PIER

PUEY UNGPHAKORN INSTITUTE
FOR ECONOMIC RESEARCH

Reconciling Climate Resilience and Farm Profitability: Evidence from New Theory Agriculture in Thailand

by

Ali Akram and Kannika Thampanishvong

September 2025
Discussion Paper
No. 239

Reconciling Climate Resilience and Farm Profitability: Evidence from New Theory Agriculture in Thailand

Ali Akram

Independent researcher

Kannika Thampanishvong*

Puey Ungphakorn Institute for Economic Research (PIER)

Abstract

Climate change threatens agricultural sustainability, making the nexus of farm-level adaptation and economic performance a critical area of scientific inquiry. In Thailand, New Theory Agriculture (NTA) is a diversification strategy designed to enhance farmer resilience against climate and market risks. This study provides an experimental evaluation of the NTA's effectiveness, quantifying its impacts by comparing a treatment cohort of NTA adopters against a control group of non-adopters. The analysis reveals that NTA has a statistically significant positive effect on both farm diversification and profitability. Notably, participants in the NTA earned an average of $971 more in net farm revenue per growing season than their counterparts. This result contributes to the literature by empirically challenging the posited trade-off between resilience-oriented diversification and economic returns. Ultimately, the findings demonstrate that NTA represents an effective paradigm for concurrently achieving climate adaptation and economic sustainability in the Thai agricultural sector.

Keywords: New Theory Agriculture; Thailand; climate change adaptation; agricultural diversification

JEL Classifications: Q12, Q18, Q54

* Corresponding author. Puey Ungphakorn Institute for Economic Research, 273 Samsen Rd, Phra Nakhon, Bangkok 10200, E-mail: KannikTh@bot.or.th

1. Introduction

Thailand is increasingly vulnerable to the impacts of climate change, which are characterized by the increasing frequency and severity of natural hazards. Data from the EM-DAT international disaster database confirms this trend, illustrating a marked rise in extreme weather events affecting Thailand (**Figure 1**). Floods are the most prevalent hazard, and are particularly acute in low-lying and riverine regions, such as the Chao Phraya Basin and the Northeastern floodplains. Furthermore, storms and droughts have also occurred with significant frequency, inflicting substantial damage upon the agricultural sector. Projections from climate models, based on Representative Concentration Pathways (RCPs) 4.5 and 8.5, forecast a clear warming trajectory for Thailand, with mean temperatures projected to rise by approximately 3–5°C by the end of the 21st century (**Figure 2**). This degree of warming is expected to exacerbate existing climate risks, including prolonged droughts, intense heatwaves, and erratic rainfall patterns. Such changes pose severe implications for Thailand's agricultural sector, which remains a vital component of the national economy and a primary source of employment for a substantial portion of the population.

The agricultural sector's inherent reliance on specific climatic conditions makes it susceptible to climate variability and natural disasters. A significant portion of Thai farmers are smallholders with limited landholdings (Attavanich et al., 2019). Around 50% of these farm households operate on less than 10 rai (approximately 1.6 hectares), while only 20% possess land exceeding 20 rai (around 3.2 hectares). Furthermore, the limited access to critical resources exacerbates this vulnerability: only 42% of agricultural households have access to water, and a mere 26% are connected to irrigation systems (Attavanich et al., 2019). Consequently, these farmers are highly exposed to the impacts of droughts, floods, and unpredictable weather patterns.

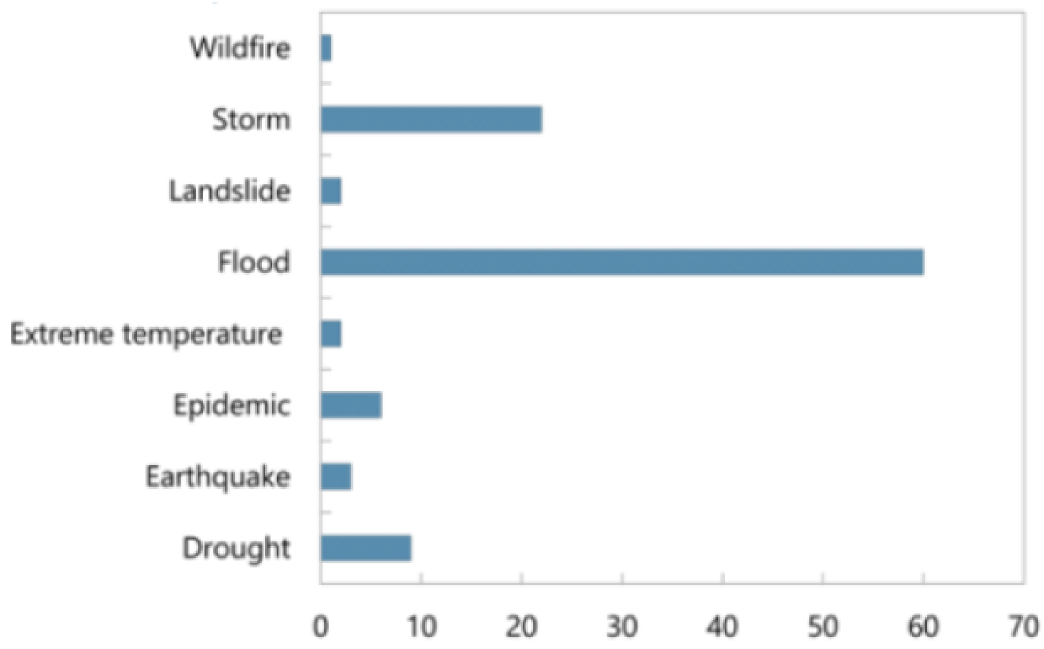


Figure 1 Frequency of natural hazards and extreme weather events in Thailand during 2000-2022

Source: EM-DAT International Disaster Database

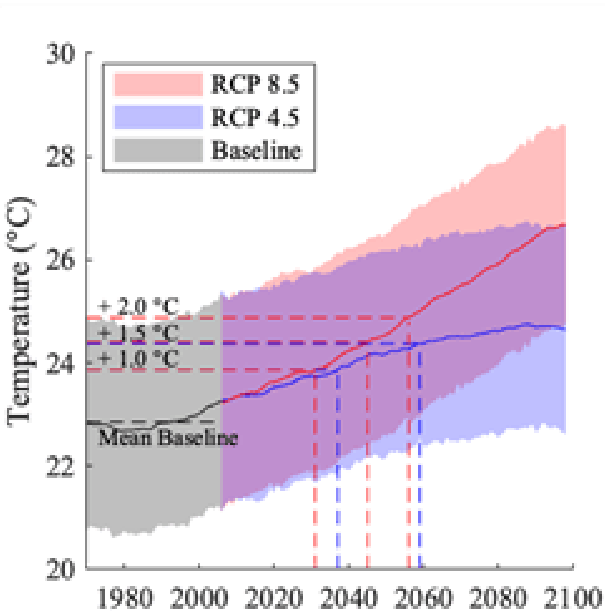


Figure 2 Mean temperature in Thailand during 1980-2100

Source: RU-CORE

A growing body of empirical literature has demonstrated that escalating temperatures and extreme weather events have a substantial negative impact on the value of agricultural output. The inherent reliance of crop, livestock, and fisheries production on specific temperature and precipitation patterns makes them highly susceptible to climatic deviations, which can profoundly compromise productivity. Temperatures exceeding the optimal threshold for crop development are well-documented to diminish yields, with rice exhibiting particular sensitivity during its grain-filling stage (Liu et al., 2021; Song et al., 2022). Sinnarong et al. (2019) further corroborate this by estimating that fluctuations in rainfall and other climatic variables could precipitate a decline in rice yields of up to 16%. The increasing prevalence and severity of extreme weather events, such as droughts and floods, intensify the risks borne by agricultural producers. A study conducted by Prommawin et al. (2024) highlighted the detrimental effect of rising temperatures on Thai agricultural production, underscoring the exceptional vulnerability of monoculture households. Their analysis suggests that a one-degree Celsius temperature increase could result in a 10% reduction in output value. Furthermore, Attavanich (2017) projected that the cumulative economic damages from climate change in Thailand's agricultural sector from 2011 to 2045 could range from 0.61 to 2.85 trillion baht (approximately 18.91 to 88.35 billion USD), with areas lacking irrigation infrastructure incurring the highest losses.

