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Soil conservation and smallholder welfare under cassava-based systems in Thailand

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Abstract

Land degradation, declining soil fertility, and erosion continue to plague agricultural production in many developing countries. In response to these farm production constraints and environmental challenges, a range of soil conservation technologies and practices have been developed and disseminated to tackle soil nutrient and fertility declines. However, evidence on the association between soil conservation, farm performance, and smallholder welfare is scarce. In this study, we examine the relationship between soil conservation, farm performance, and welfare outcomes of smallholder cassava farmers in Thailand. We use a farm household survey of 602 cassava growers and apply a doubly robust multivalued treatment effect estimator to estimate the relationship between soil conservation, farm performance, and welfare as well as the observable characteristics associated with the use of soil conservation practices. We observe a positive association between the use of soil conservation practices and cassava yields which is most likely associated with higher-income streams. Similar insights are also observed for other welfare outcomes such as asset accumulation, including livestock which represents rural wealth to a considerable extent. The positive association between soil conservation and livestock ownership hints at some form of rural diversification. Given these insights, our analysis supports and gives credence to initiatives that promote the adoption of soil conservation as they are not only pro-poor but also environmentally friendly with significant concerns for ecological safeguards.

KEYWORDS
environmentally friendly, erosion, income, rural wealth, soil fertility, yields

1 | INTRODUCTION

Declining soil fertility and erosion continue to plague agricultural production and deplete natural resources in many developing countries that still depend on the agricultural sector for food, development, and economic growth. These are usually accompanied and exacerbated by deforestation, land-use intensification, and soil degradation. These challenges are even more prevalent in the sloping uplands of Asian countries such as the Philippines, Vietnam, and Thailand (Lapar, 1999; Leknoi & Likitlersuang, 2020). In these countries, the cultivation of various root and tuber crops has taken centre stage as they can grow relatively well on marginal and degraded soils. Cassava (*Manihot esculenta* Crantz) is one propitious crop able to thrive optimally on depleted and degraded soils, under low soil fertility. However, it may also degrade soil or deplete large amounts of nutrients, leading to soil exhaustion and biodiversity loss (Delaquis et al., 2018).

In response to such farm production constraints and environmental challenges, a range of technologies and practices have been developed and disseminated to farmers in many developing nations where food insecurity and rural poverty continue to take precedence. A case in point has been the implementation of the Nippon Foundation Project (NFP) between 1993 and 2003 in Thailand and other Asian countries, which sought to reduce environmental degradation and improve soil fertility among cassava farmers. Farmers were introduced to a blanket of soil erosion and soil fertility practices that were intended to prevent the loss of soil nutrients, restore degraded and depleted soils as well as improve soil quality. For brevity, we broadly refer to these soil erosion-preventing practices and soil fertility-enhancing practices as soil conservation practices (Table 1).

This study examines the relationship between soil conservation and four welfare outcomes (yields, income, asset ownership, and livestock ownership) in cassava-based systems in Thailand. We take advantage of the implementation of the NFP between 1993 and 2003, which sought to reduce environmental degradation and improve soil fertility among cassava farmers. The NFP aimed to disseminate improved farm production practices with potentials of increasing farm performance and welfare while also preventing soil degradation by nutrient depletion and soil erosion. We revisit the project area in 2017, interviewing 602 cassava farmers and collecting extensive information on their farm management decisions. We then investigate how the adoption of soil conservation is associated with farm productivity and household welfare.

From an agronomic perspective, it has been documented that the uptake and use of soil conservation practices increase yields while reducing soil degradation (Adams et al., 2020; Adolwa et al., 2019; Nunes et al., 2018; Xiong et al., 2018). However, the impacts of the adoption of

TABLE 1 Soil conservation practices promoted by the Nippon Foundation

Soil fertility	Soil erosion practices
Chemical fertilizers	Contour ridging
Intercropping Tephrosia candida	Hedgerows with vetiver grass and *Paspalum atratum*
Green manuring	Water harvesting
Closer planting space	Terracing
Crop residues	Mulching
Subsoiling	Tree planting
Compost	Minimum tillage
On-farm manure	Soil and stone bunds
Off-farm manure	
Soil amendments	
Foliar fertilization	
Soil inoculants	
Crop rotation	
Organic fertilizers	

Source: Agrifood Consulting International, (2004); Dalton et al. (2011).

