Sowing Diversity, Harvesting Profits?

Analyzing economic outcomes of functional crop diversification in changing climatic conditions

Sara Hammer

Degree project/Independent project • 15 credits
Swedish University of Agricultural Sciences, SLU
Faculty of Natural Resources and Agricultural Sciences/Department of Economics
Business and Economics – Sustainable Development
Degree project/SLU, Department of Economics, 1685 • ISSN 1401-4084
Uppsala 2025

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Sara Hammer

Supervisor:	**Shaibu Mellon, Swedish University of Agricultural Sciences, Department of Economics**
Examiner:	Shon Ferguson, Swedish University of Agricultural Sciences, Department of Economics

Credits:	15 hp
Level:	Bachelor´s level, G2E
Course title:	Independent project in Economics
Course code:	EX0903
Programme/education:	Business and Economics – Sustainable Development
Course coordinating dept:	Department of Economics
Place of publication:	Uppsala
Year of publication:	2025
Copyright:	All featured images are used with permission from the copyright owner.
Title of series:	Degree project/SLU, Department of Economics
Part number:	1685
ISSN:	1401-4084
Keywords:	Functional crop diversity, Climate change adaptation, Farm income, Agricultural resilience, Sustainable farming systems

Swedish University of Agricultural Sciences
Faculty of Natural Resources and Agricultural Sciences
Department of Economics

Abstract

Climate change poses increasing risks to agriculture, prompting interest in strategies like crop diversification to improve resilience. This study investigates whether functional crop diversity enhances farmers' economic resilience to temperature variations. Using panel data from 266 Swedish municipalities over 18 years (2001 - 2018), a panel regression analysis was used to examine the effects of temperature, precipitation, and functional crop diversity on farm income, proxied by value added per labor unit. Temperature increases were found to have a significant positive effect on farm income, while precipitation had no significant impact. Functional crop diversity had a negative and insignificant effect on farm income, and the interaction between temperature and functional diversity was also not statistically significant. While functional crop diversity does not appear to influence short-term income, it may still provide long-term ecological benefits. Policymakers may consider supporting diversification to enhance agricultural resilience under climate change.

Keywords: Functional crop diversity, Climate change adaptation, Farm income, Agricultural resilience, Sustainable farming systems

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1. Introduction

Diversified farming could be the strategy that ensures farmers income in uncertain climatic conditions. Not only could it increase farmers' resilience to change in climatic conditions, diversified farming might also ensure a more secure food supply to the population because it could make the food supply less dependent on a consistent favorable climate (Fabri et al., 2024). Additionally, diversified farming decreases the need of using external inputs in the form of fertilizers or pesticides, making the farming more environmentally sustainable (Kremen & Miles, 2012). However, in recent years, the shift towards less diverse farming has been noticeable (Schaak et al., 2023)

This paper aims to investigate the economic outcomes of diversified farming and more specifically functional crop diversity. Crop diversity can be separated into two different groups, related diversity and functional diversity. According to Finney and Kaye (2017) Related diversity is growing a diverse number of crops but they all have the same functions in the ecosystem, for example, growing multiple types of cereals which grow in the same way, uses the same nutrition in the soil and have the same optimal conditions for growth. Functional diversity, however, utilizes different types of crops that have different functions in the ecosystem, for example, one might bind nitrogen in the soil while the other one needs the nitrogen to grow, or one crop needs protection from the scorching sun which the other one provides, this type of diversity could be crucial for the ecosystem functioning (Finney & Kaye, 2017).

However, the scope of this paper is more focused on the potential that functional crop diversity has to increase farmers' resilience in different climatic conditions. As climate change intensifies due to human activities, farmers could choose to adapt by diversifying, and through that reduce the risk of losing their entire income. However, that risk is reduced at the cost of the lower expected income of diversified farms as opposed to monoculture farms that have a higher expected income (Fabri et al., 2024). This thesis aims to answer the question whether functional crop diversity increases farmers' resilience, this is evaluated using an index for diversity and interacting it with temperature. The question is therefore: Does functional diversity increase farmers' resilience to temperature?

