Empirical analysis of agricultural crop diversification in Irrigation District 053, State of Colima

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ABSTRACT

Objective: To examine the potential of crop diversification as a risk management strategy in the 053 State of Colima Irrigation District during the 1997/98-2021/22 period.

Design/methodology/approach: The relationship between yield, price, and income risk levels and the degree of diversification in annual agricultural portfolios for the autumn-winter (A-W), spring-summer (S-S) cycles, and perennial crops was analyzed. Diversification was measured using the Herfindahl Index (HI). Risk was interpreted as the instability of the variables, represented by the standard deviation and calculated using Markowitz's mean-variance methodology.

Results: It was found that agricultural portfolio diversification is a useful strategy to reduce price risk in both agricultural cycles, as well as yield and income risk in perennial crops (significantly positive correlations). However, it proved unfavorable for managing these latter two risks in the S-S cycle (considerably negative correlations). It was also observed that in all three crop groups, income risk is primarily determined by price variation (market risk).

Study limitations/implications: The results lose validity when the elements of the variance-covariance matrix in the irrigation district change. The analysis can be complemented by calculating the optimal (analytical) portfolio for each crop group.

Findings/conclusions: It is concluded that, in order to contribute positively to income stability in the irrigation district, special attention should be given to managing price fluctuations (market risk) across the three crop groups and to increasing diversification, particularly in perennial crops.

Keywords: agricultural portfolios, Herfindahl index, risk management.

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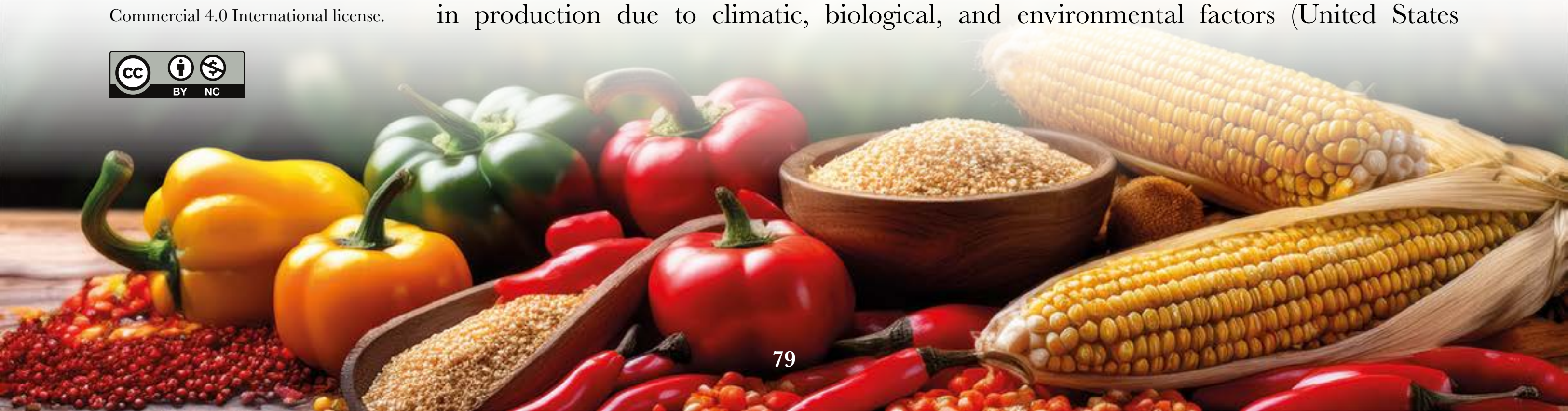
INTRODUCTION

Globally, the agricultural sector experiences significant annual losses and damages in production due to climatic, biological, and environmental factors (United States