these practices may also be context-dependent. For instance, Adimassu et al. (2017) reported decreasing yields under the use of some soil and water conservation techniques. On the other hand, the use of agronomic soil and water conservation practices such as organic soil amendments, intercropping and composting were found to increase yields (Adams et al., 2020; Adolwa et al., 2019; Nunes et al., 2018; Xiong et al., 2018). Adoption of soil conservation has also been shown to increase farm profits (Pannell et al., 2014). Beyond yield and profit increases, adoption of soil conservation could further induce welfare changes given that the benefits of adopting soil conservation are not immediate[1] (Knowler & Bradshaw, 2007; Lapar, 1999; Pannell et al., 2014). The adoption of organic soil amendments, a critical component of soil conservation, has been shown to increase food security (Tabe-Ojong, Fabinin, et al., 2022). That said, existing studies report significant heterogeneity and context-dependency, calling for a wider evidence base to improve learning on the relationship between soil conservation and welfare.

Our study offers three main contributions to the empirical literature on the relationship between the adoption of soil conservation and smallholder welfare. In the first place, we provide evidence of the relationship between the adoption of soil conservation and welfare in the context of cassava-based systems. This is quite scarce in the adoption literature, especially as far as soil conservation is concerned. Given that cassava cultivation can take place on marginal and degraded soils, as well as simultaneously cause environmental degradation through critical soil disturbance, understanding the welfare implications is crucial. This could avoid trade-offs while ensuring synergies in achieving some of the sustainable development goals (Barbier & Hochard, 2018; Barrett & Bevis, 2015). Second, unlike studies in the broad adoption literature, we consider a plethora of different soil fertility and erosion practices and establish how they are associated with the welfare and livelihoods of smallholder farmers.

Last but most importantly, we consider a shrubby root and tuber crop, cassava, which is mainly cultivated by resource-poor farmers who usually operate on marginal lands (Alene et al., 2018; Delaquis et al., 2018). This is, even more, the case in Thailand where cassava is a key export/cash crop[2] for smallholder farmers. Cassava is also one of the largest calorie-producing crops in the root and tubers family, making it not only an important crop in resource-poor agricultural settings but also in the development of biofuels (Zhou & Thomson, 2009). Being a tropical crop, it thrives under high temperatures and withstands seasonal droughts (El-Sharkawy, 2014). In this regard, understanding the welfare association of soil conservation under cassava-based production systems has deep implications on the ongoing debates about the hitherto considered environmentally benign crop which is increasingly argued to contribute to environmental degradation, threatening sustainable crop production (Reynolds et al., 2015).

2 | CASSAVA PRODUCTION AND SOIL CONSERVATION

Cassava production, both in terms of area under cultivation and yields has increased over the last 50 years and is mostly cultivated in the tropics (Delaquis et al., 2018; Molua et al., 2020). It is cultivated on approximately 27 million ha throughout tropical and subtropical regions in Africa and Asia, of which 1.4 million ha (5%) is from Thailand (FAOSTAT, 2021). Compared to the world average of about 12 tons per ha, Thailand currently reaches a yield level of about 22 tons per ha (FAOSTAT, 2021). Unlike many countries in Africa such as Nigeria and Congo as well as South America where cassava is mainly cultivated as a staple food for human consumption, cassava in Thailand and other South-East Asian countries is cultivated and regarded as a cash crop with a more industrial orientation. However, production is in the hands of small scale and usually resource-poor farmers. In these countries, cassava is mainly processed into dry chips and pellets and exported to be used as starch, and animal feed (Alene et al., 2018).

The growing area and importance of cassava throughout the global tropics are due to its attractiveness to small-scale and resource-poor farmers who constitute the majority of households in these tropical and subtropical regions. Given this, cassava cultivation has the potential to achieve targets such as reducing hunger and food insecurity, and increasing smallholder incomes and welfare while stirring development in rural areas. Beyond serving the purposes of food and improving welfare, cassava is also used as a feedstock in the production of biomass energy (Zhou & Thomson, 2009). In the face of high temperatures and exposure to uncertain weather events, cassava could provide options for climate change adaptation given that it is climate-resilient and can withstand extreme weather conditions (El-Sharkawy, 2014; Jarvis et al., 2012).

Because cassava is cultivated and thrives well on degraded and marginal lands, there is usually little addition of chemical fertilizers or organic soil amendments to improve the fertility of the soil (Delaquis et al., 2018). This could explain the global low yield levels and yield gaps observed in many cassava-producing regions (Fermont et al., 2009). Closing these yield gaps and achieving yield increases is possible under the use of effective weed management strategies, chemical fertilizers, organic soil amendments and the use of various soil fertility and erosion practices that improve soil fertility, and nutrient retention and prevent further soil erosion, exhaustion, and degradation (Fermont et al., 2009).