As farms get more specialized, a growing body of literature proposes a different approach - highlighting that increasing crop diversity can enhance sustainability by using ecosystem services, while maintaining productivity levels comparable to those of traditional, specialized farming systems. Examples of ecosystem services that can be used for the farms own gain are suppressing weeds, pollination, improved soil quality and pest control (Kremen & Miles, 2012). Additionally, studies have found that diversified farming systems can create employment opportunities without reducing profits, it can therefore be a way to ensure farmers livelihoods and in extension a stable food supply for the population (Sánchez et al., 2022).

Many researchers agree that climate change is one of the biggest environmental problems at this time (IPCC, 2023), one sector that is especially affected by climate change is the agricultural sector which could explain why a lot of research is made on the topic. Climate change could greatly impact production in agriculture and farmers might need to make adaptations to lessen the impact climate change could have on their yields. The types of adaptation of farmers differ, depending on a multitude of factors. For example, size of the farm, type of organization and leadership. Having multiple different farm types that adapt differently could lessen the impact of climate change for the population, but specific farmers could still be vulnerable to losing yield and in extension income (Reidsma et al., 2009). One type of adaptation that seems to catch a lot of attention is diversification, which studies have shown can be a successful strategy at a regional level. However, there is less evidence of diversification having a significant impact on a field level. But, there are studies that show evidence that the yield increases with diverse crop rotation compared to monocultures and that diverse crop rotation can decrease the loss of yield from extreme climate conditions, especially in dry conditions. These results could be due to the positive effects diverse crop rotation has on the soil structure, the organic matter in the soil and the soil's improved water retention capacity (Marini et al., 2020). The stabilization of food systems through increased crop diversity has been found to increase resilience to climate change. One way of increasing resilience to climate change is spreading out the production of crops over multiple farms and therefore spreading out the production risk and the risk that extreme weather events or pest outbreaks reduce the yield. Spreading out production over multiple farms is one way to increase diversity, another is to increase the number of crops grown on one farm. Research shows that a combination of both types is the most efficient way to increase resilience to climate change and stabilize food systems (Egli et al., 2021).

Studies have found that climate change may have different effects depending on the original climate in the region. A temperature increase in a cold climate region can increase the area used for growing crops and therefore increase production, while a warm climate region could experience a decrease in land used for growing crops in the event of a temperature increase. The same applies to precipitation: long-term increases can expand crop land in dry regions but reduce it in humid ones (Cui & Zhong, 2024). As well as climate change might have an effect on the amount of land that can be used for growing crops, climate change could also affect different crops in different ways and some crops might get an increased share of the cropland with rising temperature (Cui & Zhong, 2024).

Crop diversity is an adaptation strategy to climate change that could stabilize agricultural production and therefore make the food system more resilient (Altieri et al., 2015). However, there are many ways to measure diversity, one way is measuring the total number and relative abundance of species, which is called the Shannon diversity index. Another way to measure diversity is through functional diversity, functional diversity separates crops into groups with similar functional traits in the ecosystem and can then be compared to related diversity, which would be calculated using the Shannon index for the respective functional groups (Nilsson et al. 2022). This thesis builds on Nilsson et al. (2022) and contributes to the research by evaluating the possible effect of temperature on farm income and to what extent the effect of temperature depends on the level of functional diversity. This thesis contributes to understanding the economic effects of increased crop diversity compared to monoculture, and whether greater diversity can enhance farmers' resilience to climate change, particularly in response to temperature changes.

The rest of the thesis is structured as follows, Section 2 presents the dataset, highlighting its panel structure across 266 Swedish municipalities over 18 years and the description of key variables like value added per labor unit and the functional diversity index. Section 3 outlines the econometric framework, including the reason for treating temperature as an exogenous variable and the inclusion of interaction terms to test for differing effects. Section 4 presents the core results, notably the positive effect of temperature on farm income and the absence of significant effects of precipitation and functional diversity. Section 5 interprets the results and discusses potential explanations and limitations, and connects them to the previous literature on the subject. Finally, section 6 concludes by considering the implications of the results or future research and policy aimed at increasing climate resilience in agriculture.