In response to these challenges, the adoption of adaptive agricultural practices is essential for Thai farmers to mitigate climate change risks and secure their livelihoods (Dhakal et al., 2022). Diversification across enterprises, including both crops and livestock, represents a robust adaptation strategy that demonstrably reduces sensitivity to climatic variability (Prommawin et al., 2024). However, this practice has not been widely adopted, as approximately two-thirds of Thai farm households continue to grow a single crop per year, especially key economic crops (Attavanich et al., 2019; Kasem and Thapa, 2011). This reliance on monoculture increases vulnerability to pest and disease outbreaks, as the genetic uniformity of crops offers little resistance to biological threats (Balogh, 2021). Furthermore, monoculture systems weaken the resilience of the ecosystem, making them less capable of withstanding extreme weather events (John, 2021). While crop failure is an intrinsic risk in farming, climate change is projected to intensify both its frequency and severity (FAO, 2015), leaving farmers reliant on a single crop highly exposed to climate-related shocks and potential income loss.

Given the inherent vulnerability of monoculture to climate-induced risks, there is a clear imperative to transition toward more resilient and sustainable farming practices. Crop diversification is a strategy that has been shown to enhance productivity and stabilize the incomes of smallholders (Maggio et al., 2018; Yang et al., 2024). Critically, it allows farmers to distribute production and income risks across multiple crops, thereby mitigating their overall vulnerability to climate-related shocks. Moreover, diversification can confer significant agronomic benefits, such as improved pest management—a particularly pressing concern under changing climatic conditions (Lin, 2011).

New Theory Agriculture (NTA) is a crop diversification plan for farmers. It is an integrated and sustainable farming model targeting smallholder family farms in rural communities, enabling them to reduce their vulnerability to climate change, and increase their financial stability, self-reliance, and food security. To achieve these goals, NTA prescribes integrated or mixed farming to replace monocropping. The core prescription of the NTA farming model is division of farmland into four parts, with a ratio of 30:30:30:10 (Chaipattana Foundation, 2021). The first 30% is designated for on-farm ponds to harvest rainwater during the rainy season and to supply farm water during the dry season. In the areas where there are no irrigation systems or natural water supplies, this on-farm water storage is crucial for the farmers to mitigate the risks of drought during the dry season. The second 30% of farmland is allocated for rice cultivation to fulfil the farm households' consumption needs throughout the year and to cut down food expenses. The third 30% of farmland is set aside for fruit, perennial trees, vegetables, field crops, and herbs for household use and sale of surplus. The last 10% of farmland is allocated for building structures in the farmlands such as houses, roads, and areas for animal husbandry. To be eligible for the NTA program, participants were required to have water storage on their farmlands, own land title deeds or land leasing contracts, and starts on an empty farmland, or the farmland that used to be for monoculture. All participants joined the NTA program voluntarily.

Once enrolled in the NTA program, farmers benefit from a variety of support measures designed to facilitate the implementation of NTA. First, treated farmers receive training on New Theory Agriculture principles and ongoing guidance from local agencies and agricultural experts. Second, farmers enrolled in the NTA are supplied with essential inputs such as organic fertilizers, bio-extracts, and necessary equipment tailored to farmers' needs. In addition, the NTA program encourages farmers to form strong groups for knowledge sharing, and farmers can participate in workshops, field visits to successful model farms, and planning sessions to improve their practices. These supports aim to improve farmers' livelihoods, promote self-reliance, and ensure sustainable agricultural development.

In this paper, we evaluate the impact of the NTA on key economic outcomes for farm households in Thailand. Specifically, we investigate how the adoption of NTA influences household revenue, production costs, overall farm profitability, and food-related expenditures and consumption. By examining these dimensions, we provide empirical evidence on the effectiveness of NTA as a climate-resilient and economically sustainable farming strategy for smallholder farmers.

To evaluate the impacts of the NTA on farm household outcomes, we used a quasi-experiment design that combined pre- and post-intervention survey data for NTA and non-NTA farmers. The experimental framework consists of two groups: a treatment group comprising farmers who participated in the NTA program, and a control group of farmers who did not adopt the NTA. By comparing changes in key indicators—farm revenue, production costs, profitability, and food-related expenditures and consumption—between the two groups over time, the study aims to identify the causal effects of NTA adoption.

The remainder of this paper is organized as follows. Section 2 outlines the research methodology and describes the data sources used in the analysis. Section 3 presents the main empirical findings, focusing on the impacts of NTA on farm household outcomes. Finally, Section 4 is devoted to discuss about NTA as a climate adaptation strategy, while Section 5 contains the concluding remarks and discusses key policy implications.

2. Methodology and data

2.1. Methodology

We use a quasi-experimental design to study the impacts of NTA. Specifically, we use a difference-in-differences estimation strategy to compare temporal changes in key indicators—net farm revenue, revenue variability, food consumption, and food expenditure—between households that adopted NTA and those that did not.

2.1.1 Study design

The analysis for this study is derived from a field study in rural communities where NTA was introduced. While participation was voluntary, eligibility was contingent upon certain criteria. Specifically, farmers were required to have access to on-farm water storage, possess land title deeds or formal leasing contracts, and either develop previously unused land or convert land from monoculture. These requirements were put in place to ensure participants could realistically implement the NTA model, which is predicated on integrated farming and efficient water management.

Since farmers self-selected into the program, households were not randomly assigned to the treatment and control groups. The treatment group is composed of households that adopted and implemented the NTA model, while the control group consists of households that did not participate and maintained conventional farming practices. To support causal inference within a difference-in-difference framework, structured surveys were administered to both groups before and after the NTA's implementation, creating a panel dataset for the analysis.

2.1.2 Empirical estimation

To estimate the impact of NTA, the study uses the following difference-in-difference regression specification:

$$Y_{it} = \alpha + \beta_1 Post_t + \beta_2 Treatment_i + \delta(Post_t \times Treatment_i) + \gamma \boldsymbol{X}'_{it} + \varepsilon_{it}$$

where:

Y_{it} is the outcome variable for household *i* at time *t* (e.g., net revenue, revenue variability, food consumption, or food expenditure).

$Post_t$ is a binary indicator equal to 1 for the post-treatment period and 0 for the baseline.

$Treatment_i$ is a binary indicator equal to 1 if the household is in the treatment group and 0 otherwise.

$Post_t \times Treatment_i$ is the interaction term capturing the difference-in-difference estimator.