Cassava cultivation could also lead to soil erosion and degradation (Reynolds et al., 2015; Valentin et al., 2008). This is due in part to its mode of harvesting which involves critical soil disturbance, poor canopy cover which is less resistant to heavy rains, and its potential to thrive on degraded soils (Valentin et al., 2008). Despite this, cassava cultivation is also prone to emerging infectious diseases arising from arthropod pests, pathogens, and other soil microorganisms when the soil biological function declines and the plant builds a low immune response due to inadequate management of the crop (Graziosi et al., 2016; Vurro et al., 2010). All these reduce yields and make it seemingly hard to close the yield gap. However, the use of various soil fertility-enhancing techniques and soil erosion and exhaustion preventive practices may make it possible to fully explore the benefits inherent in the cultivation of cassava while tackling some of its associated environmental implications.

The International Center for Tropical Agriculture (CIAT) and its partners in Southeast Asia have worked for almost 40 years on soil management research to achieve some of these goals like maximizing cassava productivity, preventing erosion, and ultimately, improving farmer livelihoods and welfare. Farmer participatory research and extension (FPRE) methodologies have been used in these activities and implemented in collaboration with local agricultural extension staff aiming to increase the opportunities for local innovation and adoption. Participatory research here refers to the use of various active learning approaches such as on-farm experimentation of farmer-developed innovations, training courses and peer to peer exchanges, and learning (Agrifood Consulting International, 2004). It is estimated that about 400 FPRE trials were conducted in Thailand with many technologies introduced to improve cassava yields, reduce soil erosion, and improve the sustainability of cassava-based cropping systems (Dalton et al., 2011). So far, different project reports and official statistics have estimated that several dozens of thousands of cassava growers in Southeast Asia have adopted the promoted soil fertility and erosion control practices (Agrifood Consulting International, 2004; Dalton et al., 2011). Increase in adoption and use of these management innovations may have led to a substantial increase in cassava productivity with ensuing implications on other welfare outcomes. Some of the practices promoted by the NFP are shown in Table 1.

3 | FARM HOUSEHOLD SURVEY

An ideal data set to use to understand the relationship between soil conservation, farm performance, and welfare outcomes would either be a controlled experiment that involves a baseline and an end-line data or a multi-wave panel dataset. However, there was no baseline data collection carried out before or during the implementation of the Nippon Foundation Project. Because of this, we rely on a cross-sectional farm household survey conducted among 602 cassava farmers in Thailand in 2017. This is combined with a village-level survey of 60 villages in the study region. Households were drawn from the four main cassava-producing areas in Thailand (Figure 1) including Nakhon Ratchasima, Chachoengsao, Kalasin, and Parchin Buri provinces where CIAT and its partners have played an active role in promoting the use of soil conservation through the "Enhancing the Sustainability of Cassava-based Cropping Systems in Asia" Project. Funded by the Nippon Foundation, this project was implemented in Vietnam, Thailand, China, and Indonesia from 1993 to 2003 and used Farmer Participatory Research and Extension approaches to test and develop the most suitable practices to control erosion and maintain soil fertility in cassava-based systems (Howeler, 2014). In the early 2000s, the project had succeeded in increasing the use of chemical fertilizers, green manure, and adoption of hedgerows in several targeted areas in Thailand. During project implementation, several practices and packages were directly tested by farmers and their results were shared with the wider community.

We used a purposive and stratified sampling strategy to first select villages in the main cassava-producing provinces, and secondly to randomly select households within these villages. From each province, we included all the project villages (eight villages). We then