Department of Agriculture [USDA], 2021; Food and Agriculture Organization of the United Nations [FAO], 2021). Disruptions in production (yields) and market conditions (prices) caused by these factors lead to pronounced income instability for producers, thereby compromising their economic, productive, and social stability (Duncan & Myers, 2000), as well as the sustainability and prosperity of the agri-food sector, particularly in countries with higher poverty levels (FAO, 2023). In this context, and considering that globally, the majority of people living in extreme poverty (around 80%) reside in rural areas of developing countries and rely primarily on agriculture for their livelihood (FAO, 2021), the implementation of policies, mechanisms, and strategies that offer greater certainty, stability, and economic resilience to producers becomes a top priority (Solano-Alonso *et al.*, 2021). Crop diversification is considered a logical, feasible, and necessary alternative for mitigating risks and uncertainty in farming operations (Deshpande *et al.*, 2007; Khanam *et al.*, 2018; Mango *et al.*, 2018). However, in Mexico, empirical studies clearly demonstrating its benefits remain scarce. The aim of this research was to explore the potential of crop diversification as a risk management mechanism in the 053 Irrigation District, State of Colima, during the 1997/98-2021/22 period. Additionally, trends in diversification, income risk, and expected income in the district were analyzed, and the historical minimum income risk portfolio was identified for the autumn-winter and spring-summer cycles, as well as for perennial crops. The results of this analysis are expected to serve as a reference for producers in the district and neighboring regions to make more efficient allocations of their productive resources.

MATERIALS AND METHODS

Data

The data used for this analysis were obtained from the agricultural statistics section of the irrigation districts, published annually by the National Water Commission (CONAGUA) in Microsoft Excel format. From this dataset, information corresponding to the 053 Irrigation District in the State of Colima was extracted, covering the 25 available agricultural cycles (1997/98-2021/22). The variables considered were: a) area planted (ha), b) yield (tons/ha), and c) rural average price (thousand MX$/ton). Based on variables b and c, a fourth variable was generated: d) income (thousand MX$/ha), calculated as the product of yield and rural average price.

Both the rural average price and income were deflated and expressed in real terms using the National Consumer Price Index (INPC%) provided by the Economic Information Bank of the National Institute of Statistics and Geography (BIE-INEGI), with 2018 as the base year.

The degree of diversification of annual agricultural portfolios was measured using the Herfindahl Index (HI), mathematically defined as:

$$IH = \sum_{i=1}^{n} p_i^2 = \sum_{i=1}^{n} \left(\frac{S_i}{S_T}\right)^2 \tag{1}$$

Where p_i is the proportion of the area planted with the *i*-th crop that makes up the agricultural portfolio, defined as the area under each crop (S_i) between the total cultivated area $\left(S_T = \sum_{i=1}^{n} S_i\right)$. Of course $\sum_{i=1}^{n} p_i = 1$ (Mukherjee, 2012).

The IH takes values between zero and one $(0 < IH < 1)$. A value close to zero $(IH \rightarrow 0)$. indicates a relatively high level of diversification $(i \rightarrow \infty)$, while a value close to unity $(IH \rightarrow 1)$ implies a relatively low level of diversification $(i \rightarrow 1)$. The unit $(IH = 1)$ evidently means perfect specialization $(i = 1)$ (Malaisamy, 2021; Kaur *et al.*, 2021). The reciprocal of the IH $\left(IH^{-1}\right)$ reflects the number of crops on which an agricultural portfolio is concentrated.

Expected Income and Risk

The expected income and risk levels of the annual agricultural portfolios were calculated using Markowitz's (1952) mean-variance model. The expected income was determined using the following expression $\left(E\left[\underline{I}_P\right]\right)$ (Avilés Cano *et al.*, 2006).

$$E\left(\underline{I}_P\right) = p_1 E\left(I_1\right) + p_2 E\left(I_2\right) + \ldots + p_n E\left(I_n\right) = \sum_{i=1}^{n} p_i E\left(I_i\right) \tag{2}$$

With the following conditions: $0 \leq p_i \leq 1$ and $\sum_{i=1}^{n} p_i = 1$; and $E\left(I_i\right)$ defined as (Díaz-Carreño *et al.*, 2007):

$$E\left(I_i\right) = \underline{I}_i = \frac{1}{m} \sum_{i=1}^{n} I_{ij} \tag{3}$$

For its part, the income risk of the portfolios was represented by the variance of their generated income $\left(Var\left[\underline{I}_P\right]\right)$ (Díaz-Carreño *et al.*, 2007), calculated as:

$$\sigma_P^2 = Var\left(\sum_{i=1}^{n} p_i E\left(I_i\right)\right) = \sum_{i=1}^{n} \sum_{j=1}^{n} p_i p_j \sigma_{ij} \tag{4}$$

Provided that $i = j, \sigma_{ij}$ represents the variance of the income of each of the crops that make up the portfolio and when $i \neq j, \sigma_{ij}$ is the covariance of income between crop *i* and crop *j* (Avilés Cano *et al.*, 2006).