$\boldsymbol{X}'_{it}$ is a vector of household-level control variables (e.g., household size, education, land size, access to irrigation).

ε_{it} is the error term.

The coefficient of interest, δ, captures the average treatment effect of NTA on the outcome variable. Robust standard errors are used to account for potential heteroskedasticity and clustering at the village level.

2.1.3 Addressing selection bias

Since farm households were not randomly assigned to control and treatment groups, there can be pre-existing differences between the groups that might influence the outcome. Consequently, matching farm households in treatment and control groups is needed to reduce bias and ensure that any observed differences in outcomes are truly due to the intervention (i.e. NTA), rather than other confounding factors. By creating groups with similar observed characteristics, we can more confidently attribute effects to the treatment. Along with increasing internal validity, matching can also increase the statistical power of a study as it reduces variability between the matched groups, leading to more precise estimates of the treatment effect.

We used Coarsened Exact Matching (CEM) (Iacus et al., 2012). CEM is a non-parametric matching method that allows researchers to temporarily coarsen covariates into meaningful categories and then match units exactly on these coarsened values. This approach reduces imbalance in covariate distributions between groups and improves the robustness of causal inference in observational studies. In our study, farmers were matched based on three key pre-treatment characteristics, namely education level, farming experience and land ownership. Education was classified into three categories: no education, primary education, and secondary education. Duration in the agricultural sector was classified into two categories: less than 10-years of experience and more than 10-years of experience. And finally, land ownership as a binary category was used. These variables were selected based on their relevance to both NTA eligibility criteria and their potential influence on farming outcomes.

A total of 634 farmers were selected for our study: 423 in the control group, and 211 in the treatment group. After executing CEM, a total of 400 farmers were successfully matched: 194 in the treatment group (NTA participants) and 206 in the control group (non-participants). This matched sample was then used in a difference-in-difference estimation to assess the impact of NTA on net revenue, revenue variability, food consumption, and food expenditure. By combining CEM with difference-in-difference, the study strengthens its identification strategy and enhances the credibility of its findings, while acknowledging the limitations inherent in non-randomized program participation.

2.2. Data

This study uses data from farms in Thailand's Central region that were part of the 2018 NTA program.

2.2.1 Sampling

A multi-stage sampling design was used to select the study population. Using the NTA program database of the Ministry of Agriculture and Cooperative, researchers selected three provinces in the Central region of Thailand with the highest NTA enrollment, namely Nakhon Sawan, Lopburi and Chainat (**Figure 3**). From those three provinces, the top three districts, then the top three sub-districts, and finally the top three villages were selected, resulting in a total of 81 villages. From these villages, a total of 634 farmers were initially selected: 211 for the treatment group (NTA participants) and 423 for the control group (non-participants).

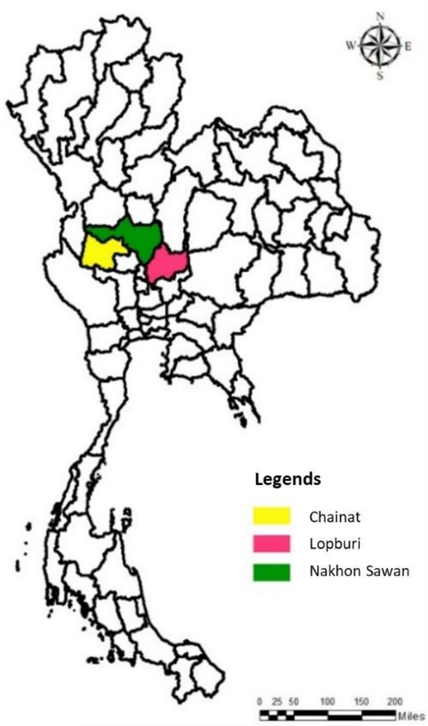


Figure 3: Location for NTA impact evaluation

2.2.2 Data collection

Two rounds of field surveys were conducted to collect panel data: a baseline survey in June 2018 before the NTA program began, and an endline survey in December 2018 after enrollment in the NTA program (**Figure 4**). The baseline survey included all 634 farmers. The endline survey, however, focused on a subset of 400 matched farmers i.e., 194 from the treatment group and 206 from the control group.

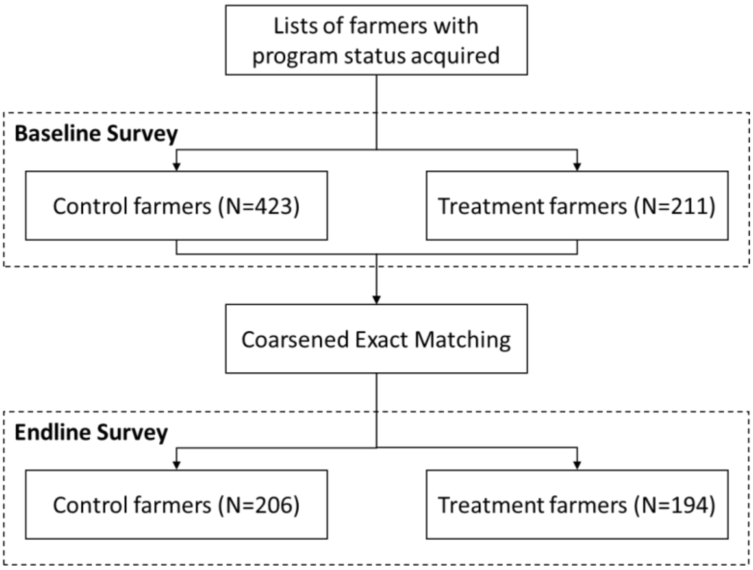


Figure 4: Sample size in the baseline and endline surveys before and after applying Coarsened Exact Matching

2.2.3 Survey process

The data collected for baseline and endline surveys included quantitative data on crop variety, units of each crop type, livestock type and variety, units of each livestock type, fishery type and variety, units of each fishery type, the quantity of fertilizer, the quantity of bio extract, and food sources per household, and revenue. The endline survey also collected additional information on NTA farmers' self-reported change in knowledge of water management, farm management, household accounting, soil conservation, marketing, and bio-agriculture.

We collected data on several key outcome variables, including net revenue, cost of production, agricultural income, probability of zero or negative income, number of crops grown on the farm, food expenditure, food expenditure saving, and additional variables associated with access to agricultural commodities such as types of crops and livestock. For agricultural income, the questions focused on quantities of crops, livestock and fisheries produced and sold, and their prices per unit. We used these to calculate income from the sales of their agricultural output.

To calculate the total costs of production, respondents were asked to identify the quantities and unit price of each type of farm input they were using for each type of their crops, livestock, and fishery. The net revenues were calculated from the total income from crops, livestock and fishery. For food expenditure and food expenditure savings, respondents were asked about their food expenses both during the baseline and endline survey.

To ensure consistency in data collection, both baseline and endline surveys were managed by the same team of enumerators. Before fielding the survey, the research team used "role play" techniques i.e., enumerators enumerate each other using the survey instruments, to improve the questionnaire and remove any ambiguities or errors. There were three teams of enumerators, one responsible for each province and each team was composed of two supervisors. The main duties of the field supervisor included consistency checks of field data, providing suggestions to the enumerators when questions or problems arose, and doing the data coding. Before the field survey, the supervisors contacted the farmers who were randomly selected to schedule the interviews to avoid no-shows. However, if they did not show up on the interview date, the field supervisors would contact the next farmers on their list. After each interview, the field supervisor would go through the completed questionnaire as part of quality control to ensure that all questions were completed without any missing data.

