Specifically, we ask: How are farmers' perceptions of land use rights and tenure security related to their degree of crop diversification? And to what extent do decision-making autonomy and institutional support, such as access to extension services and agricultural knowledge correspond with diversification levels? Based on prior empirical work, we expect that farmers who perceive greater land use rights and tenure security and enjoy higher decision-making autonomy display higher levels of crop diversification. Similarly, better access to institutional support services is anticipated to be positively associated with diversification, whereas limited training diversity is expected to correspond with lower diversification due to fewer opportunities to acquire relevant agronomic knowledge.

Uzbekistan offers a unique case for exploring the role of institutional factors in crop diversification. Decades of state-controlled agricultural policies focused on cotton and wheat monocultures, but reforms since 2017 aim to diversify production, enhance sustainability, and improve rural livelihoods (Djanibekov et al., 2024). Measures include land optimisation, market liberalisation, and promotion of high-value crops. A long history of top-down instruction limited farmers' autonomy, affecting their perceptions about land tenure and hindering crop diversification (Petrick and Djanibekov, 2016). The recent wave of rapid agricultural reforms initiated in 2019 under the Agri-Food Development Strategy aims to support the transition towards a market-oriented agricultural system by reducing reliance on cotton monoculture and promoting greater crop diversification (Djanibekov et al., 2024). Substantial progress is still needed to strengthen land tenure security and decision-making autonomy of farmers (Babadjanov & Petrick, 2023; World Bank, 2022; Kurbanov et al., 2025).

Understanding these factors can contribute to agricultural policy discussions in Uzbekistan and provide new evidence for debates about land use rights and tenure security. By examining these institutional factors using a robust econometric approach on original survey data, our study offers new evidence on the micro-level institutional drivers of agricultural diversification in a transition economy.

The remainder of this paper is organised as follows. Section 2 reviews the relevant literature on crop diversification and its determinants, focusing on institutional factors. Section 3 outlines the methodological framework and describes the data collection process. Section 4 presents the results of the empirical analysis, highlighting the role of institutional variables in shaping crop diversification patterns. Section 5 discusses the findings in the context of Uzbekistan's agricultural reforms and compares them with global experiences. Finally, Section 6 summarises the key insights and outlines policy implications.

## 2. Institutional settings in Uzbekistan and crop diversification

Uzbekistan's agricultural sector has historically revolved around the dominance of cotton and wheat monoculture, a legacy rooted in Soviet-

era central planning. Cotton, referred to as “white gold,” served as the backbone of export revenues, while wheat was strategically cultivated to ensure food security (Djanibekov et al., 2020). However, these crops were subject to rigid state controls, including centrally managed procurement systems, fixed prices, and production quotas. These constraints limited farmers’ decision-making autonomy and suppressed incentives for innovation and diversification (Petrick and Djanibekov, 2016). Until recently, the dominance of cotton and wheat persisted despite significant inefficiencies. Cotton production faced implicit taxation, where the state retained substantial revenues through fixed prices, and wheat farmers struggled with unprofitable cultivation due to state-mandated production quotas (Zorya et al., 2019). Agricultural education and public media have remained heavily focused on strategic crops such as cotton and wheat, reinforcing monoculture norms and limiting farmers’ exposure to viable alternatives (Kurbanov et al., 2024). Agricultural curricula and textbooks are slow to change and continue to prioritise these crop specialisations (World Bank, 2021), while public media largely reproduce messages on the production of strategic crops and the use of state-supported technologies. As a result, both education and media channels provide limited knowledge on alternative crops and diversified production systems. These systemic inefficiencies created substantial barriers to adopting diversified cropping systems (Petrick and Djanibekov, 2016). Prolonged focus on monoculture has exacerbated environmental challenges, such as soil salinity and water scarcity, particularly in regions like Karakalpakstan, where cotton and wheat collectively occupy over 80% of arable land (Rustamova et al., 2023).

Since independence, Uzbekistan has undergone several waves of agricultural reform, including farm restructuring initiatives to address inefficiencies. Early reforms focused on fragmenting large state-owned farms into smaller units. However, subsequent consolidation efforts sought to create larger, economically viable farms that met state production targets for cotton and wheat (Djanibekov et al., 2012; Zorya et al., 2019). Institutional challenges impeded diversification efforts. Weak enforcement of land use rights and the absence of a functioning land market were significant barriers to fostering long-term investments in diversified cropping systems (Zorya et al., 2019; Kurbanov et al., 2025). State-mandated cropping systems limited farmers’ ability to respond to market signals and adopt alternative crops (Rustamova et al., 2023). While farm consolidation aimed to improve productivity, its implementation introduced significant challenges, particularly regarding land tenure security. Frequent reallocations of farmland under government programs created uncertainty among farmers, discouraging long-term investments in land improvement and crop diversification (Djanibekov et al., 2024; Kurbanov et al., 2025). The inability to lease or sublease land further restricted the efficient redistribution of resources, as land could not move freely from less to more productive farmers (Akhmadiyeva and Herzfeld, 2021). In response to these constraints, informal land transfers to farm workers emerged as a widespread practice to compensate labour and sustain production (Mukhamedova and Pomfret, 2019). Farm managers often allocate small plots to permanent or seasonal workers under verbal or short-term arrangements, typically in exchange for labour services or shared output (Djanibekov et al., 2013). Although not legally recognised, the land-for-labour arrangements remain an important feature of Uzbekistan’s agrarian system (Mukhamedova & Pomfret, 2019).

Since 2017, Uzbekistan has initiated a new wave of reforms under its Agri-Food Development Strategy to transition to a market-oriented agricultural system. These reforms emphasise enhancing private investment, improving productivity, and promoting crop diversification (Djanibekov et al., 2024). Central to these reforms is the gradual reduction of cotton and wheat production areas. Between 2016 and 2020, approximately 330,500 ha of land under cotton and winter wheat were repurposed for higher-value crops such as fruits, vegetables, and oilseeds (CERR, 2023). Crop diversification has been prioritised as a cornerstone of Uzbekistan’s new wave of agricultural reforms. To enable a gradual shift towards more sustainable and economically viable

agriculture, the government has invested in mechanisation and irrigation infrastructure to support diversification.