The above equation can be rewritten as:

$$\begin{aligned} \sigma_P^2 &= Vp_{n,1}{}' \cdot \Omega_{n,n} \cdot Vp_{n,1} \\ &= \begin{bmatrix} p_1 & p_2 & \cdots & p_n \end{bmatrix} \cdot \begin{bmatrix} \sigma_{11} & \sigma_{12} & \cdots & \sigma_{1n} \\ \sigma_{21} & \sigma_{22} & \cdots & \sigma_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \sigma_{n1} & \sigma_{n2} & \cdots & \sigma_{nn} \end{bmatrix} \cdot \begin{bmatrix} p_1 \\ p_2 \\ \vdots \\ p_n \end{bmatrix} \end{aligned} \tag{5}$$

Where $Vp_{n,1}$ is the vector of shares of each crop, $Vp_{n,1}{}'$ is the aforementioned vector but transposed; and $\Omega_{n,n}$ is the variance and covariance matrix of income $\left[\sigma_{ij}\right]$ among the crops in the portfolio.

The solution to equation five was performed in Microsoft Excel using the following function:

$$\sigma_P^2 = MMULT\left(TRANSPONER\left(Vp_{n,1}\right), MMULT\left(\Omega_{n,n}, Vp_{n,1}\right)\right) \quad (6)$$

RESULTS AND DISCUSSION

Crop diversification analysis

Figure 1 shows the degree of diversification in the annual agricultural portfolios observed in the 053 Irrigation District, State of Colima, during the analysis period (1997/98-2021/22).

As shown, the annual portfolios of perennial crops are generally the most diversified (or least concentrated), with a virtually stable trend over the analyzed period. According to the average Herfindahl Index value (HI=0.1994), the area planted with perennial crops is, on average, distributed among five crops. In contrast, the least diversified (or most concentrated) portfolios correspond to the spring-summer (S-S) cycle. Based on the average HI for these portfolios (0.3692), the planted area is concentrated, on average, in 2.7 crops. Moreover, the standard deviation of the HI in this cycle (13.13%) indicates higher variability in crop diversification over time compared to the autumn-winter (A-W) and perennial cycles, which show standard deviations of 10.93% and 1.84%, respectively. The degree of diversification in A-W portfolios typically falls between the values observed for the other two groups, with an average HI of 0.3247, suggesting that the planted area is, on average, distributed among three crops. It is worth noting that the HI of the cyclical crop portfolios (A-W and S-S) shows an increasing trend over time $(HI \rightarrow 1)$, reflecting a progressive concentration of the planted area in fewer crops —in other words, a clear trend toward specialization.

Analysis of expected revenue and revenue risk

F-I Cycle

Figure 2 presents the expected income $\left(E\left[I_P\right]\right)$ nd income risk levels (σ_i) of the annual agricultural portfolios observed in the FY cycle.

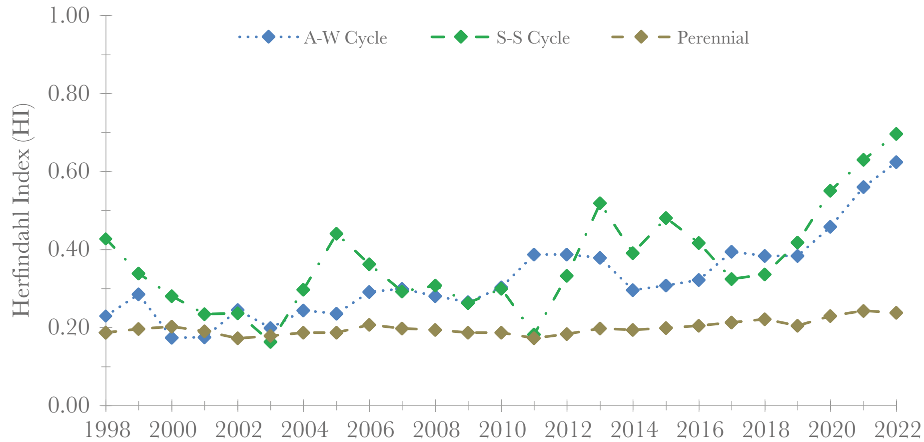


Figure 1. Herfindahl Index of the 053 Irrigation District, State of Colima (1997/98-2021/22).