All farmers we approached for the survey were actively consented and could opt out of the survey at any time.

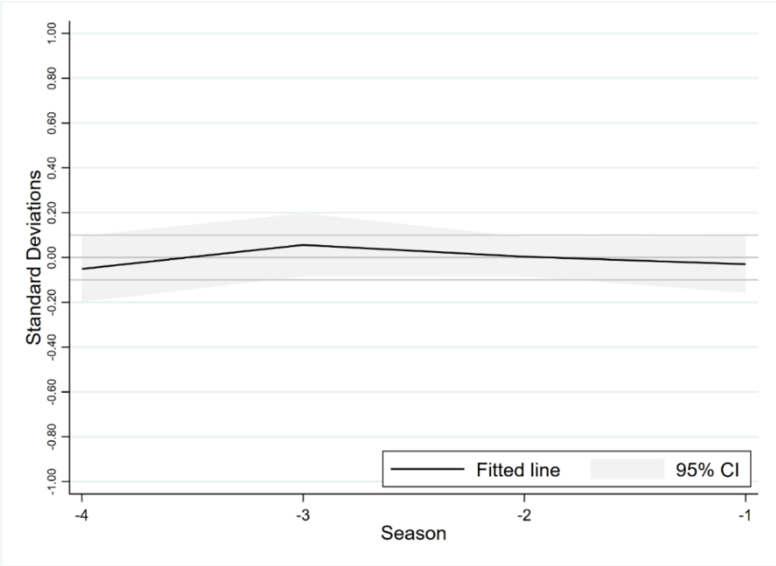
3. Results

3.1. Demonstrating parallel trends

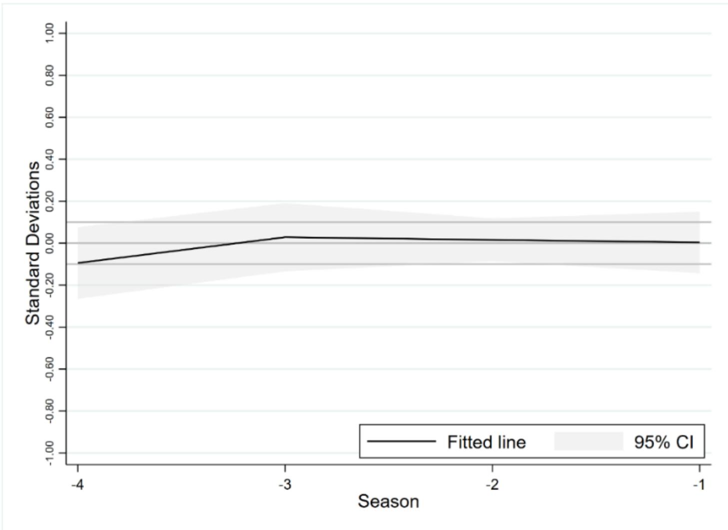
We start by establishing that the two groups of farmers in our study—those who received NTA and those who did not—are comparable. First, we check for the parallel trends assumption

(**Figure 5**) using normalized pre-intervention trends for three key outcome variables: total revenue (**Figure 5a**), total cost (**Figure 5b**), and net revenue (**Figure 5c**). The horizontal axis represents the four seasons leading up to the intervention, with "Season -1" being the last season before the NTA program began. The vertical axis shows the mean difference between the treatment and control groups, normalized in standard deviations of the control group for better comparability. The line in each panel of **Figure 5** shows the normalized difference of the treatment group compared to the control group (the horizontal zero line represents the control value). We subtract the control group's mean from the outcome value for each outcome and divide it by the control group's standard deviation for each season. This enables us to plot the mean difference by season for all four preceding seasons, along with a 95% confidence interval. We find that the treatment group does not differ from the control group; all differences are within 0.1 SD of the control group.

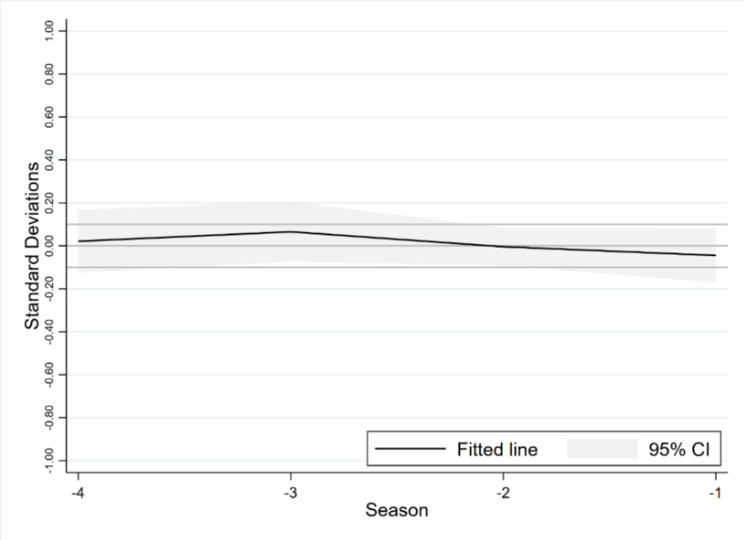
Figure 5 demonstrates that for all three outcomes, the fitted lines representing the mean difference between the treatment and control groups remain close to the zero-horizontal line throughout the four pre-intervention seasons. More importantly, the 95% confidence intervals (shaded grey areas) consistently overlap with the zero line. This indicates that the observed differences between the treatment and control groups are not statistically significant at the 5% level. The minimal deviations from the zero line, all well within 0.1 SD, further confirm that the treatment and control groups were following a very similar trajectory before the intervention.



(a) Total Revenue



(b) Total Cost



(c) Net Revenue

Figure 5: Pre-trends for total revenue (a), total cost (b) and net revenue (c)

The graphs show the difference of the treatment group's total revenue (panel a), total cost (panel b) and net revenue (panel c) with the control group over the previous four seasons leading up to the intervention. The zero line represents the control group, while the plotted line shows the standardized difference. All differences are less than 0.1 standard deviations, suggesting that there is little difference between the control group and treatment group prior to the intervention.

3.2 Balance test of observable characteristics

In addition to the pre-trend analysis, we performed a balance test to confirm the comparability of the treatment and control groups on observable baseline characteristics. **Table 1** shows the results of balance test of pre-treatment characteristics and shows that the matched control and treatment samples are similar to each other on all observed characteristics. This suggests that the matching procedure created two groups that are relatively balanced on a range of crucial demographic and farm-specific variables, including total land size, household composition, education levels, and agricultural equipment ownership. The statistical similarity of these characteristics at baseline reinforces the validity of the parallel trends assumption and strengthens the credibility of our analysis.