2. Data

The data used in this thesis is a panel dataset spanning 18 years from 2001 to 2018. The dataset consists of observations from 266 municipalities (in Swedish: Kommuner). The dataset is constructed using variables gathered from different databases, Statistics Sweden provides informatin on farm characteristics like land, agricultural education and the economic variables. Copernicus E-OBS is used for the climatic variables, temperature and precipitation. Data from Land Parcel Identification System (LPIS) is used to calculate the functional diversity index. The dataset is considered unbalanced because a few municipalities have missing observations for certain years. However, the vast majority have complete data for all years. The dataset consists of aggregate data on all farms in the municipality, however, a few of the variables are expressed as the mean of all the farms in the municipality, in those cases that is clearly mentioned in the explanation of the variable.

The variable VA is farm value added expressed in thousand capitals, sek. Farm value added is standardized by dividing it by labor units, LU, expressed in the number of employees; this is done because of the difference in size of the farms. A large farm with more employees likely gets a greater value added than a farm with a few employees. The variable VA/LU can be used as a proxy for farm income (Nilsson et al., 2022). VA/LU in its logarithmic form is used as the dependent variable in the regression. The data on value added and labor units are collected from Statistics Sweden. Another variable is gross value of production, GVP, expressed in thousand capitals, sek, and also standardized using labor units. The logarithmic form of GVP/LU is used as a dependent variable in the robustness checks and the data is collected from Statistics Sweden.

The variable annual temperature is measured as the average yearly temperature per municipality. The data on annual temperature is gathered from Copernicus EOBS and it is used as an explanatory variable in the regression, it is also used as an explanatory interaction variable with the functional diversity index. In the regression, temperature is an exogenous variable, meaning that it is not correlated with the error term. Another variable is precipitation, which is measured as the total amount of precipitation per year in a municipality. In the regression both precipitation and precipitation squared is included, this is because the possible effect of precipitation is not expected to be linear. The data on precipitation is also collected from Copernicus E-OBS.

Following Nilsson et al. (2022) the data for calculating the diversity indices are gathered from LPIS which is the Land Parcel Identification System, in Sweden managed by the Swedish Board of Agriculture. The LPIS includes information on what crops are grown on a farmers parcel or block where one parcel may include several fields (Reumaux et al., 2023). The diversity indices are calculated in the same way as Nilsson et al. (2022). The variable for functional diversity is calculated through dividing all crops into groups with similar functions in the ecosystem, then calculating the shares of each group on the farm. The calculation can therefore look like this:

$$H^F = - \sum^{k}_{g=1} p_g * ln(p_g)$$

Where pg is the share of land used for crop group g. For this calculation crops are separated into 9 different crop groups, g can therefore be 1, …, 9. The nine different functional groups are, legumes, oilseed, cereals, berries/fruit, vegetables, fodder, energy crops, pasture and fallow. The variable for functional diversity is used as an explanatory variable in the regression. The variable is also used in the interaction variable between functional diversity and temperature.

The variable Age manager is the average age of the managers of the farms in the municipality, the data is collected from Statistics Sweden. This variable is used as a control variable and is expected to reflect the experience and knowledge a farmer could get with age. However, it could also reflect the farmers willingness to adopt new strategies on the farm. It is also expected that experience could increase production and therefore farm income (Nilsson et al., 2022). Land is also included as a control variable to control for the differing sizes of the farms. The variable is expressed as the average land size of the farms in the municipality. This is because production, especially crop production, is largely dependent on the amount of arable land a farm has access to. A variable of clay content in the soil is also used, the data is collected from a digital map displaying the percentage of clay in the soil (Piikki and Söderström, 2019), this is important because the structure of the soil could impact the production on the farm. It is expected that more clay in the soil contributes to a smaller production. The last control variable is agricultural education, this data is gathered from Statistics Sweden and it shows the employees average agricultural education in years. This variable controls for knowledge of agricultural practices on the farm. These four control variables are used in the robustness checks. A Table including the variables explained above follows.