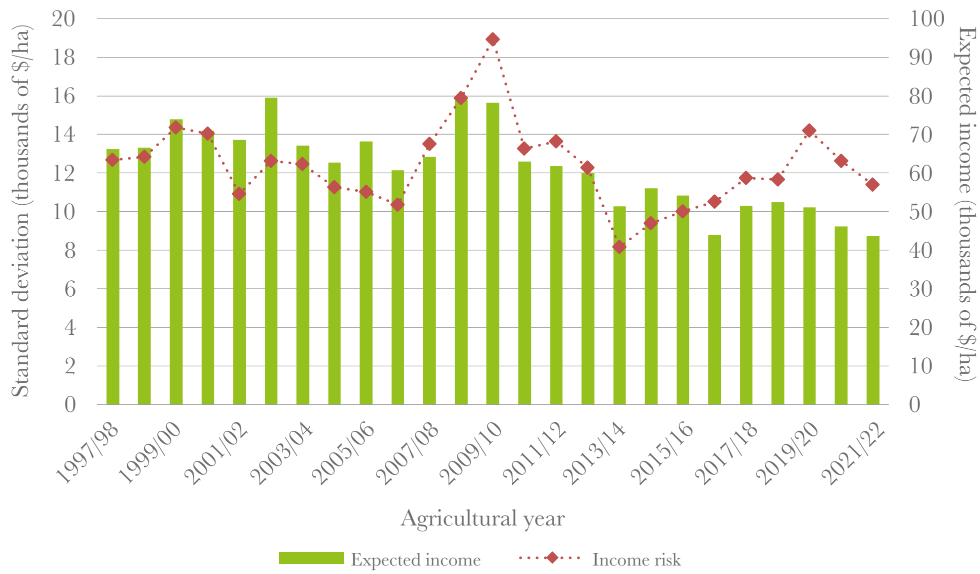


Figure 2. Expected income and income risk in the O-I cycle of DR 053.

As can be observed, the expected income and income risk level of the agricultural portfolios corresponding to this cycle show a moderately positive association, with a correlation of 57.81%. Additionally, a slight downward trend is noted over time. The minimum income risk portfolio for this cycle corresponds to the 2013/14 agricultural year, with its characteristics presented in Table 1.

P-V Cycle

As shown in Figure 3, the expected income and income risk of agricultural portfolios in the P-V cycle exhibit a strong positive correlation (96.28%) and a clear downward trend over the analyzed period. The minimum income risk portfolio identified in this cycle

Table 1. Portfolio of minimum risk of entry in the O-I cycle of DR 053 Edo. Colima.

<table>
<tr><th>Agricultural year</th><th>Assets</th><th>Surface (ha)</th><th>Pi (%)</th><th>Risk (σ_i)</th><th>$E(I_P)$</th><th>IH</th></tr>
<tr><td rowspan="12">2013/14</td><td>Chile</td><td>175</td><td>7.13</td><td rowspan="12">8.166</td><td rowspan="12">51.361</td><td rowspan="12">0.297</td></tr>
<tr><td>Tomato</td><td>9</td><td>0.37</td></tr>
<tr><td>Sweet Corn</td><td>1,109</td><td>45.21</td></tr>
<tr><td>Forage Corn</td><td>5</td><td>0.20</td></tr>
<tr><td>Grain Corn</td><td>697</td><td>28.41</td></tr>
<tr><td>Melon</td><td>106</td><td>4.32</td></tr>
<tr><td>Cucumber</td><td>96</td><td>3.91</td></tr>
<tr><td>Watermelon</td><td>27</td><td>1.10</td></tr>
<tr><td>Forage Sorghum</td><td>90</td><td>3.67</td></tr>
<tr><td>Grain Sorghum</td><td>91</td><td>3.71</td></tr>
<tr><td>Tomato</td><td>48</td><td>1.96</td></tr>
<tr><td>Total</td><td>2,453</td><td>100.00</td></tr>
</table>

Note: Pi=share; σ_i=standard deviation of income (thousands of $/ha); $E(I_P)$=expected income (thousands of $/ha).