To broaden farmers’ knowledge portfolios and introduce practical alternatives to cotton and wheat, recent reforms have encouraged a more diversified agricultural extension system. Public extension services have expanded their activities beyond strategic crops by organising training courses, demonstration plots and field days on horticulture, fodder crops, water-saving irrigation and improved farm management practices (World Bank, 2024). Programmes of international organisations and donor-funded projects complement these efforts by introducing additional topics and methods of diversified crop production. Private agribusinesses, including cotton-textile clusters, contribute additional crop-specific technical advice linked to input supply and emerging output markets. Farmer-to-farmer exchanges, including those on smartphone-based groups, and local advisory providers diffuse practical knowledge among rural neighbours and farmers (Kurbanov et al., 2024; Tadjiev et al., 2025).

New policies have also promoted public-private partnerships to integrate farmers into value chains and diversify to high-value crops (Rustamova et al., 2023). Efforts to increase farmers’ decision-making autonomy and integrate them into modern value chains show promise. Initiatives such as contract farming and cooperatives can help address market access and credit barriers, enabling broader participation in crop diversification strategies (Bobojonov et al., 2013). Secure land tenure and access to resource-conserving practices, such as crop rotation with legumes, supported crop diversification (Rustamova et al., 2023). These reforms, combined with targeted support for farmers, have the potential to transform Uzbekistan’s agricultural landscape into a more resilient and sustainable system.

The government’s active role in promoting crop diversification aligns with broader sustainable development goals. By reducing the reliance on cotton and wheat monocultures, Uzbekistan is laying the groundwork for a more resilient and competitive agricultural sector. However, achieving these objectives requires continued efforts to address institutional bottlenecks, improve land governance, and strengthen market infrastructure. The transition from cotton and wheat monocultures to diverse cropping systems aims to enhance food security, income stability, and environmental sustainability. For instance, the area under fruit and grape cultivation increased from 349,200 ha in 2016 to 495,700 ha by 2021, reflecting significant progress in high-value crop production (UN Uzbekistan, 2023). Export-driven diversification has also gained momentum. Between 2017 and 2019, the export of fruits and vegetables nearly doubled, demonstrating the economic potential of high-value crops. However, challenges remain, including limited access to modern technologies, markets, and credit, which constrain smallholder farmers’ diversification ability (Lombardoizzi, 2024).

### 3. Methodology

#### 3.1. Data

The analysis in our study draws on data collected through a survey of farm enterprises conducted in three districts (Jomboy, Pastdargom, and Payarik) of the Samarkand region of Uzbekistan in April–May 2022. The region is particularly relevant for studying institutional drivers of crop diversification due to its diversity of farming systems and exposure to recent agricultural reforms. Samarkand province includes both state-regulated cotton-wheat producing districts (Pastdargom and Payarik) and relatively liberalised horticultural areas (Jomboy), thus capturing a wide range of institutional settings within the same regional context. It was also among the first regions where the Agri-Food Development Strategy was actively implemented, making it a representative case for observing the behavioural effects of reform-driven changes in tenure perceptions and decision-making autonomy. Therefore, while our analysis is limited to one province, the internal institutional

heterogeneity and reform exposure provide analytical leverage for cautiously generalising findings to other parts of Uzbekistan with similar governance structures and reform trajectories.

The survey was part of the SUSADICA project (Structured Doctoral Programme on Sustainable Agricultural Development in Central Asia), funded by the Volkswagen Foundation. The survey questionnaire was developed and piloted by the project researchers. Survey implementation was carried out with the support of a professional data collection agency, Nazar Business and Technology (NBT). The primary respondents were farm managers or main decision-makers at farm enterprises. Formal ethics approval for the survey was granted internally by the Research Ethics Committee of the Leibniz Institute of Agricultural Development in Transition Economies (IAMO).

The farm survey gathered detailed information on farm managers' socio-demographic and behavioural characteristics, farm operations, and respondents' perceptions about land tenure security and land use rights, field-level practices, and geographical contexts. The survey included a representative sample of 450 farm enterprises randomly selected from a farm enterprise list provided by the local farm administration. Our sample consists of a mix of cotton-growing farmers, reflecting the region's long-standing specialisation in cotton cultivation (in Pastdargom and Payarik districts) and non-cotton growers engaged in cultivating various horticultural crops (in Jomboy district).

### 3.2. Description of dependent variable

Following Conrad et al. (2017), we employed the Simpson Diversification Index (SDI) to measure the extent of farm crop diversification versus specialisation. The SDI was measured according to:

$$SDI = 1 - \frac{\sum_{m=1}^M n_m(n_m - 1)}{N(N - 1)} \quad (1)$$

where  $n$  represents the area under a specific crop  $m$ .  $M$  is the total number of cultivated crops, and  $N$  refers to the total crop area sown by the farm. The index ranges from 0 to 1, where a value closer to 1 indicates a diverse cropping pattern and a value of 0 indicates a specialised cropping pattern. Based on farming households' SDI scores, we constructed three categories of farms. Previous studies guided the SDI categories' construction and thresholds (Gebiso et al., 2023). To ensure a minimum of fifty observations in each category (Sudman, 1976), we followed the following thresholds for low = "0" if the SDI score was between 0 and 0.33, medium = "1" if the SDI score was between 0.331 and 0.55, and high = "2" if the SDI score was above 0.551.