Table 1. Variable explanation

Variable	**Explanation**	**Source**
VA	Farm value added expressed in k sek	Statistics Sweden
LU	Labor units expressed in number of employees	Statistics Sweden
GVP	Gross value of production expressed in k sek	Statistics Sweden
VA/LU	Farm value added divided by labor units, used as a proxy for farm income following (Nilsson et al., 2022)	Statistics Sweden
Functional diversity	Index expressing the average functional diversity on farms in a municipality	LPIS
Annual temperature	Average yearly temperature per municipality	Copernicus E-OBS
Precipitation	Total yearly precipitation per municipality	Copernicus E-OBS
Age manager	Average age of the managers of farms in the municipality	Statistics Sweden
Land	Average land size of the farms in the municipality	Statistics Sweden
Claycontent	Average claycontent	(Piikki and Söderström, 2019)
Agricultural education	Employees average agricultural education	Statistics Sweden

Table 2. Descriptive statistics

	(1)	(2)	(3)	(4)	(5)
Variables	N	mean	sd	min	max
VA	4,418	59,576	71,282	4	673,359
LU	4,418	133.8	148.3	1	1,329
Functional diversity	4,418	56.19	63.86	0	771.0
Temperature	4,418	7.082	1.348	-0.143	10.37
Precipitation	4,418	342.5	88.48	163.5	736.5
Age Manager	4,418	52.65	4.556	22	79
Land	4,418	81.08	46.77	1.250	1,091
Claycontent	4,418	20.05	10.57	0	48.00
Agricultural education	4,418	0.557	0.357	0	9
VA/LU	4,418	439.5	239.3	4	6,584
Number of kommun	266	266	266	266	266

3. Methodology

To investigate the question of how functional diversity increase farmers' resilience to temperature, an econometric method is used. The method used in this paper is an Ordinary Least Squares regression using a panel dataset. The regression analyses are performed in STATA using the xtreg command, which is designed for panel data. The use of an OLS regression is possible because the variable of interest, temperature, is exogenous, meaning that it is not correlated with the error term. The regressions are run using a logarithmic outcome variable making it possible to interpret the coefficients as a 1 unit increase in the independent variable leads to a $\beta * 100$ percentage change in the dependent variable, with all other things being equal.

Firstly, a regression is run using the logarithm of VA/LU as the dependent variable and temperature as the independent variable (function 1). This regression is run to find the potential impact of temperature on VA/LU on farm income. Secondly, a regression is run where precipitation and precipitation squared is also included (function 2). This regression is run to find the potential effect of precipitation on VA/LU and also evaluate the coefficient on temperature. The coefficient on temperature is expected to remain the same in the second regression as in the first because it is an exogenous variable. Both regressions are run using standard errors that are clustered by municipality to adjust for the possible correlation within municipalities and therefore avoid overstated statistical significance. Time fixed effects (α) are also included in both regressions to control for variations like the Covid-19 pandemic or changes in policies. The error term is also included in both regression specifications. The econometric specification of the regressions are as follows:

1) $Ln\ (VA/LU_{it}) = \beta_0 + \beta_1(temperature_{it}) + \alpha + \varepsilon$

2) $Ln\ (VA/LU_{it}) = \beta_0 + \beta_1(temperature_{it}) + \beta_2(precipitation_{it}) + \beta_3(precipitation^2_{it}) + \alpha + \varepsilon$

Thirdly, a regression is run with the same variables and where the functional diversity index is also included (function 3). This regression is run to estimate the potential effect of functional diversity on value added per labor unit (VA/LU). It is reasonable to expect a slightly negative coefficient for functional diversity, as it is often considered more labor-intensive and costly than monoculture. Lastly, a regression where an interaction variable between temperature and the functional diversity index is run (function 4). These regressions are also run using clustered standard errors. The interaction variable is included in the regression because it could be argued that the effect of temperature on VA/LU depends on the level of functional diversity. Time fixed effects (α) are also included in both regressions to control for variations like the Covid-19 pandemic or changes in policies. The error term is also included in the econometric specification. The econometric specification of the regressions is as follows:

3) $Ln\ (VA/LU_{it}) = \beta_0 + \beta_1(temperature_{it}) + \beta_2(precipitation_{it}) + \beta_3(precipitation^2_{it}) + \beta_4(functional\ diversity_{it}) + \alpha + \varepsilon$

4) $Ln\ (VA/LU_{it}) = \beta_0 + \beta_1(temperature_{it}) + \beta_2(precipitation_{it}) + \beta_3(precipitation^2_{it}) + \beta_4(functional\ diversity_{it}) + \beta_5(functional\ diversity_{it} * temperature_{it}) + \alpha + \varepsilon$

The independent variable in the regression is temperature and the main assumption for this thesis is that temperature is an exogenous variable. Exogeneity is assumed because that means that temperature is not correlated with the error term, this matters because if a variable is exogenous the effect it has on the dependent variable can be seen as causal. In this specific case that would imply that the effect temperature has on VA/LU is causal and not just correlated. However, there are also other assumptions that need to hold for it to be possible to interpret the results causally. For example, the model needs to be specified correctly, the functional form must be correct. There cannot be any measurement error in the key variable and the sampling should be random. Lastly, the treatment status of one unit should not be influenced by the treatment of another unit, also known as SUTVA, and there should not be any selection bias.

In addition to these regressions there were also a few robustness checks carried out. Firstly, a regression was run using VA/LU as the dependent variable and temperature as the independent variable, however, control variables that control for age of the manager, the level of agricultural education on the farm, the amount of land on the farm, the amount of labor units and the clay content in the soil was also included to check the robustness of the coefficients. The same thing was done for the second regression which includes the index for functional diversity and the interaction variable for functional diversity and temperature. To further check the robustness of the results the four main regressions are run a second time substituting the dependent variable from VA/LU to GVP/LU.

4. Results

The results of the estimations are presented in Table 3 and Table 4. The results in Table 3 show that temperature has a significant positive effect on VA/LU in both equations 1 and 2. The effect of temperature on VA/LU is 8 percent, if the temperature increases with one degree the value added per labor unit increases by 8%. The result can be interpreted in this way because the dependent variable is in logarithmic form. The result is significant at the 1% level. The Table also shows that precipitation has no significant effect on VA/LU. It is possible that there is an effect when precipitation is extreme, however, the data used for this regression is yearly precipitation and precipitation is rarely extreme enough in Sweden to show a significant increase over a whole year. The yearly data may smooth out the variation in precipitation. To better estimate the effect of precipitation on VA/LU the data would have to be in smaller increments, monthly or possibly even weekly. The estimation of the effect of precipitation in this analysis is reasonable because of the reasoning above.

Table 3. Results for temperature and precipitation

	(1)	(2)
Variables	Ln (VA/LU)	Ln (VA/LU)
Temperature	0.0800***	0.0824***
	(0.0260)	(0.0261)
Precipitation		-0.000502
		(0.000405)
Precipitation^2		2.19e-07
		(4.57e-07)
Constant	5.176***	5.313***
	(0.180)	(0.203)
Observations	4,418	4,418
Number of kommun	266	266

Note: Robust standard errors in parenthesis. *** p<0,01, ** p<0,05, * p<0,1. All regressions include year fixed effects. Dependent variable is VA/LU in logarithmic form.

Table 3 also shows that the coefficient for temperature is relatively unchanged even when precipitation and precipitation squared is added to the regression. This can imply that temperature is not affected by precipitation, this is one of the main assumptions in the thesis, temperature is exogenous and should not be affected by another variable. It should be noted that all regressions include time fixed effects which control for factors that vary over time but are constant across all municipalities.

Table 4 includes the same variables in temperature and precipitation, in this Table however, the index for functional diversity and the interaction variable between temperature and functional diversity. The regression shows the same result regarding temperature and precipitation as the regression in Table 3. The Table shows that the effect of functional diversity on its own has an insignificant negative effect on value added per labor unit. The interaction variable between temperature and functional diversity has an insignificant positive effect on the dependent variable. The intuition of the interaction variable is that the effect of temperature on VA/LU could be dependent on the level of functional diversity. However, because the estimated coefficient is insignificant, it is not possible to say that there are any differences in effect of temperature on VA/LU depending on functional diversity.