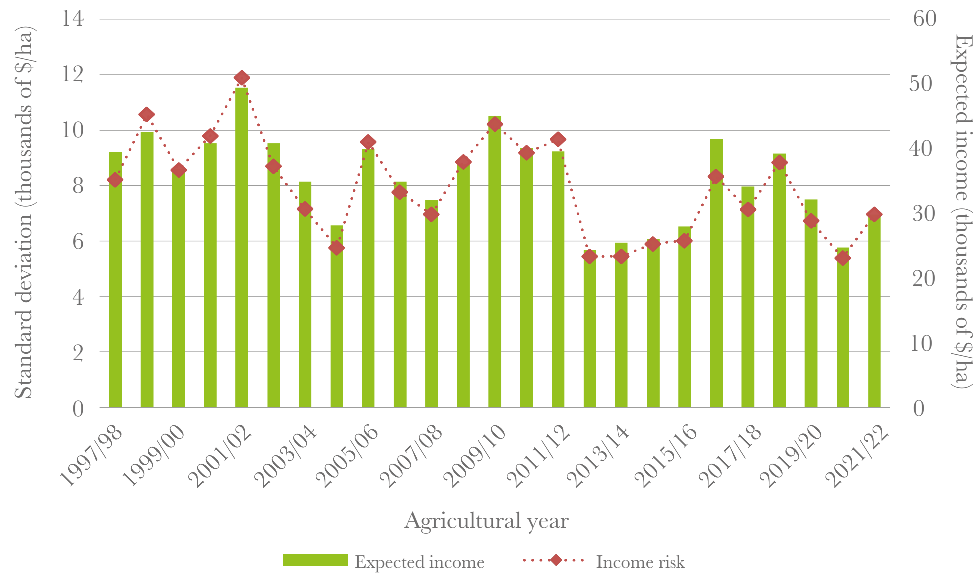


Figure 3. Expected income and income risk in the P-V cycle of DR 053.

corresponds to the 2020/21 agricultural year, the specific characteristics of which are detailed in Table 2.

Perennial crops

As shown in Figure 4, the expected income and income risk of agricultural portfolios for perennial crops display a strong positive correlation (97.77%) and a marked upward trend over time. The minimum income risk portfolio for this group of crops corresponds to the 1998/99 agricultural year, with its components presented in Table 3.

Correspondence analysis between risks and diversification

O-I Cycle

According to the correlations between yield risk (σ_r), price risk (σ_p), income risk (σ_i), and the HI of the annual agricultural portfolios for the O-I cycle in DR 053, State of Colima (see Table 4), greater crop diversification $(IH \rightarrow 0)$ tends to significantly reduce

Table 2. Minimum income risk portfolio in the P-V cycle of DR 053, Colima State.

Agricultural year	Assets	Surface (ha)	Pi (%)	Risk (σ_i)	$E(\underline{I}_P)$	IH
2020/21	Rice	678	78.75	5.390	24.695	0.630
	Sweet corn	54	6.27			
	Grain corn	40	4.65			
	Cucumber	20	2.32			
	Forage sorghum	45	5.23			
	Grain sorghum	24	2.79			
	Total	861	100.00			

Note: Pi=share; σ_i=standard deviation of income (thousands of $/ha); $E(\underline{I}_P)$=expected income (thousands of $/ha).