.Table 1: Balance test of observable characteristics

Variables	N	(1) Control Mean/SE	N	(2) Treatment Mean/SE	t-test Difference (1)-(2)
Total land rented	190	15.250	191	15.386	-0.136
		[1.743]		[1.570]	
Total land	206	40.889	193	37.807	3.081
		[2.653]		[2.241]	
Marital status	206	1.073	194	1.026	0.047
		[0.032]		[0.032]	
Age	206	55.306	194	55.175	0.131
		[0.752]		[0.783]	
Total household member	206	3.699	194	3.716	-0.017
		[0.115]		[0.119]	
Total adult member	206	3.024	194	2.923	0.102
		[0.093]		[0.092]	
Total farm member	206	1.864	194	1.948	-0.084
		[0.050]		[0.051]	
Total non-farm member	200	0.875	187	0.749	0.126
		[0.086]		[0.070]	
Education	206	2.325	194	2.428	-0.103
		[0.057]		[0.068]	
Spouse education	206	3.320	194	3.448	-0.128
		[0.167]		[0.165]	
Farming experience	206	32.573	194	32.062	0.511
		[0.993]		[1.053]	
Owns tractor	203	0.217	183	0.240	-0.024
		[0.029]		[0.032]	
Owns wheel plough	203	0.719	183	0.781	-0.062
		[0.032]		[0.031]	
Owns water pump	203	0.828	183	0.809	0.019
		[0.027]		[0.029]	
Owns sprayer	203	0.793	183	0.863	-0.070*
		[0.029]		[0.025]	
Owns weed control equipment	203	0.542	183	0.623	-0.081
		[0.035]		[0.036]	
Owns seed sowing equipment	203	0.483	183	0.464	0.018
		[0.035]		[0.037]	
Owns harvester	203	0.034	183	0.027	0.007
		[0.013]		[0.012]	
Owns rice thresher	203	0.005	183	0.005	-0.001
		[0.005]		[0.005]	
Owns rice huller	203	0.010	183	0.022	-0.012

Variables	N	(1) Control Mean/SE	N	(2) Treatment Mean/SE	t-test Difference (1)-(2)
		[0.007]		[0.011]	
Owns milking machine	203	0.005	183	0.005	-0.001
		[0.005]		[0.005]	
Member of agriculture association	206	0.820	194	0.840	-0.020
		[0.027]		[0.026]	
Member of farmer group	188	0.356	166	0.416	-0.059
		[0.035]		[0.038]	
Member of cooperative	188	0.346	165	0.430	-0.085
		[0.035]		[0.039]	
Member of agricultural institute	188	0.021	165	0.006	0.015
		[0.011]		[0.006]	
Member of agriculture rehabilitation group	188	0.037	164	0.055	-0.018
		[0.014]		[0.018]	
Has household debt	206	0.845	194	0.825	0.020
		[0.033]		[0.037]	

The value displayed for t-tests are the differences in the means across the groups. ***, **, and * indicate statistical significance at the 1, 5, and 10 percent critical level.

3.3 Farm profitability

We begin by considering the impacts of NTA on profitability, i.e., net revenue, total cost, total revenue, probability of zero income, and probability of zero or negative net revenue (**Table 2).** We find that net revenue for NTA farmers in the 2018 wet season increased by THB 33,808 (around 971 US dollars) (specification 1 in **Table 2**). To put this in perspective, the average farm income in Thailand was THB 60,272 (1,732 US dollars) per annum (Chantarat et al., 2020). This gain in net revenue results from the decrease in the costs of production of THB 9,863 (283 US dollars; specification 2 in **Table 2**), and an increase in total revenue of THB 23,086 (663 US dollars; specification 3 in **Table 2**). Although these results have lower precision than the main result on net revenue gains, they show that change in the production process made a difference in both input (reflected by the reduced costs) and output (reflected by the increased revenues). We also find that NTA farmers are less likely to report zero income by 12 percentage points and less likely to report zero or negative net revenue by eight percentage points.

Table 2: Impact on profitability

VARIABLES	(1) Net Revenue	(2) Total Cost	(3) Total Income	(4) Zero Income	(5) Zero or Negative Net Revenue
NTA	-9,521.68	-1,160.54	-10,474.90	-0.02	0.04
	(10,387.49)	(7,381.01)	(16,038.62)	(0.02)	(0.03)
Post	-90,119.42***	3,020.77	-86,838.91***	0.42***	0.38***
	(19,089.68)	(3,475.80)	(17,413.76)	(0.06)	(0.07)
NTA x Post	33,808.04**	-9,862.77*	23,085.59	-0.12***	-0.08*
	(14,483.77)	(5,680.03)	(14,583.33)	(0.04)	(0.04)
Constant	53,265.09***	84,299.83***	137,255.78***	0.29***	0.38***
	(16,584.63)	(7,034.37)	(19,817.89)	(0.08)	(0.09)
Observations	800	800	800	800	800
R-squared	0.06	0.00	0.04	0.14	0.12

***, **, and * indicate significance at the 1, 5, and 10 percent critical level.

Next, we analyze farmer production to find what components are driving change (**Table 3**). First, we found that farmers in the NTA program tended to grow more crops. A typical NTA farmer grew about one-fifth (0.17) more crops than a typical non-NTA farmer. We break down the farmer work streams into crops, livestock and fishery and look at the revenue generated and cost incurred for each workstream. We found that the bulk of farmer income gain came from increased crop revenue (THB 21,487 or 617 US dollars), followed by livestock revenue (THB 1,583 or 45 US dollars) and a negligible increase in fishery revenue (THB 16 or 0.46 US dollars). At the same time, we noted that crop and livestock production saw a decline in costs while fishery production costs saw a small increase.

Table 3: Disaggregation of impacts on profitability and diversification

VARIABLES	(1) Number of Crops Grown	(2) Cost: Crop	(3) Income: Crop	(4) Cost: Livestock	(5) Income: Livestock	(6) Cost: Fisheries	(7) Income: Fisheries
NTA	0.32**	-9,360.21	-27,040.68**	7,787.87**	16,341.02*	411.80**	224.76
	(0.12)	(6,012.74)	(12,154.64)	(3,735.74)	(8,926.58)	(152.94)	(178.19)
Post	0.16***	3,605.61	-86,650.54***	-680.99	-183.51	96.15**	-4.85
	(0.06)	(3,635.43)	(17,511.33)	(1,909.55)	(264.90)	(44.42)	(21.40)
NTA x Post	0.17*	-6,328.48	21,487.20*	-4,288.83	1,582.71	754.55*	15.68
	(0.10)	(4,623.79)	(12,178.49)	(3,457.51)	(6,562.44)	(399.29)	(37.56)
Constant	1.49***	81,932.56***	132,364.81***	2,351.24	4,873.98	16.03	16.99
	(0.10)	(6,774.50)	(18,744.95)	(1,639.67)	(3,930.45)	(9.57)	(17.45)
Observations	800	800	800	800	800	800	800
R-squared	0.05	0.01	0.07	0.01	0.01	0.03	0.00

***, **, and * indicate significance at the 1, 5, and 10 percent critical level and robust standard errors are contained in the parentheses.

3.4. Farmer food expenditure and consumption

Our next set of results look at farmer food expenditure and consumption (**Table 4**). In **Table 4** we explored the results related to expenditure and non-protein food consumption and in **Table 5** we explored the results related to the consumption of protein-rich foods. Specification (1) in **Table 4** suggests that farmers in our treatment group do not incur any additional food expenditures compared to those in the control. When asked if they saved money on their staple food by consuming on-farm produce more than they did in the previous season, we found that farmers in the treatment group saved a small amount, THB 27 (0.78 US dollars). So, farmers maintained their overall level of food expenditure but saved on certain categories of their staple foods. Furthermore, they do not report a change in consuming vegetables they grew. NTA participants were 14 percentage points more likely to consume fruits from their own farms.