### 3.3. Ordered Probit model

We apply the ordered probit model (McElvey and Zavoina, 1975). As the model's coefficient lacks meaningful economic interpretation (Greene and Hensher, 2008), we estimated marginal effects following Chen et al. (2002). The construction of the SDI categories based on the recommended thresholds of SDI resulted in an explicit ordinal nature of the dependent variables (Gebiso et al., 2023). The empirical framework to employ the ordered probit model was guided by Mutyasira et al. (2018) and Gebiso et al. (2023) regarding the socioeconomic factors of the respondents to determine SDI categories/sustainable agricultural practices. Hence, we employed the ordered probit model to determine if institutional factors (land tenure security, training diversity, decision autonomy, land used as incentives to farm workers), including respondents' socioeconomic factors (age, agricultural education) and geographic variables (plot location to canal, farm distance to local market, and districts dummies) and farm specific characteristics (farm size, soil quality, media as agricultural knowledge source) are related to respondents' respective SDI categories (see Table 2).  $y_i$  denotes three ordinal categories of the dependent variable: Low SDI = 0, Medium SDI = 1, and High SDI = 2. Hence, following Greene and Hensher (2008), we

can write:

$$y_i^* = \beta'Z_i + \varepsilon_i, i = 1, \dots, N, \varepsilon_i \sim \text{NID}(0, 1) \quad (2)$$

$y_i^*$  = The latent variable can be observed through a censoring mechanism.

$y_i$  = observed variable not in the equation.

$y_i = 0$  if  $y_i^* \leq \mu_1$ ,

$y_i = 1$  if  $\mu_1 < y_i^* \leq \mu_2$ ,

$y_i = 2$  if  $\mu_2 < y_i^*$ ,

where  $Z_i$  is a set of different institutional factors, including respondents' socioeconomic factors and  $\beta$  are the estimated parameters for the corresponding institutional factors, including respondents' socioeconomic factors. The stochastic disturbance term  $\varepsilon_i$  is assumed to be NID(0, 1). Here  $\mu$  is an unknown cut point (or threshold parameter, if  $y_i$  takes three SDI categories, then there will be two cut points,  $\mu_1$  and  $\mu_2$ ), therefore,  $\mu$  is jointly estimated with  $\beta$ . Following McElvey and Zavoina (1975), the model assumes standard normal random utility maximisation and subsequent probabilities (see, for example, Maddala (1983)). The guidelines to include the relevant independent variables were taken from recent empirical studies regarding diversification, sustainable agricultural practices, and climate-smart agriculture (Mutyasira et al., 2018; Gebiso et al., 2023; Tabe-Ojong et al., 2024).

We acknowledge the issue of heterogeneity in the residual variance when dealing with farm-level data and ordinal nature dependent variable (Greene and Hensher, 2008). Therefore, for robustness, following Litchfield et al. (2012), we considered the heteroscedastic ordered probit model, which is the minor extension of our basic model in Eq. (2) above, and allowed us to determine the individual impacts of explanatory variables on the mean and variance of the latent dependent variable. Hence, a modified form is provided by:

$$\sigma_i = \exp X_i \delta \quad (3)$$

where  $X_i$  includes a matrix of variables reflected to be the source for the residual scattering and  $\delta$  is a vector of unknown parameters.

## 4. Results

### 4.1. Description of independent variables

Table 1 provides insights into farmers' socioeconomic and institutional characteristics influencing crop diversification in Uzbekistan. The average farm size in our sample is 72.41 ha but with substantial variability ranging from 5 to 825 ha. Half of the respondents perceived land tenure as secure, while decision-making autonomy has a moderate mean score of 2.82 on a scale from 1 (very low) to 5 (very high). Approximately 35% of farmers access agronomic information through extension services, while 46% rely on media sources such as newspapers, radio, TV, and the Internet. On average, farmers participated in 2.84 out of 11 types of training sessions. Proximity to local markets averages 12.73 km, ranging from 1 km to 35 km, and about 19% of farms in our sample are situated near the head of the water canal. Additionally, 29% of farmers incentivise their workers by allowing secondary crop cultivation on farmland. A complete description of the variables is provided in the Appendix Table A1.

Table 1 also presents the mean differences between sampled farmers across three SDI categories of low, medium, and high SDI. Several variables show statistically significant differences. Overall, Table 1 suggests that farm size, land tenure security, access to training and extension services, and geographical location are key factors differentiating levels of crop diversification among farmers.

Farm size shows the most notable differences, with medium SDI farmers having 47.31 ha more land on average than low SDI farmers ( $p < 0.01$ ) and high SDI farmers having 29.31 ha more land than low SDI farmers ( $p < 0.05$ ). However, the difference between high and medium SDI farmers is smaller and insignificant. Land tenure security is

**Table 1**  
Descriptive statistics of the sampled farmers (N = 450) and the mean difference of the sampled farmers concerning SDI categories.

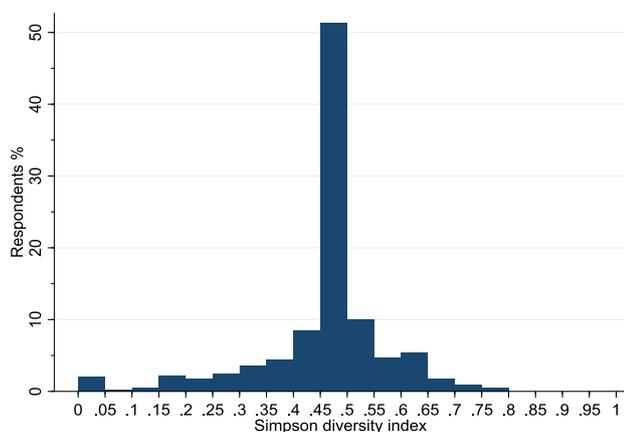
Variable	Mean	Min	Max	Expected sign	References	Mean Diff medium & low SDI	Mean Diff high & low SDI	Mean Diff high & medium SDI
Age	46.53	22	71	-/+	Gebiso et al. (2023)	2.11	2.43	0.31
Agricultural education	0.50	0	1	+	Ahmadzai and Morrissey (2025)	0.46	0.38	-0.07
Farm size	72.41	5	825	+	Gebiso et al. (2023)	47.31***	29.31**	-18.00
Soil quality	0.68	0	1	+	Bobojonov et al. (2013)	0.06	0.09	0.03
Distance to the local market	12.73	1	35	-	Conrad et al. (2017)	1.73	3.09**	1.36
Plot location to the canal	0.19	0	1	+	Buisson and Balasubramanya (2019)	-0.11	-0.12	-0.01
Land as an incentive to farm workers	0.29	0	1	+	Binswanger and Rosenzweig (1986)	0.14	0.10	-0.04
Extension service source	0.35	0	1	+	Mwololo et al. (2019)	0.29***	0.11	-0.01
Media source	0.46	0	1	+	Kasem and Thapa (2011)	0.13	-0.03	-0.16
Training diversity	2.84	0	7	+	Buisson and Balasubramanya (2019)	1.06***	0.77	-0.29
Decision autonomy	2.82	1	5	+	Djanibekov et al. (2024)	0.22	0.44	0.22
Land tenure security	0.50	0	1	+	Akhmadiyeva and Herzfeld (2021)	0.25***	0.25**	-0.003
Jomboy	0.32	0	1			-0.58***	-0.16	0.42***
Pastdargom	0.34	0	1			0.34***	0.16	-0.18**
Payarik	0.33	0	1			0.23***	-0.00	-0.23***