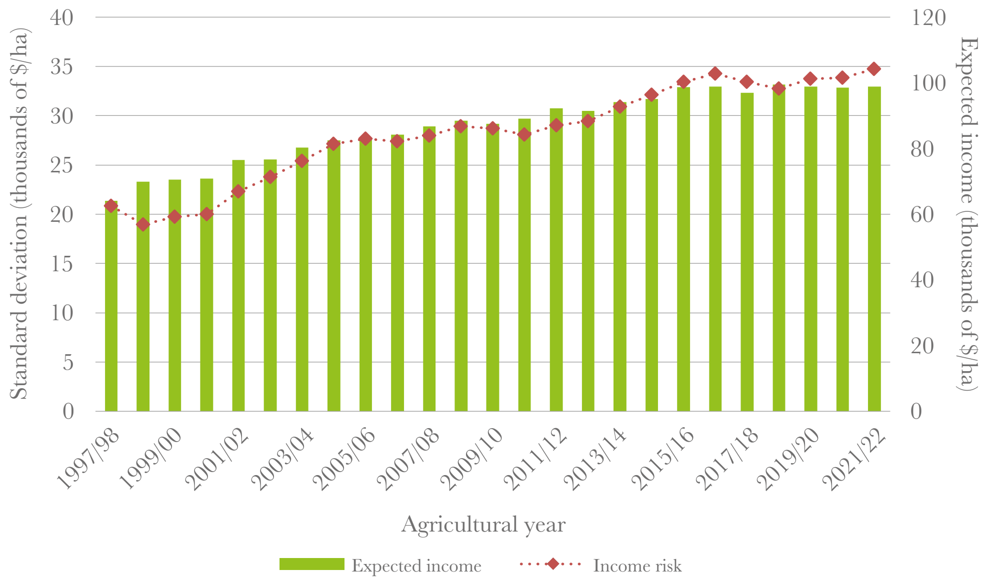


Figure 4. Expected income and risk of entry in perennial crops in DR 053.

Table 3. Minimum entry risk portfolio in perennial crops in DR 053, Colima State.

Agricultural year	Assets	Surface (ha)	Pi (%)	Risk (σ_i)	$E(I_P)$	IH
1998/99	Sugarcane	1,309	7.46	18.952	69.934	0.197
	Coconut tree	761	4.34			
	Associated fruit trees	36	0.21			
	Soursop	82	0.47			
	Lime	20	0.11			
	Lemon	6,338	36.13			
	Associated lemon	3,045	17.36			
	Mango	464	2.65			
	Associated mango	72	0.41			
	Orange	140	0.80			
	Other crops*	83	0.47			
	Papayo	88	0.50			
	Banana	1,227	6.99			
	Associated banana	2,037	11.61			
	Tamarind	123	0.70			
	Others**	1,717	9.79			
	Total	17,542	100.00			

Note: Pi=share; σ_i=standard deviation of income (thousands of $/ha); $E(I_P)$=expected income (thousands of $/ha). *Grouped by CONAGUA, 2023. **Grouped by the author; includes blueberry, Bermuda grass, associated forages, associated soursop, lychee, associated orange, other forages, other grasses, associated papaya, and jackfruit.

price risk (positive correlation of 78%). However, this diversification slightly increases the variability of yields and incomes, as indicated by the negative correlations of 10.9% and 10.7%, respectively.

Additionally, comparing risks (measured by the coefficient of variation [CV]) (see Figure 5), it is clear that income risk in this agricultural cycle is determined to a greater extent by price fluctuations (positive correlation of 89%); although it also corresponds considerably positively with yield uncertainty (correlation of 64%).

P-V Cycle

According to the correlation matrix between risks (measured as standard deviation) and the HI for this agricultural cycle (see Table 5), crop diversification $(IH \rightarrow 0)$ in the P-V

Table 4. Correlations (%) between risks and diversification in the F-I cycle (1997/98-2021/22).

	Crop yield (σ_r)	**Price** (σ_p)	**Income** (σ_i)	**IH**
Crop yield (σ_r)	100.00	26.63	93.91	−10.88
Price (σ_p)	26.63	100.00	29.49	78.13
Income (σ_i)	93.91	29.49	100.00	−10.74
IH	−10.88	78.13	−10.74	100.00

Note: σ_r, σ_p and σ_i are the standard deviations of the expected (average) yield (ton/ha), price (thousands of dollars/ton) and income (thousands of dollars/ha) of the annual agricultural portfolios.