Table 4: Impacts of NTA on food expenditure and non-protein food consumption from own sources

VARIABLES	(1) Food Expenditure Incurred	(2) Savings on Food Expenditures	(3) Vegetables	(4) Fruits
NTA	-5.72	0.54	0.12***	0.07
	(6.95)	(3.09)	(0.03)	(0.06)
Post	24.02***	-21.48***	-0.15***	-0.23***
	(8.55)	(5.77)	(0.05)	(0.04)
NTA x Post	7.32	27.05*	-0.05	-0.14**
	(25.10)	(15.65)	(0.05)	(0.06)
Constant	150.95***	55.40***	0.80***	0.48***
	(7.83)	(5.10)	(0.03)	(0.03)
Observations	799	799	799	799
R-squared	0.00	0.01	0.06	0.10

***, **, and * indicate significance at the 1, 5, and 10 percent critical level and robust standard errors are contained in the parentheses.

Next, we looked at the variety of proteins consumed in food (**Table 5**). We found that consumption of eggs increased in the NTA group. The number of NTA farmers who consume eggs is 16% higher than the control group. Given many sources of protein available, we grouped them into two indices – one for protein (encompassing all types) and one for protein from poultry (i.e., just increased protein consumption from chicken and duck). The results for these indices are shown in specifications (8) and (9) in **Table 5**. The coefficient of interest for both is positive, though of a small magnitude and not statistically significant at conventional levels.

Table 5: Impacts of NTA on protein intake

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
VARIABLES	**Fish**	**Chicken**	**Duck**	**Pork**	**Beef**	**Chicken Egg**	**Duck Egg**	**Composite index for all protein sources**	**Composite index for protein from poultry**
NTA	0.08*	0.05*	0.01	0.01	0.01	0.11***	0.02	0.18***	0.21**
	(0.04)	(0.02)	(0.01)	(0.01)	(0.01)	(0.03)	(0.02)	(0.05)	(0.09)
Post	-0.17***	-0.03*	-0.00	-0.00	-0.00	-0.02*	-0.00	-0.17***	-0.09
	(0.06)	(0.02)	(0.01)	(0.00)	(0.00)	(0.01)	(0.02)	(0.05)	(0.06)
NTA x Post	0.06	-0.02	0.00	-0.01	0.02	0.16***	-0.03	0.07	0.01
	(0.06)	(0.02)	(0.01)	(0.01)	(0.01)	(0.04)	(0.02)	(0.08)	(0.09)
Constant	0.48***	0.07***	0.00	0.00	0.00	0.05***	0.03**	0.09*	0.04
	(0.05)	(0.01)	(0.01)	(0.00)	(0.00)	(0.01)	(0.01)	(0.05)	(0.05)
Observations	799	799	799	799	799	799	799	799	799
R-squared	0.03	0.01	0.01	0.00	0.01	0.10	0.00	0.04	0.02

***, **, and * indicate significance at the 1, 5, and 10 percent critical level and robust standard errors are contained in the parentheses.

4. Discussion: NTA as a climate adaptation strategy

The empirical evidence from our study strongly suggests that the NTA has the potential to be a highly effective strategic response for smallholder farmers to the increasing risks posed by climate change. The NTA's core principle of diversification is a powerful mechanism for not only enhancing economic profitability but also building resilience against climate variability. Crop diversification is widely recognized as a key means for farmers to adapt to climate change (Belay et al., 2017; Dittmer et al., 2023; FAO, 2019; Kiani et al., 2021; Makate et al., 2016; Van Etten, 2019). At the same time, there is a large literature which documents that diversification tends to reduce farmer efficiency therefore farmer profitability (Jones et al., 2023; Komarek et al., 2018; Kurdyś-Kujawska et al., 2021; Li et al., 2023; Mzyece and Ng'ombe, 2020). We have shown that NTA—a type of diversification program for farmers—is able to substantively increase farmer diversification thus climate resilience while increasing farmer profit. This is significant, as we do not see the typical loss in profits typically associated with diversification. More significantly, NTA does not introduce diversification without affecting profits – it successfully introduces diversification with an *increase* in farmer profits.

To understand the specific pathways through which NTA delivers these benefits, we conducted a granular analysis of its impact on production components. The data reveals that farmers enrolling in the NTA significantly increased the number of crops they cultivated, a direct behavioral change consistent with the model's recommendations and the principles of climate change adaptation. This shift to a more diversified crop mix led to a fundamental change in the farmers' income streams. Specifically, the increase in total income was overwhelmingly driven by crop production. While the reduction in costs was also substantial, its proportional distribution was more balanced, with crop production contributing 64% of the total cost reduction. Livestock production played a supporting role, contributing a smaller but still significant 7% to the total revenue increase and a more substantial 36% to the cost reduction. In contrast, changes in fishery production were found to be negligible.

This disaggregated analysis provides a clear picture of the synergistic benefits of the NTA. The model's emphasis on cultivating a variety of crops, livestock, and fisheries enables a more constant and reliable flow of income throughout the year, as opposed to the seasonal and often volatile income from a monoculture system. By spreading production across multiple enterprises, farmers are less exposed to the catastrophic impacts of climate shocks, such as a drought or flood that could wipe out a single harvest. This diversification thus significantly reduces income variability and enhances the overall financial stability and resilience of the farm household.

Our findings confirm that farmers enrolled in the NTA successfully modified their production practices in alignment with the program's recommendations. This shift included moving from monoculture to a diversified crop mix and integrating practices such as using animal manure for fertilizer and recycling on-farm water. The most promising result is that these changes, while designed for diversification, also delivered a significant increase in profitability for the farmers. This dual benefit makes the NTA a highly attractive and scalable solution for addressing climate change adaptation in the agricultural sector.

5. Conclusion and policy implications

Our study provides compelling empirical evidence that the NTA model represents a viable and effective strategy for smallholder farmers to adapt to climate change. Our findings demonstrate that NTA is more than a simple adaptation strategy; it is a profitable one, successfully threading the needle between diversification and financial gain. The program's core principle of diversification, which incorporates complementary farming activities like crops, livestock, and fisheries, led to a significant increase in farmers' net revenue.

Our results have two implications: a short-term implication for farmer welfare, and a long-run implication for farmer welfare grounded in adaptation to climate change. The short run implication is increased farmer welfare: the NTA resulted in substantial benefits for smallholder farmers. Relatively simple and easy-to-implement farming methods produced impressive improvements to farm enterprises, with real gains in revenue and lower costs of production, resulting in higher profit. Additionally, farmers generated sufficient yields for both household consumption and income generation, increasing the overall quality of life. Thus, NTA is a useful tool for policymakers to improve farmer welfare in the short run – it is a useful policy regardless of climate change.

The long-term policy implication is the improved potential of NTA farmers to adapt to climate change since we found strong evidence that farmers did diversify their crop mix. Our findings in this regard are remarkable as they thread the needle of profitability while addressing climate resilience. Farmers around the world over focus their practice by monocropping to maximize profit i.e., they choose not to diversity their crops in order to protect profitability (Howden et al., 2007). Yet, crop diversification is seen as a technique with strong adaptive potential for a changing climate (Antonelli et al., 2022; Howden et al., 2007; Lin, 2011; Vernooy, 2022). Thus, seemingly, the profitability of specialization is at odds with the resilience that diversification delivers. However, NTA is able to deliver on both i.e., it is a profitable way to diversify which sets farmers up to be better adapted to a changing climate.