*Table 4. Results for functional diversity and functional diversity*temperature*

	(3)	(4)
Variables	Ln (VA/LU)	Ln (VA/LU)
Temperature	0.0820***	0.0816***
	(0.0262)	(0.0272)
Precipitation	-0.000503	-0.000501
	(0.000406)	(0.000402)
Precipitation^2	2.20e-07	2.18e-07
	(4.58e-07)	(4.55e-07)
Functional diversity	4.18e-05	-9.62e-05
	(0.000364)	(0.000733)
Temperature*Functional diversity		1.82e-05
		(9.42e-05)
Constant	5.314***	5.317***
	(0.203)	(0.211)
Observations	4,418	4,418
Number of kommun	266	266

Note: Robust standard errors in parenthesis. *** p<0,01, ** p<0,05, * p<0,1. All regressions include year fixed effects. Dependent variable is VA/LU in logarithmic form.

The results in Table 4 also shows almost identical coefficients on temperature both between themselves and in comparison, to the results in Table 3. As mentioned before, this implies that the estimated coefficient of temperature is correctly estimated.

4.1 Robustness checks

To check the robustness of the results of the regressions a few robustness checks were carried out, the first one was including the control variables to the previous regressions. The complete results of the robustness checks are presented in the appendix. The results of the robustness checks show a small decline in the coefficient of temperature, it is however minimal and it is still significant at the 1% level, shown in Table A1 and A2. Other control variables that can be considered significant are age manager, the variable for land, the variable for labor units and the variable for clay content, shown in Table A1. It is not surprising that the variable for land is significant because it has a great impact on the production of a farm. However, it is surprising that the coefficient for labor units is significant and negative, which would imply that one more employee leads to a decrease in VA/LU of 0,02%, also shown in Table A1. Tables A3 and A4 show the same regressions as in Table 2 and 3 but with the outcome variable being the logarithmic form of GVP/LU. These regressions show similar significance as the main regressions providing support that the coefficient for temperature is correctly estimated.

5. Discussion

The findings presented in this thesis contribute to the growing body of literature on the role of functional crop diversity in building resilience within the agricultural sector, particularly in the context of a changing climate. This discussion unpacks the results of the regression analyses, explores potential explanations and limitations, and relates them to previous research and theoretical frameworks.

In the analysis a clear and significant relationship was found between temperature and farm income, measured as value added per labor unit (VA/LU). The analysis shows that an increase in average annual temperature correlates with an 8% increase in VA/LU, a result that holds across all model specifications and is robust even when control variables are included. This finding aligns with previous research (Cui & Zhong, 2024) suggesting that Swedish agriculture may benefit from moderate warming, possibly due to longer growing seasons and improved conditions for certain crops. However, this positive impact should be interpreted with caution. While the moderate temperature increase may be beneficial in northern regions like Sweden, if the temperature keeps increasing or Sweden experiences more frequent temperature extremes the positive trend may turn negative. The linear structure of the model assumes a constant positive effect of temperature which may not capture the real complexity of the problem. A nonlinear model and data that is measured per season or monthly may be necessary to further investigate the relationship.

The analysis of functional diversity, on the other hand, yields less clear results. The coefficient for functional diversity on its own is negative but insignificant, indicating that more functionally diverse farms do not, on average, generate higher income per labor unit than less diverse ones. This finding appears to support the general assumption that diversification, while ecologically beneficial, may come with economic trade-offs due to increased labor requirements. However, it is worth noting that the negative coefficient is relatively small, and the lack of significance suggests that there is no strong evidence that it has a harmful impact on farm income. This opens an opportunity for further investigation into potential indirect or long-term benefits of functional diversity. For example, functional diversity could enhance soil health, reduce input costs, or stabilize yields over time (Nilsson et al., 2022), especially under more variable climatic conditions.