Notes: Mean differences between the SDI categories using Bonferroni correction. The level of significance is \*\*\*  $p < 0.01$ ; \*\*  $p < 0.05$ ; \*  $p < 0.1$ .  
Source: Authors' own elaboration using the farm survey data.

significantly higher among medium and high SDI farmers than low SDI farmers, with mean differences of 0.259 and 0.256, respectively ( $p < 0.01$  and  $p < 0.05$ ). This suggests that secure land tenure positively correlates with higher levels of crop diversification.

Participation in various farm trainings (training diversity) is significantly greater for medium SDI farmers compared to low SDI farmers (mean difference of 1.06,  $p < 0.01$ ), indicating that farmers with more training opportunities are likely to diversify more. Extension service use is also higher for medium SDI farmers compared to low SDI farmers (mean difference of 0.29,  $p < 0.01$ ), highlighting the role of institutional support in promoting diversification. Geographical differences are also evident. Farmers in Jomboy are more likely to fall into the low SDI category, with a mean difference of -0.58 compared to medium SDI farmers ( $p < 0.01$ ). On the other hand, farmers in Pastdargom and Payarik districts are more likely to have medium and high SDI scores, with significant positive differences relative to low SDI farmers. Interestingly, we find significant differences among the farmers' access to institutional variables regarding their districts. Table A2 in the Appendix illustrates the mean difference of the institutional variables with respect to the sampled districts.

Fig. 1 shows that a significant proportion of farmers, approximately



**Fig. 1.** Relative distribution of Simpson's diversity index.  
Source: Authors' own elaboration using the farm survey data.

50%, have SDI values between 0.45 and 0.5. This pattern reflects the prevalence of a two-crop system in Uzbekistan due to the institutional setting effect on crop cultivation. According to this policy, Uzbekistan's farmers allocate about half of the sown area to cotton, and the remaining 50% is dedicated to wheat, the second strategic crop after cotton.

Table 2 illustrates the distribution of farmers across three SDI categories in our sample. Among the 450 farmers surveyed, the majority (75.3%) fall into the medium-diversification category, with a mean SDI of 0.47. Farmers in the high-diversification category represent 13.1% of the sample, with a mean SDI of 0.62, while those in the low-diversification category account for 11.6% of the sample, with a mean SDI of 0.20. The cumulative percentages indicate that 86.9% of farmers achieve at least medium diversification. Across the full sample, the overall mean SDI is 0.46, reflecting a predominance of medium levels of crop diversification among the farmers surveyed.

4.2. Factors associated with crop diversification

Table 3 presents the ordered probit regression results, identifying key factors associated with crop diversification in Uzbekistan, as measured by SDI. The model's overall robustness is confirmed by a Wald chi-squared statistic of 40.66 ( $p < 0.01$ ) and a non-significant link test ( $p = 0.333$ ), indicating no specification errors. Larger farms, distant market locations, diverse training opportunities, and institutional autonomy will likely have higher crop diversification. At the same time, specialised agricultural education and reliance on available media channels for agronomic knowledge are likely to constrain crop diversification.

The assumption of constant variance, based on the estimates presented in Table 3, was rejected ( $\chi^2$  (14 d.f.) = 37.60,  $p = 0.0006$ ). Therefore, we interpreted and discussed the estimates of the heteroscedastic ordered probit model in the following sub-section.

**Table 2**  
Farmers' distribution w.r.t SDI categories.

Ordered	Mean SDI	Frequency	Percent	Cumulative
Low SDI (= 0)	0.20	52	11.56	11.56
Medium SDI (= 1)	0.47	339	75.33	86.89
High SDI (= 2)	0.62	59	13.11	100.00
Full sample	0.46	450	100.00	

Source: Authors' own elaboration using the farm survey data.

**Table 3**  
Coefficients and marginal effects estimate of the ordered probit models.

Explanatory variables	Coeff.	Robust SE	Marginal Effects		
			=0	=1	=2
Age	0.01	0.01	-0.001	-0.0001	0.001
Agricultural education	-0.31**	0.12	0.05**	0.01	-0.06**
Farm size	0.002**	0.001	-0.0004**	-0.0001	0.001**
Soil quality	0.17	0.17	-0.03	-0.004	0.03
Distance to the local market	0.02**	0.01	-0.004**	-0.001	0.004**
Plot location to the canal	-0.28*	0.16	0.06	-0.01	-0.05*
Land as an incentive to farm workers	0.19	0.17	-0.03	-0.01	0.04
Extension service source	-0.12	0.13	0.02	0.002	-0.02
Media source	-0.23*	0.12	0.04*	0.004	-0.05*
Training diversity	0.06**	0.03	-0.01**	-0.001	0.01**
Decision-making autonomy	0.15***	0.06	-0.03**	-0.003	0.03***
Land tenure security	0.25*	0.14	-0.04*	-0.01	0.05*
Pastdargom	-0.24	0.25	0.04	0.001	-0.05
Payarik	0.16	0.19	-0.03	-0.01	0.03
Threshold parameters	-0.03	0.35			
Threshold parameters	2.44	0.37			
Model summary					
No. of observations	450				
Wald (14 d.f.)	40.66***				
Linktest hatsq p-value	0.333				
Log-likelihood	-310.52				

Notes: \*\*\* p < 0.01; \*\* p < 0.05; \* p < 0.1.  
Source: Authors' own elaboration using the farm survey data.