While this is an encouraging set of results, what lessons does it present that policymakers in other contexts can carry over? Our data are limited therefore we can conjecture based on local (Thailand) facts. We suggest that there are two possible reasons for these positive results. First, the institutional and environmental setting in which this program was rolled out likely played a role in its success. The success of any diversification program depends heavily on local institutional and environmental conditions (Delgado and Siamwalla, 2018). Examples of factors that determine whether farmers adopt a farming system—such as diversification in our case—include their access to inputs, local agricultural policy, market outlets for agricultural produce and geophysical environment. This variation in the institutional and physical environments results in farm households being subject to different transaction costs for producing and selling the same output mix (Akerlof, 1970; Lopez, 1984;De Janvry et al., 1991). Additionally, local policy also plays a role e.g., price distortion in the form of price subsidies or differential protection of some specific crops, can reduce incentives for crop diversification but instead lead to overspecialization (Delgado and Siamwalla, 2018).

Second, the program was well calibrated to local farmers, suiting their existing practices and conditions. Farmers were asked to diversify by focusing on agricultural activities that complemented each other, using their diversified production to save costs by recycling inputs of production e.g., using livestock manure to save on chemical fertilizer. Farmers also leveraged the presence of economies of scope (Chavas and Di Falco, 2012; Kim et al., 2012). Economies of scope are generated when inputs are shared, and the cost of producing two or more product lines is less than the cost of producing each product separately. Thus, farm households might choose to diversify agricultural production to take full advantage of economies of scope producing complementary items, such as eggs, poultry, fish and vegetables, and selling a fuller range of products to market (Benedek et al., 2021). In addition, farmers could put together a combination of agricultural production practices that had a variety of income frequencies: vegetables that could be harvested and sold on a daily or weekly basis, perennial crops that could be harvested on a monthly or quarterly basis, and field crops that could be harvested or sold on a semi-annual or annual basis. In this way, farmers had a stable income throughout the year. Moreover, they also used their diverse agricultural production for own-consumption to save on food expenditures. Thus, the NTA "recipe" had a lot of features that were attractive for farmers, enabling them to genuinely improve their farm enterprise and own wellbeing.

Consequently, to promote the NTA and reduce barriers to its adoption, policymakers must focus on providing crucial support related to land tenure, water resource access, knowledge transfer, and technology access:

- Provide financial and technical support for water infrastructure: The government, possibly through an agricultural and/or development bank e.g., the Bank for Agriculture and Agricultural Cooperatives (BAAC) in Thailand, should offer subsidized loans or grants to help smallholders construct on-farm ponds and other water storage systems. This could be coupled with technical assistance to ensure the infrastructure is designed and built correctly for efficient water management. Providing access to cost-effective water pumps and irrigation equipment would also reduce the financial burden on farmers.

- Formalize land tenure: A significant number of smallholder farmers lack formal land title deeds, which prevents them from accessing credit and participating in programs like NTA. Policies should be enacted to streamline the process of land titling or to create alternative legal frameworks, such as long-term leasing contracts, that provide a similar level of security. This would enable more farmers to meet the program's eligibility requirements and invest in their land.
- Establish public-private partnerships: Policymakers should facilitate partnerships between government agencies, NGOs, and private companies to support adoption of diversification programs like the NTA. These partnerships could provide a range of services, including subsidies for agricultural inputs, access to affordable tools and technology, and training programs on diversified farming techniques. Private sector involvement can also help establish reliable market linkages for the diversified produce, ensuring farmers have a stable outlet for their goods.
- Develop context-specific models: While NTA is highly effective, it may not be suitable for all regions or farm types. It is crucial to develop alternative or adapted models of diversified farming that do not require extensive land or water resources. This could include promoting small-scale urban agriculture, vertical farming, or community-based farming cooperatives in areas where individual resources are scarce. This approach ensures that the benefits of diversification are accessible to all farmers, regardless of their land or resource constraints.
- Enhance knowledge and training: It is not enough for farmers to simply have access to resources; they need the knowledge to use them effectively. The government should establish extension services and farmer field schools that provide tailored training on how to select suitable crop mixes for their specific soil type, climate, and market conditions.

These programs should also educate farmers on integrated pest management and sustainable farming practices that complement the NTA model.

- Unlock access to technology: To fully realize the benefits of NTA, farmers need access to modern agricultural technology. Policymakers should create programs that subsidize or provide low-cost access to tools like soil moisture sensors, weather forecasting apps, and simple drip irrigation systems. These technologies can help farmers make informed decisions, optimize resource use, and enhance productivity.

Taken together, our results show that the diversification and profitability needle can be threaded – the NTA program demonstrates this. This is a useful result for policymakers as they contend with climate change adaptation. We do note that our results and the conclusions we draw from them are not meant to suggest that diversification alone is sufficient to protect farmers from a changing climate. Adaptation to a changing climate is a dynamic and coordinated multi-sectoral approach that takes into account specific local conditions for any given set of farmers (Howden et al., 2007). The type of diversification that NTA recommended was tailored for the specific context it was deployed in – and it worked well. The broad concept of diversification will need to be interpreted for and need to respond to the nuances of the specific context in which it is deployed. NTA certainly adds to the evidence base for effectively devised and deployed diversification as a way to adapt to a changing climate.

Despite these compelling results, our study has three key limitations that should be considered. First, our reliance on farmer recall to collect pre-intervention data on historical income and production costs introduces a potential for recall bias. While we expect this bias to be similar across both groups, it is an inherent limitation of the data. Second, our endline survey was conducted over a relatively short timeframe—one growing season. The full, long-term impacts of the NTA program may take longer to materialize, highlighting the need for future studies with a longer follow-up period to assess sustained effects. Finally, our study's geographic scope was limited to three provinces. While this was necessary for feasibility, future research should expand the study area to test the scalability and generalizability of the NTA model in other regions.

References

Akerlof, G. (1970). The Market for Lemons: Qualitative Uncertainty and the Market Mechanism, *Quarterly Journal of Economics*, 84, 488-500.

Antonelli, C., Coromaldi, M., and Pallante, G. (2022). Crop and income diversification for rural adaptation: Insights from Ugandan panel data. *Ecological Economics*, 195, 107390.

Attavanich, W. (2017). Effect of Climate Change on Thailand's Agriculture: New Results. Working Paper#25/2017. Department of Economics, Kasetsart University.

Attavanich, W., S. Chantarat, J. Chenphuengpawn, P. Mahasuweerachai, and K. Thampanishvong (2019). Farms, Farmers and Farming: a Perspective through Data and Behavioral Insights, PIER Discussion Paper No. 122.

Balogh, A. (2021). The rise and fall of monoculture farming. Horizon: the EU Research and Innovation Magazine, 13 December 2021.

Belay, A., Recha, J. W., Woldeamanuel, T., & Morton, J. F. (2017). Smallholder farmers' adaptation to climate change and determinants of their adaptation decisions in the Central Rift Valley of Ethiopia. *Agriculture & Food Security*, *6*(1), 24.