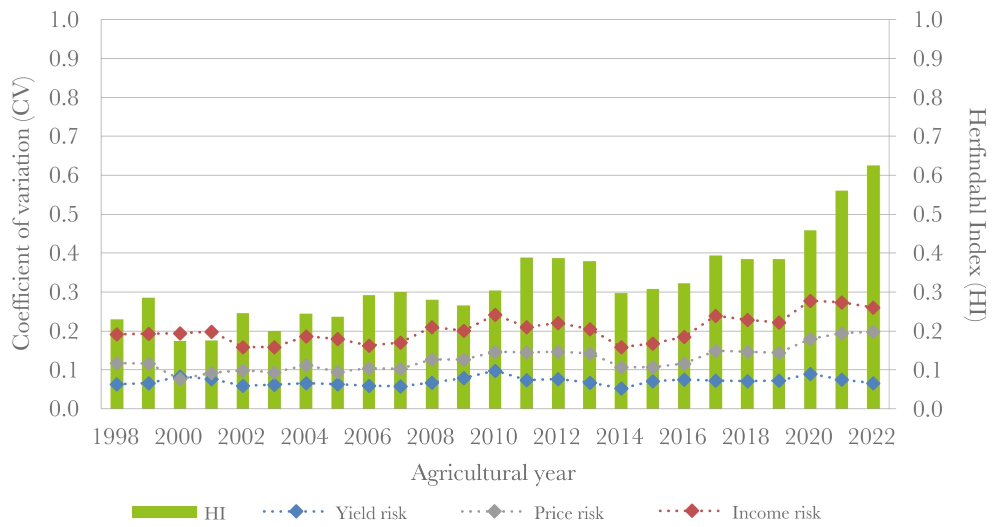


Figure 5. Risks and diversification in the F-W cycle (1997/98-2021/22).

Table 5. Correlations (%) between risks and diversification in the P-V cycle (1997/98-2021/22).

	Crop yield (σ_r)	**Price** (σ_p)	**Income** (σ_i)	**IH**
Crop yield (σ_r)	100.00	−78.70	83.01	−64.47
Price (σ_p)	−78.70	100.00	−56.48	80.07
Income (σ_i)	83.01	−56.48	100.00	−62.44
IH	−64.47	80.07	−62.44	100.00

Note: σ_r, σ_p and σ_i are the standard deviations of the expected (average) yield (ton/ha), price (thousands of dollars/ton) and income (thousands of dollars/ha) of the annual agricultural portfolios.

cycle considerably reduces price risk (positive correlation of 80%), but it also significantly increases the variability of yields and incomes, as indicated by the negative correlations of 64% and 62%, respectively).

Similarly, comparing risks (measured by the CV) (see Figure 6), it is evident that in this agricultural cycle as well, price risk is the main driver of income variation. However, income risk maintains a certain degree of positive association with the dynamics of yields (correlation of 30%).

Perennial crops

According to the correlation matrix between the three types of risk analyzed (measured as standard deviation) and the HI (see Table 6), it is observed that diversification of perennial crops $(IH \rightarrow 0)$ moderately reduces yield risk and income risk (positive correlations of 67% and 61%, respectively).

Reviewing the trends and correlations between risks (measured by the CV) (see Figure 7), it can be inferred that, as with cyclical crops, income risk in perennial crops stems mainly from price uncertainty and is highly associated with the variation in agricultural yields (positive correlation of 81%).

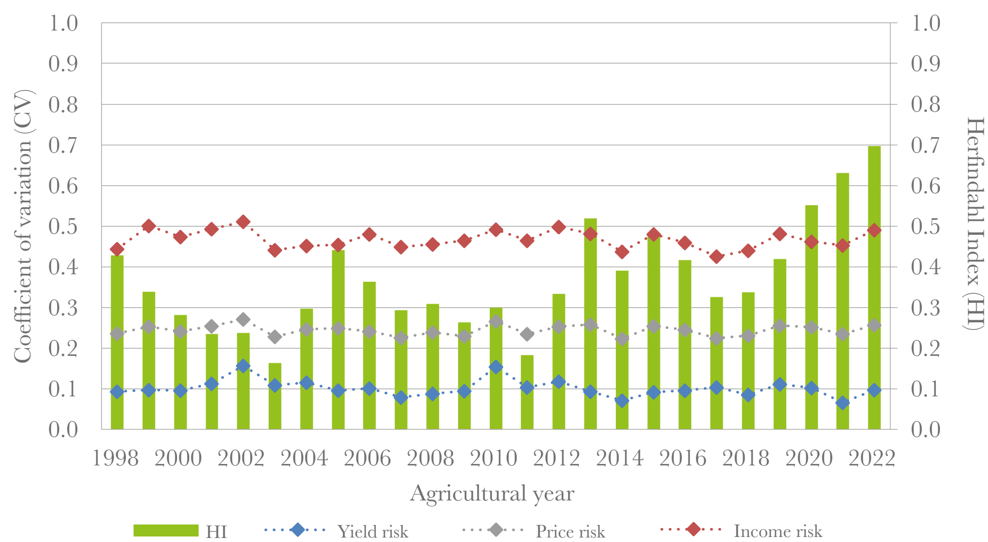


Figure 6. Risks and diversification in the P-V cycle (1997/98-2021/22).