**4.3. Factors associated with crop diversification after accounting for heteroscedasticity**

Table 4 presents estimated coefficients of the heteroscedastic ordered probit models. For interpretational purposes, we calculated the marginal effects estimate of the coefficients of the second column of Table 4. The last column of Table 4 presents the estimates of variance

**Table 4**  
Coefficients of the heteroscedastic ordered probit models.

Explanatory variables	Heteroscedastic ordered probit model Mean Function		Homoscedastic ordered probit model Mean Function		Variance Function	
	Coeff.	Robust SE	Coeff.	Robust SE	Coeff.	Robust SE
Agricultural education	-0.192***	0.061	-0.285**	0.119	0.089	0.100
Farm size	0.001***	0.000	0.001	0.001	-0.009***	0.001
Soil quality	-0.015	0.090	0.149	0.167	-	-
Distance to the local market	0.002	0.005	0.018**	0.008	-	-
Plot location to the canal	-0.072	0.087	-0.256	0.159	0.082	0.130
Land as an incentive to workers	0.216***	0.086	0.352**	0.141	-0.334***	0.110
Extension service source	-0.006	0.065	-0.102	0.120	-0.177	0.111
Media source	-0.166***	0.066	-0.253**	0.121	-	-
Training diversity	0.031**	0.014	0.048*	0.028	-	-
Decision-making autonomy	0.082***	0.032	0.113**	0.054	-	-
Land tenure security	0.123*	0.070	0.190	0.134	-	-
Threshold parameters	-0.343***	0.132	-0.53**	0.243	-	-
Threshold parameters	0.930***	0.167	1.918***	0.258	-	-
Model summary						
No. of observations	450		450			
Wald (11 d.f.)	60.90***		35.97***			
AIC	584.92		650.77			
BIC	658.88		704.19			
Log-likelihood	-274.46		-312.38			

Notes: \*\*\* p < 0.01; \*\* p < 0.05; \* p < 0.1.  
Source: Authors' own elaboration using the farm survey data.

function and accounting heteroscedasticity concerning farm size and land incentives to workers, which is statistically significant. A statistically significant Wald test of  $\ln\sigma_i=0$  with  $\chi^2$  (5 d.f.) = 60.13, and a p-value of 0.000 indicates a justification of the heteroscedastic ordered probit model. The lower AIC and BIC values indicate greater explanatory power, thereby avoiding overfitting. Likewise, a higher log-likelihood indicates a better fit to the observed data and leads to more reliable inferences. Together, these criteria suggest that the heteroscedastic probit model explains the data more effectively than the homoscedastic model.

Table 5 presents the marginal effects estimate of the heteroscedastic ordered probit models based on the second column of Table 4. The results presented in this section speak directly to the research questions and expectations outlined in the Introduction. We describe how institutional variables, particularly perceived land use rights and tenure security, decision-making autonomy, and institutional support, correspond with different levels of crop diversification. Land tenure security appears to be important for crop diversification. Farmers perceiving their land rights as secure are 4.7% more likely to achieve high SDI scores and 3.5% less likely to fall into the low SDI category ( $p < 0.1$ ). This finding is consistent with our expectation that higher perceived land tenure security is associated with a greater likelihood of crop diversification.

Decision-making autonomy has a positive association with crop

**Table 5**  
Marginal effects estimate of the heteroscedastic ordered probit models.

Explanatory variables	Marginal Effects		
	=0	=1	=2
Agricultural education	0.071***	-0.017	-0.054*
Farm size	-0.002***	0.004***	-0.002***
Soil quality	0.004	0.002	-0.006
Distance to the local market	-0.001	0.000	0.001
Plot location to the canal	0.039	-0.031	-0.008
Land as an incentive to farm workers	-0.097***	0.081**	0.016
Extension service source	-0.031	0.072*	-0.041
Media source	0.048**	0.014	-0.062***
Training diversity	-0.009**	-0.003	0.012**
Decision-making autonomy	-0.023**	-0.008	0.031***
Land tenure security	-0.035*	-0.012	0.047*

Notes: \*\*\* p < 0.01; \*\* p < 0.05; \* p < 0.1.  
Source: Authors' own elaboration using the farm survey data.

diversification. Farmers who perceive higher decision-making autonomy are 3.1% more likely to fall into the high SDI category and 2.3% less likely to fall into the low SDI category ( $p < 0.01$ ). This emphasises the importance of decision-making autonomy for multi-cropping decisions aligning with local agroecological conditions, market signals, and own experience/knowledge, as well as better responding to environmental and economic shocks. This aligns with the expectation that decision-making autonomy contributes positively to diversification outcomes.

The results for farm plots that incentivise farm workers show a mixed but significant relationship with crop diversification. Farmers who provide land to motivate their workers' efforts are 9.7% less likely to fall into the low SDI category ( $p < 0.01$ ) and 8.1% more likely to achieve medium SDI scores ( $p < 0.05$ ). However, the impact on the likelihood of achieving high SDI is modest at 1.6% and not statistically significant. These results suggest that offering plots of land as an incentive to farm workers can encourage crop diversification by attracting workers with skills required for cultivating multiple crops. However, the nature of such informal land-for-labour arrangements is insufficient to drive high diversification.

Farm size also appears important for crop diversification but has mixed effects. A one-hectare increase in farm size decreases the likelihood of falling into the low SDI category by 0.2% ( $p < 0.01$ ). Similarly, the probability of achieving high SDI scores declines by 0.2% ( $p < 0.01$ ) with additional farm size. This suggests that huge farms may not necessarily adopt a highly diversified crop portfolio. However, the likelihood of being in the medium SDI category increases by 0.4% ( $p < 0.01$ ) with each additional hectare. These results suggest that farmers tend to move away from monoculture as farm size increases but may opt for moderate rather than high crop diversification, potentially due to resource optimisation or management constraints.