Benedek, Z., I. Ferto, C. G. Marreiros, P. M. de Aguiar, C. B. Pocol, L. Cechura, A. Poder, P. Paaso Z. Bakues (2021). Farm diversification as a potential success factor for small-scale farmers constrained by COVID-related lockdown. Contributions from a survey conducted in four European countries during the first wave of COVID-19. PLoS One, 16(5).Chaipattana Foundation (2021). New Theory Agriculture. Available at https://www.chaipat.or.th/eng/concepts-theories/sufficiency-economy-new-theory.html

Chaipattana Foundation (2021). Agricultural Development. Available at the following url: https://www.chaipat.or.th/eng/index.php/our-work/agricultural-development

Chantarat, S., A. Lamsam, N. Adultananusak, L. Ratanavararak, C. Rittinon and B. Sa-ngimnet (2020). Distributional Impacts of Covid-19 Pandemic on Agricultural Households. PIER Discussion Paper.

Chavas, J. P. and S. Di Falco (2012). On the role of risk versus economies of scope in farm diversification with an application to Ethiopian farms. *Journal of Agricultural Economics*, 63(1), 25-55.

Dhakal, C., Khadka, S., Park, C., Escalante, C.L. (2022). Climate change adaptation and its impacts on farm income and downside risk exposure. *Resources, Environment and Sustainability*, 10.

Dittmer, K. M., Rose, S., Snapp, S. S., Kebede, Y., Brickman, S., Shelton, S., ... & Wollenberg, E. (2023). Agroecology can promote climate change adaptation outcomes without compromising yield in smallholder systems. *Environmental Management*, *72*(2), 333-342.

De Janvry, A., M. Fafchamps, and E. Sadoulet (1991). Peasant Household Behaviour: Some paradoxes explained. *The Economic Journal,* 101, 1400-1417.

Delgado, C. L., and Siamwalla, A. (2018). Rural economy and farm income diversification in developing countries. In Food Security, Diversification and Resource Management: Refocusing the Role of Agriculture? (pp. 126-143). Routledge.

FAO Food and Agriculture Organization of the United Nations (2015). Climate change and food security: risks and responses. United Nations.

FAO Food and Agriculture Organization of the United Nations, Economic and Policy Analysis of Climate Change Team. (2019). *Cropping systems diversification to enhance productivity and adaptation to climate change in Malawi* (FAO Technical Brief).

Howden, S. M., Soussana, J. F., Tubiello, F. N., Chhetri, N., Dunlop, M., and Meinke, H. (2007). Adapting agriculture to climate change. *Proceedings of the national academy of sciences*, 104(50), 19691-19696.

Iacus, S. M., King, G., & Porro, G. (2012). Causal inference without balance checking: Coarsened exact matching. *Political analysis*, *20*(1), 1-24.

John, J. (2021). Monoculture Could Worsen Vulnerability to Climate Change. Available at the following url: https://foodtank.com/news/2021/02/monoculture-could-worsen-vulnerability-to-climate-change/

Jones, S. K., Sánchez, A. C., Beillouin, D., Juventia, S. D., Mosnier, A., Remans, R., & Carmona, N. E. (2023). Achieving win-win outcomes for biodiversity and yield through diversified farming. *Basic and Applied Ecology*, *67*, 14-31.

Kasem, S., & Thapa, G. B. (2011). Crop diversification in Thailand: Status, determinants, and effects on income and use of inputs. *Land Use Policy*, *28*(3), 618-628.

Kiani, A. K., Sardar, A., Khan, W. U., He, Y., Bilgic, A., Kuslu, Y., & Raja, M. A. Z. (2021). Role of agricultural diversification in improving resilience to climate change: An empirical analysis with Gaussian paradigm. *Sustainability*, *13*(17), 9539.

Kim, K., J. P. Chavas, B. Barham, and J. Foltz (2012). Specialization, diversification, and productivity: a panel data analysis of rice farms in Korea, Agricultural Economics 43(6), 687-700.Kray, Holger A.; Heumesser, Christine; Mikulcak, Friederike; Giertz, Åsa; Bucik, Marko (2018). Productive Diversification in African Agriculture and its Effects on Resilience and Nutrition (English). Washington, D.C.: World Bank Group.

Komarek, A. M., Koo, J., Haile, B., Msangi, S., & Azzarri, C. (2018). Trade-offs and synergies between yield, labor, profit, and risk in Malawian maize-based cropping systems. *Agronomy for Sustainable Development*, *38*(3), 32.

Kurdyś-Kujawska, A., Strzelecka, A., & Zawadzka, D. (2021). The impact of crop diversification on the economic efficiency of small farms in Poland. *Agriculture*, *11*(3), 250.

Li, C., Stomph, T. J., Makowski, D., Li, H., Zhang, C., Zhang, F., & Van der Werf, W. (2023). The productive performance of intercropping. *Proceedings of the National Academy of Sciences*, *120*(2), e2201886120.

Lin, B. B. (2011). Resilience in agriculture through crop diversification: adaptive management for environmental change. *BioScience*, *61*(3), 183-193.

Liu, W., T. Yin, Y. Zhao, X. Wang, K. Wang, Y. Shen, Y. Ding, and S. Tang (2021). Effects of High Temperature on Rice Grain Development and Quality Formation Based on Proteomics Comparative Analysis Under Field Warming. *Frontiers in Plant Sciences*, 12.

Lopez, R. (1984). Estimating Labour Supply and Production Decisions of Self-employed Farm Producers. *European Economic Review*, 24, 61-82.

Maggio, G., Sitko, N. J. and Ignaciuk, Ada, 2018. "Cropping system diversification in Eastern and Southern Africa: Identifying policy options to enhance productivity and build resilience," ESA Working Papers 288953, Food and Agriculture Organization of the United Nations, Agricultural Development Economics Division (ESA).

Makate, C., Wang, R., Makate, M., & Mango, N. (2016). Crop diversification and livelihoods of smallholder farmers in Zimbabwe: adaptive management for environmental change. *SpringerPlus*, *5*(1), 1135.

Mzyece, A., & Ng'ombe, J. N. (2020). Does crop diversification involve a trade-off between technical efficiency and income stability for rural farmers? Evidence from Zambia. *Agronomy*, *10*(12), 1875.

Prommawin, B., Svavasu, N., Tanpraphan, S., Saengavut, V., Jithitikulchai, T., Attavanich, W., and McCarl, B. A. (2024). Impacts of climate change and agricultural diversification on agricultural production value of Thai farm households. *Climatic Change*, *177*(7), 112.

Sinnarong, N., C. Chen, B. McCarl and B. Tran (2019). Estimating the Potential Effects of Climate Change on Rice Production in Thailand. *Paddy and water environment*, 17.4: 761-9.

Song, Y., C. Wang, H.W. Linderholm, Y. Fu, W. Cai, J. Xu, L. Zhuang, M. Wu, Y. Shi, G. Wang, and D. Chen (2022). The negative impact of increasing temperatures on rice yields in southern China. *Science of The Total Environment*, 820.

Van Etten, J., De Sousa, K., Aguilar, A., Barrios, M., Coto, A., Dell'Acqua, M., ... & Steinke, J. (2019). Crop variety management for climate adaptation supported by citizen science. *Proceedings of the National Academy of Sciences*, *116*(10), 4194-4199.

Vernooy, R. (2022). Does crop diversification lead to climate-related resilience? Improving the theory through insights on practice. *Agroecology and Sustainable Food Systems*, 46(6), 877-901.

Yang, X., Xiong, J., Du, T., Ju, X., Gan, Y., Li, S., ... & Butterbach-Bahl, K. (2024). Diversifying crop rotation increases food production, reduces net greenhouse gas emissions and improves soil health. *Nature Communications*, *15*(1), 198.