The interaction term between temperature and functional diversity was included to assess whether diversity modifies the effect of temperature on farm income.

Intuitively, it might be expected that diverse farms have a better buffer against changes in temperature, for example because crops may have different tolerances to heat exposure (Kremen & Miles, 2012; Finney & Kaye, 2017). However, the interaction effect was statistically insignificant and only slightly positive, showing minimal support for the hypothesis in the studied dataset. The reason for this result may come from different factors. First, the level of functional diversity in the municipalities might not vary enough to reveal strong interactive effects. Second, the benefits of diversity may not show in data of annual averages; the data may need to be more frequent to capture the real benefits.

Unlike temperature, precipitation was found to have no significant effect on VA/LU, either in its linear or squared form. The most likely explanation for this is the use of annual precipitation data which may smooth out short-term fluctuations that are more relevant for crop yields, such as periods of drought or intense rainfall during critical growth stages. This result does not necessarily imply that precipitation is irrelevant. On the contrary, other studies have shown that extreme events, particularly droughts, can greatly impact yields (Martini et al., 2020). Future research could benefit from using more frequent data, such as monthly precipitation levels or drought indices, to better capture the timing and severity of water-related stress.

The robustness checks give further confidence to the main findings. When including control variables such as average manager age, education level, labor input, land size and soil clay content, the key result regarding the positive impact of temperature remains stable and highly significant. This indicates that the temperature effect is not confounded by observable farm characteristics. Among the control variables, land had the most intuitive effect. Larger land holdings are associated with higher productivity per labor unit, likely due to economies of scale.

The results of the study can have both theoretical and practical implications. Theoretically, the findings support the view that climate variables can have measurable and economically significant impacts on agricultural outcomes. In Sweden, a country with relatively mild climate stress, moderate warming may still enhance productivity. However, the anticipated resilience benefits of functional diversity were not strongly supported by the data. Functional diversity may offer long-term stability and ecological benefits that are not immediately reflected in short-term economic metrics, especially at the municipality level. For policymakers, this means that encouraging functional diversity may not lead to immediate economic returns for farmers, making it difficult to implement without proper incentives. However, because of the potential benefits presented in other studies it may still be a strategy worth trying, maybe in combination with payment for the ecosystem services it provides.

There are several limitations with this study that should be acknowledged. The use of municipality-level data makes it difficult to see the differences between farms in a municipality. Second, climatic variables were averaged annually, potentially missing the variation within each year. Future research could address these limitations by using higher frequency data for both space and time, or investigate alternative outcome variables like yield variability. Moreover, qualitative research could complement this quantitative analysis by exploring farmers' motivations and perceived barriers to diversification.

6. Conclusions

This thesis investigated whether functional crop diversity enhances farmers' resilience to temperature changes, using municipality-level data from Sweden. The results provide insights into the relationship between climate and economic outcomes in agriculture. While the analysis confirms a strong and significant positive effect of temperature on farm income no significant evidence was found that functional crop diversity on its own, or in interaction with temperature, has a direct impact on income. These findings offer a contribution to the ongoing discussion around the economic implications of diversification in a changing climate.

The positive relationship between temperature and VA/LU could reflect the benefits that a slight increase in temperature may have in colder climates like Sweden, like a longer growing season or improved crop conditions. However, the estimate should be interpreted with caution, as future temperature increases or climate extremes may reverse this trend. Additionally, the linear model may not fully capture nonlinear impacts of temperature on yields, suggesting the need for higher frequency data and more advanced models in future research.

While the coefficient for functional diversity was negative and insignificant, this does not imply that crop diversification harms the farmer economically. It may instead reflect the short-term economic trade-offs of more labor intensive or complex farming systems, which do not yield an immediate increase in productivity. Moreover, functional diversity could yield long-term ecological benefits, such as improved soil health, pest control and weed suppression, that may not be directly observable in this analysis.

The lack of significant effects on the interaction between functional diversity and temperature could be caused by several factors, the annual data used could smooth out variation in temperature in each year or the variation of functional diversity between municipalities could be too small.