The likelihood of crop diversification increases with a higher diversity of attended farm training. Farmers are 1.2% more likely to achieve high SDI scores for every additional training type attended and 0.9% less likely to fall into the low SDI category ( $p < 0.05$ ). This suggests that exposure to a broader range of training programs equips farmers with diverse agronomic knowledge and skills that are important for effectively managing more diversified crops. This positive association between training diversity and crop diversification supports our hypothesis regarding the enabling role of institutional support services.

The results for agricultural education in Table 5 indicate that it has a statistically significant negative relationship with crop diversification. Farmers with specialised agricultural education are 7.1% more likely to fall into the low SDI category, reflecting a tendency towards specialised cropping systems ( $p < 0.01$ ). Similarly, farmers are 5.4% less likely to achieve high SDI scores, indicating lower probabilities of adopting diverse cropping systems ( $p < 0.05$ ). The marginal effect on the medium SDI category is  $-1.7\%$ , but it is not statistically significant.

Relying on media for agricultural knowledge has negative relationship with crop diversification. Farmers who reported media sources, such as newspapers, radio, or television, as their primary agricultural knowledge channels are 6% less likely to achieve high SDI scores and 4.8% more likely to fall into the low SDI category ( $p < 0.01$ ). Interestingly, there is a statistically significant difference in extension service use between low and medium SDI farmers (Table 1), with medium SDI farmers utilising extension services more frequently on average (mean difference = 0.40,  $p < 0.01$ ). Likewise, the marginal effect estimates also aligned with the finding that extension service use is higher for medium SDI farmers compared to low SDI farmers.

## 5. Discussion

The results emphasise the role of institutional factors such as tenure security, decision-making autonomy, and informal land transfers in crop diversification. These findings are relevant for policymaking in Uzbekistan which currently undergoes a transition from a state-dominated monoculture to market-oriented diversified agriculture. This section

discusses the main findings of the study in relation to existing literature and the institutional context of Uzbekistan's agriculture. Drawing on these results, this section combines key insights with policy messages to facilitate crop diversification.

### 5.1. Interpretation of findings

Tenure security emerges as a critical enabler of crop diversification. Frequent land reallocations under government-led restructuring programs in Uzbekistan have historically undermined farmers' confidence in making long-term investments (Zorya et al., 2019). This insecurity discouraged the adoption of crops requiring sustained care and inputs, such as perennials or high-value cash crops (Akhmadiyeva and Herzfeld, 2021). In contrast, higher perceptions about secure land tenure give farmers the confidence to make long-term investments in land productivity, such as crop rotation and adopting alternative crops. Farmers who perceive their land tenure secure are also more likely to experiment with high-value or non-traditional crops, as they are less concerned about losing their land (Kurbanov et al., 2025). Lessons from India and Thailand demonstrate that integrating institutional reforms with socio-economic and environmental strategies promotes crop diversification (Kumar et al., 2022; Kasem and Thapa, 2011). Additional evidence from Afghanistan confirms that even in fragile contexts, secure tenure and modest diversification can significantly improve household food security and consumption outcomes (Ahmadzai and Morrissey, 2025).

Decision-making autonomy is another important determinant of crop diversification. Farmers who perceive greater autonomy are more capable of responding to market opportunities, environmental changes, and individual preferences. Historically, agricultural policies in Uzbekistan have constrained farmers' abilities to allocate resources efficiently and diversify crops (Djanibekov et al., 2024). Takeshima et al. (2024) found that farmers who perceived low decision-making autonomy also demonstrated low resilience in technical efficiency during 2018 and 2021. The adoption of Uzbekistan's Agri-Food Development Strategy in 2017 marked a shift towards decentralising decision-making, granting farmers greater flexibility in land-use planning and crop choice (Djanibekov et al., 2024; Kurbanov et al., 2025). Lombardozzi (2024) highlighted similar dynamics in other transition economies, noting that greater autonomy allows farmers to integrate into value chains and improve their adaptive capacity. In Thailand, Kasem and Thapa (2011) found that increased autonomy, coupled with targeted government support, facilitated the adoption of high-value crops, enhancing farm incomes and reducing dependence on monocultures. Similarly, Maggio and Sitko (2021) show that decentralised decision-making is especially crucial when diversification strategies are designed to reflect heterogeneity in cropping systems.

If farm workers are typically granted access to smaller plots, this might limit extensive diversification, thereby limiting their ability to attain high SDI levels. This interpretation aligns with the finding that farm size is positively and significantly associated with moderate crop diversification. Larger farms often span spatially dispersed plots with varying soil conditions and microclimates, enabling better crop-plot matching and thus facilitating diversification. However, Uzbekistan's agricultural policy framework continues to orient larger farms towards the production of traditional crops like cotton and wheat (Djanibekov et al., 2024), potentially curbing diversification at the upper end of the SDI scale. Meanwhile, although providing land as an incentive to farm workers appears to support diversification, its effectiveness may be conditional on the size and quality of the land allocated. If incentive plots are too small or uniform in characteristics, they may not enable more complex or diversified crop plans. Notably, the negative and significant coefficients in the variance function (Table 4) for both farm size and land as an incentive to farm workers indicate that these variables reduce unobserved heterogeneity in SDI outcomes, which supports the scenario that farm/plot size may systematically moderate the effect of land as an incentive to farm workers on SDI outcomes.

The findings for land use as an incentive to farm workers in crop diversification align with insights from [Djanibekov et al. \(2013\)](#), which presented the importance of informal land-for-labour arrangements in Uzbekistan's agriculture. Providing land as an incentive reduces the likelihood of low diversification and promotes moderate diversification by motivating workers to engage in farming activities that address their subsistence needs. Such an informal arrangement allows farm managers to attract extra labour force expertise while compensating for the lack of their own expertise ([Mukhamedova and Pomfret, 2019](#)). However, the limited impact of such incentives on achieving high diversification can be due to restricted access to essential farm inputs, lack of institutional support, and the informal nature of these agreements. Formalising these land arrangements through secondary land markets or sub-lease mechanisms can address inefficiencies and help create a more diversified crop portfolio. This is in line with findings by [Binswanger and Rosenzweig \(1986\)](#), who highlighted how informal tenure and labour arrangements shape production behaviour in the absence of strong institutions.