Table 6. Correlations (%) between risks and diversification in perennial crops (1997/98-2021/22).

	Crop yield (σ_r)	Price (σ_p)	Income (σ_i)	IH
Crop yield (σ_r)	100.00	−37.79	91.68	66.67
Price (σ_p)	−37.79	100.00	−52.76	−5.78
Income (σ_i)	91.68	−52.76	100.00	60.92
IH	66.67	−5.78	60.92	100.00

Note: σ_r, σ_p and σ_i are the standard deviations of the expected (average) yield (ton/ha), price (thousands of dollars/ton) and income (thousands of dollars/ha) of the annual agricultural portfolios.

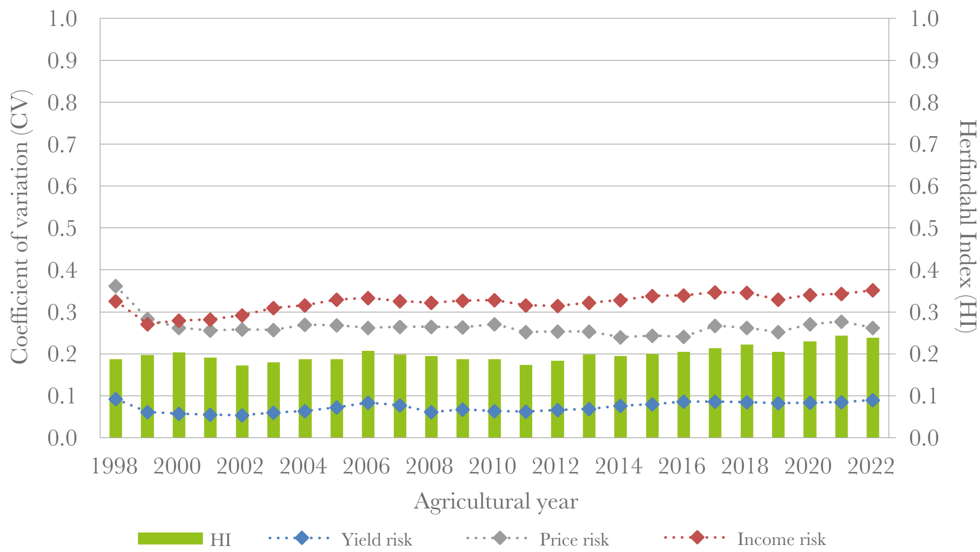


Figure 7. Risks and diversification in perennial crops (1997/98-2021/22).

CONCLUSIONS

The diversification analysis revealed that annual portfolios of perennial crops were generally the most diversified, with an almost flat HI trend over the analyzed period. In contrast, the HIs of agricultural portfolios in the O-I and P-V cycles showed an increasing trend $(HI \rightarrow 1)$, indicating a clear movement toward specialization in both cycles. A moderate positive association was observed between average income and risk level in the O-I cycle portfolios (correlation of 58%) and a very strong correspondence in the P-V cycle (correlation of 96%), both with a declining trend over time. In perennial crop portfolios, the correlation was also highly positive (98%) but showed a distinctly upward trend. The analysis of the relationship between different types of risk and the HI indicated that greater diversification $(IH \rightarrow 0)$ is an effective strategy for significantly reducing price risk in both agricultural cycles, as well as yield and income risks in perennial crops. However, in the P-V cycle, this strategy is less favorable for managing yield and income risk. Additionally, it was found that in all crop groups both cyclical and perennial income risk is mainly driven by price variability (market risk). This suggests that to strengthen income stability in the district, priority should be given to managing price fluctuations and promoting greater diversification, especially in perennial crops. The identified historical minimum income risk agricultural portfolios correspond to the 2013/14 (O-I cycle), 2020/21 (P-V cycle), and 1998/99 (perennial crops) agricultural years, representing a viable alternative for mitigating income instability in the district.

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