In summary, this study supports the view that climate variables significantly affect farm outcomes and that diversification, while not always immediately profitable, remains a promising resilience strategy.

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Appendix 1

Table A1. Results of adding control variables to the regressions including temperature, precipitation and precipitation squared

	(1)	(2)
Variables	Ln (VA/LU)	Ln (VA/LU)
Temperature	0.0800***	0.0653***
	(0.0260)	(0.0215)
Precipitation		-0.000345
		(0.000379)
Precipitation^2		1.03e-07
		(4.24e-07)
Age Manager		-0.00748*
		(0.00430)
Agricultural education		-0.0935
		(0.0888)
Ln (Land)		0.323***
		(0.0587)
LU		-0.000263**
		(0.000111)
claycontent		-0.00578*
		(0.00339)
Constant	5.176***	4.586***
	(0.180)	(0.331)
Observations	4,418	4,418
Number of kommun	266	266

Note: Robust standard errors in parenthesis. *** p<0,01, ** p<0,05, * p<0,1. All regressions include year fixed effects. Dependent variable is VA/LU in logarithmic form.

*Table A2. Results of adding control variables to regressions including temperature, precipitation, precipitation squared, functional diversity and temperature*functional diversity*

	(3)	(4)
Variables	Ln (VA/LU)	Ln (VA/LU)
Temperature	0.0820***	0.0638***
	(0.0262)	(0.0223)
Precipitation	-0.000503	-0.000353
	(0.000406)	(0.000375)
Precipitation^2	2.20e-07	1.11e-07
	(4.58e-07)	(4.20e-07)
Functional diversity	4.18e-05	0.000879
	(0.000364)	(0.000869)
Temperature*Functional diversity		-4.23e-05
		(9.01e-05)
Age Manager		-0.00745*
		(0.00431)
Agricultural education		-0.0900
		(0.0892)
Ln (Land)		0.323***
		(0.0588)
LU		-0.000403
		(0.000256)
claycontent		-0.00560
		(0.00344)
Constant	5.314***	4.574***
	(0.203)	(0.337)
Observations	4,418	4,418
Number of kommun	266	266

Note: Robust standard errors in parenthesis. *** p<0,01, ** p<0,05, * p<0,1. All regressions include year fixed effects. Dependent variable is VA/LU in logarithmic form.

Table A3. Results of regression including temperature and precipitation with Ln (GVP/LU) as the outcome variable

	(1)	(2)
Variables	Ln (GVP/LU)	Ln (GVP/LU)
Temperature	0.103***	0.105***
	(0.0246)	(0.0247)
Precipitation		-0.000520
		(0.000359)
Precipitation^2		2.78e-07
		(4.13e-07)
Constant	5.858***	5.993***
	(0.169)	(0.191)
Observations	4,418	4,418
Number of kommun	266	266

Note: Robust standard errors in parenthesis. *** p<0,01, ** p<0,05, * p<0,1. All regressions include year fixed effects. Dependent variable is GVP/LU in logarithmic form.

*Table A4. Results of regression including temperature, precipitation, precipitation squared, functional diversity and temperature*functional diversity with Ln (GVP/LU) as the outcome variable*

	(3)	(4)
Variables	Ln (GVP/LU)	Ln (GVP/LU)
Temperature	0.106***	0.106***
	(0.0249)	(0.0258)
Precipitation	-0.000517	-0.000516
	(0.000360)	(0.000357)
Precipitation^2	2.76e-07	2.74e-07
	(4.14e-07)	(4.12e-07)
Functional diversity	-9.47e-05	-0.000202
	(0.000275)	(0.000679)
Temperature*Functional diversity		1.40e-05
		(8.53e-05)
Constant	5.991***	5.994***
	(0.191)	(0.198)
Observations	4,418	4,418
Number of kommun	266	266

Note: Robust standard errors in parenthesis. *** p<0,01, ** p<0,05, * p<0,1. All regressions include year fixed effects. Dependent variable is GVP/LU in logarithmic form.

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