Training diversity is another important factor in crop diversification. Farmers exposed to diverse training programs are likelier to adopt innovative practices and experiment with alternative crops. Training expands understanding of agronomic techniques, risk management, and market opportunities. In Tajikistan, water user associations facilitated agronomic training, enabling farmers to transition to high-value crops ([Buisson and Balasubramanya, 2019](#)). Similarly, participatory training in Malawi empowered farmers to diversify through tailored crop rotations and intercropping systems ([Snapp et al., 2019](#)). In Zambia and Malawi, [Maggio and Sitko \(2021\)](#) emphasise that context-specific knowledge delivered through targeted training can support adoption of effective crop systems that balance income stability and productivity. However, in Uzbekistan, the average participation in training programs is limited, with farmers attending only 2.84 out of 11 possible types. This shortfall highlights gaps in program design, accessibility, and a persistent focus on strategic crops such as cotton and wheat ([Takeshima et al., 2024](#)). Expanding tailored training initiatives, particularly in underserved regions, can significantly accelerate the adoption of diversified cropping systems. Training diversity enhances technical efficiency and builds resilience against economic and environmental shocks ([Takeshima et al., 2024](#)). Further, as demonstrated by [Vu and Rammohan \(2022\)](#), production diversity combined with education and skill-building can positively affect household welfare and nutrition outcomes.

Despite these findings, reliance on media as a source of agricultural knowledge appears to hinder diversification efforts. Media content in Uzbekistan, until recently, has predominantly promoted the cultivation of strategic crops like cotton and wheat, in line with government priorities focused on export revenues and food self-sufficiency ([Kurbanov et al., 2024](#); [Takeshima et al., 2024](#)). This generalised, crop-specific messaging likely reduces farmers' willingness to explore alternative or niche crops, as the complexity and management of diversified cropping systems are not effectively conveyed through mass media formats ([Kurbanov et al., 2024](#)). Similarly, the content of formal agricultural education in Uzbekistan largely emphasises these two strategic crops, reflecting long-standing policy priorities. As a result, agricultural curricula and training programs often lack sufficient attention to the economic and agronomic potential of crop diversification, thereby reinforcing monoculture practices and narrowing farmers' awareness of viable alternatives. Expanding both media and agricultural education curricula to cover knowledge about alternative crops and management practices could help unlock diversification potential. Establishing dedicated farm-focused television and radio programming that provide expert advice, success stories, and practical guidance may further strengthen farmers' awareness and interest in alternative and niche crops. In contrast, the use of extension services as a source of agricultural knowledge tends to support medium SDI, as farmers actively seek targeted support to diversify. However, this relationship appears to diminish at high diversification levels, where farmers are generally more experienced and less dependent on external sources of knowledge

([Mwololo et al., 2019](#); [Rustamova et al., 2023](#)).

## 5.2. Theoretical implications

This study contributes to the growing body of research on institutional enablers of crop diversification by examining how formal, informal, and perceived institutional features shape farmers' diversification behaviour in a transition economy context ([Van Assche et al., 2014](#); [Ciaian et al., 2018](#); [Buisson and Balasubramanya, 2019](#); [Alff, 2023](#); [Rustamova et al., 2023](#)). Existing literature has often focused on structural reforms, such as land privatization or decentralization of input markets, as key pathways to diversification ([Barghouti et al., 2004](#); [Ciaian et al., 2018](#); [Buisson and Balasubramanya, 2019](#); [Rustamova et al., 2023](#)). Our findings highlight that beyond formal institutional reforms, farmers' perceptions of tenure security and decision-making autonomy play a distinct role in enabling diversified cropping strategies. This underscores the importance of perceived institutional stability as an enabling condition in contexts marked by policy uncertainty and reform fatigue ([Knook et al., 2020](#)). Our findings also contribute to knowledge about informal institutions by examining land-for-labour arrangements that remain widespread but are rarely captured in empirical analysis ([Mukhamedova and Pomfret, 2019](#)). The results suggest that such informal incentives contribute to moderate diversification outcomes and operate alongside formal institutional frameworks. This adds to the literature on land governance (e.g., [Djanibekov et al., 2013](#); [Akhmadiyeva and Herzfeld, 2021](#)) by showing how informal land access mechanisms may complement formal tenure structures, especially where official implementation is partial or uneven. Furthermore, the results contribute to debates on the extension dimension of institutional support ([Alff, 2023](#)). The observed association between training diversity and diversification extends existing accounts of institutional enablers to include not only regulatory and property rights frameworks but also agricultural extension landscape ([Knook and Turner, 2020](#)). By contrast, the limited role of traditional agricultural education and mass media points to the ways in which institutional 'inertia' in agricultural knowledge channels may reinforce existing monoculture patterns ([Van Assche et al., 2014](#)).

## 5.3. Policy and practical implications

The findings offer several actionable recommendations to enhance crop diversification in Uzbekistan by strengthening institutional support structures. The uncertainty created by the successive rounds of top-down farm optimisation in Uzbekistan has discouraged farmers from making long-term investments in diversified cropping systems ([Kurbanov et al., 2025](#)). Ensuring tenure security is therefore a critical policy priority. Farmers require clear and enforceable land-use rights to plan and invest in a diversified crop portfolio. Secure tenure would not only enhance farmers' confidence in adopting diverse and higher-value crops but also facilitate long-term resource management. In this context, formalising informal land-for-labour arrangements offer additional potential. Our findings show that this practice reduces the likelihood of low diversification and promotes moderate levels of crop diversity. However, the informal character of such arrangements limits their broader effectiveness and creates uncertainty for both farm managers and workers ([Djanibekov et al., 2013](#); [Mukhamedova and Pomfret, 2019](#)). Introducing clear regulatory frameworks for short-term sub-leases or secondary land markets could help integrate these practices into formal land governance, improving incentives for crop diversification.

Institutional reforms must also focus on strengthening farmers' decision-making autonomy ([Takeshima et al., 2024](#)). The historical legacy of state-mandated cropping patterns continues to constrain the flexibility of farm-level planning and their ability to respond more effectively to market demands and environmental challenges. Farmers often remain subject to implicit or explicit directives regarding land use, even in the context of new market-oriented reforms ([Kurbanov et al.,](#)

2025). Empowering farmers to make independent decisions about crop selection and cultivation methods will be essential. Policy measures should aim to simplify bureaucratic processes, reducing government intervention in cropping patterns, and introducing market-oriented incentives that reward higher diversification.

Our findings show that exposure to a greater variety of training programs is positively associated with diversification. Yet, current training initiatives are limited in both content and geographic reach, particularly in remote or underserved areas and focused on strategic crops such as cotton and wheat (World Bank, 2021; Takeshima et al., 2024), restricting knowledge about diversified cropping systems. Policymakers should prioritise the development of practical, context-specific training modules that address local agroecological conditions and market demands. These should cover topics such as crop rotation, soil health, intercropping, and the cultivation of high-value or climate-resilient crops. Collaborations with international agricultural organisations and research institutes can further enhance the quality and delivery of these educational and training programs. Special attention must be given to underserved regions, where smallholder farmers face the most significant challenges in diversification.

Complementing these efforts, reforms to the broader knowledge dissemination system are equally important (Bogado et al., 2024). While training programs offer targeted knowledge, mass media and school curricula define farmers' attitudes and expectations (Knook and Turner, 2020; Turner et al., 2021). At present, these channels do little to promote crop diversification. Dedicated farm-focused television and radio programming could help fill this gap by sharing expert guidance, farmer success stories, and regionally tailored extension (Zachariou et al., 2025). Similarly, agricultural curricula should be revised to include instruction on diversified farming systems. Without such reforms to the agricultural knowledge system, even well-intentioned policy measures and training efforts may struggle to shift entrenched practices.

#### 5.4. Limitations

Despite the valuable insights provided by this study, several limitations should be acknowledged. The analysis is based on data from a single province, which limits the generalisability of the findings to other regions of Uzbekistan. While the Samarkand region reflects considerable variation in institutional settings and agroecological conditions, it does not capture the full spectrum of reform responses and farming systems observed nationwide. Second, the cross-sectional design of the 2022 data restricts the ability to draw conclusions about causal relationships. In particular, potential endogeneity remains a concern for key institutional variables such as perceived land tenure security and decision-making autonomy. While our results suggest that these perceptions are positively associated with crop diversification, the direction of causality remains uncertain due to the cross-sectional nature of the data. It is plausible that farmers who already practice more diversified cropping systems perceive greater tenure security or decision-making autonomy, for example, due to income stability or stronger market engagement, or prior exposure to reform programs. In other words, diversification could enhance perceptions of autonomy and security, rather than being solely caused by them. Although we mitigate some concerns by controlling for a range of observable characteristics and estimating a heteroscedastic ordered probit model, unobserved factors and reverse causality cannot be fully ruled out. Future research could build on this study by using panel data, instrumental variable techniques, or experimental approaches to better isolate the causal pathways between institutional factors and diversification outcomes.

#### 6. Conclusions

This study examined how institutional factors relate to crop

diversification outcomes among farmers in Uzbekistan. The results indicate that perceived tenure security, decision-making autonomy, training diversity, and informal land-for-labour arrangements are associated with variation in diversification levels. These findings point to the importance of formal land tenure, farmers' experiences of decision-making autonomy and access to agricultural knowledge.

The results indicate that perceived tenure security is associated with more diverse crop portfolios. Farmers who report greater security in land use rights appear more willing to plan beyond cotton and wheat and to maintain broader crop mixes. Decision-making autonomy shows a similar association with diversification, consistent with the idea that flexibility in farm-level planning corresponds with wider crop choice under varied market and agroecological conditions. Placed alongside autonomy, land-to-worker transfers also matter. These arrangements are associated with a lower likelihood of low diversification and with moderate diversification levels. Their informal character may limit consistency and scale, which points to the relevance of clearer procedures that recognise short-term subleases or similar mechanisms within existing land governance.

Our findings show that institutional support through agricultural knowledge systems is also relevant. Training diversity is linked to higher diversification, suggesting that access to varied and practical learning opportunities corresponds with greater engagement in alternative crops and practices. By contrast, reliance on agricultural education and public media as primary agricultural knowledge sources is associated with lower diversification, reflecting long-standing content that prioritises strategic crops and provides limited guidance on alternatives. Strengthening extension services and aligning curricula and media content with diversification goals could improve the agricultural knowledge environment in which farmers make decisions.

A practical takeaway from our findings in Uzbekistan is that reforms that reinforce tenure security, empower farmers' decisions, widen access to diverse training and knowledge channels, and recognise land transfers within existing law are relevant for promoting crop diversification.

#### CRediT authorship contribution statement

**Muhammad Bilal:** Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Pishenbay Umirbekov:** Writing – original draft, Validation, Investigation, Conceptualization. **Nodir Djanibekov:** Writing – original draft, Resources, Project administration, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Abdusame Tadjiev:** Writing – original draft, Resources, Methodology, Data curation, Conceptualization. **Bakhrom Mirkasimov:** Supervision, Resources, Project administration, Funding acquisition, Conceptualization.

#### Declaration of competing interest

Nodir Djanibekov reports financial support was provided by Federal Ministry of Education and Research Bonn Office. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

#### Acknowledgements

The research was conducted as part of the project "Better Understanding of the Adoption of Sustainable Agricultural Practices in Uzbekistan" (UzFarmBarometer). The research team would like to acknowledge financial support from the Federal Ministry of Education and Research (BMBF), Germany (grant number 01DK23012), and the Innovative Development Agency under the Ministry of Higher Education, Science and Innovation of the Republic of Uzbekistan.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.agsy.2025.104574>.

## Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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