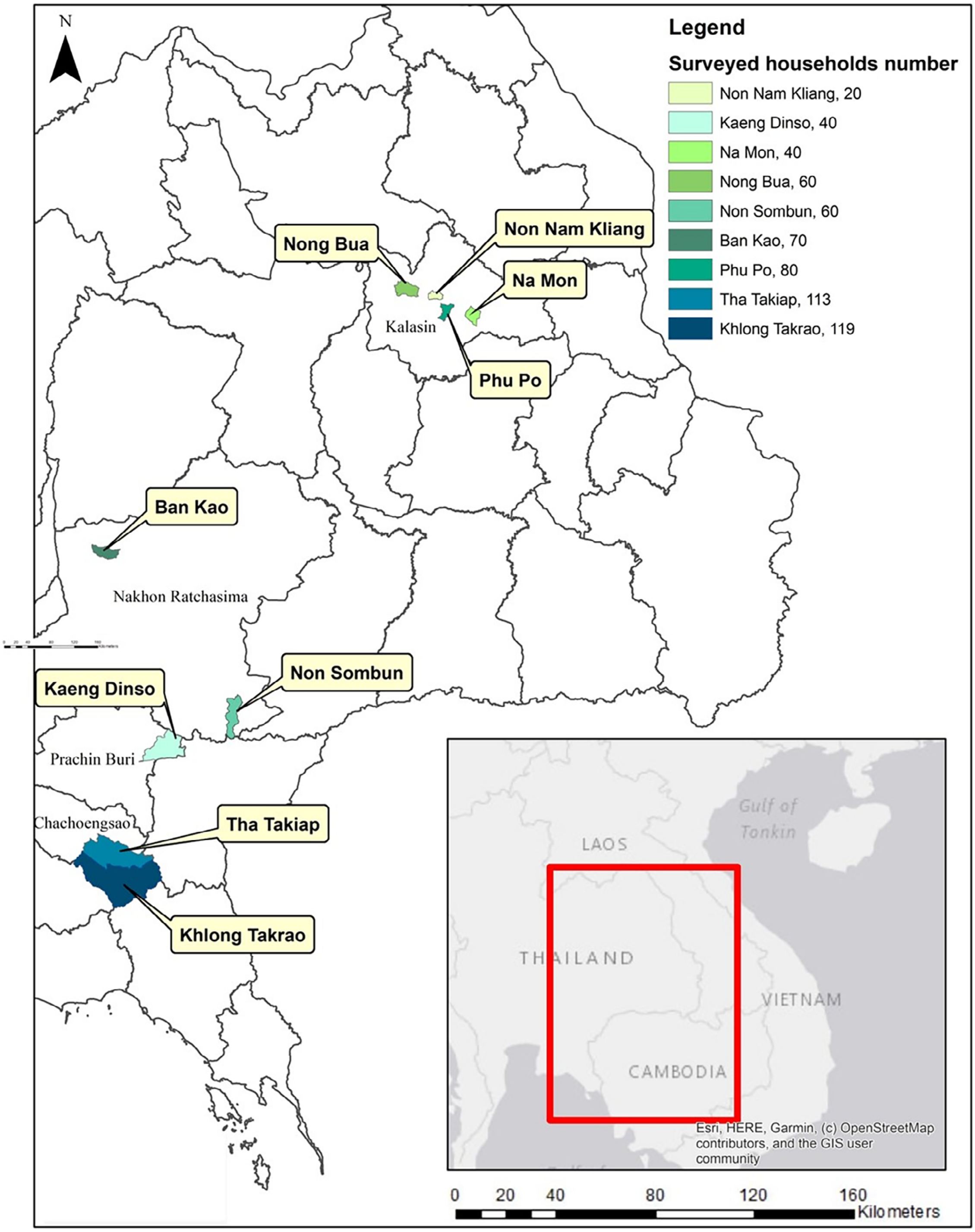

FIGURE 1 Map of study area [Colour figure can be viewed at wileyonlinelibrary.com]

selected villages located in the proximity of the project area (<10 km of distance; spillover group), where we expected any information spillover to have occurred, and villages located further away (>10 km distance, real control). Within each village, we randomly selected about 10 households using the lists of cassava farmers provided by local authorities. The final sample included 602 households distributed as follows: 84 households in 8 the project's villages; 313 households in villages located within 10 km of the project's villages and 205 households in villages located beyond 10 km of the project's villages.

The survey collected information on agronomic and soil conservation practices, yields, and other welfare characteristics like income, assets, livestock ownership, and some subjective measures of poverty such as the minimum income needed to feel financially secure and the poverty ladder. Information was also collected on household socio-economic characteristics and variables like age, educational level, exposure to shocks, and institutional characteristics like access to credit and information from extension agents and membership in producer organizations such as agricultural cooperatives.

3.1 | Measurement of soil conservation

As earlier introduced, soil conservation refers to a suite of practices either used to improve the quality and fertility of the soil or to prevent further soil loss, erosion, and degradation. For this study, we refer to soil conservation practices as either soil fertility practices or soil erosion practices. While soil fertility practices include crop rotation, green manuring, intercropping, use of chemical fertilizers, organic fertilizers, use of crop residues, foliar fertilization, and the practice of subsoiling and the use of inoculants, soil erosion practices include the use of hedgerows, contour ridges, water harvesting, terracing, mulching, soil and stone bunds, minimum tillage, and tree planting (full list of practice is shown in Table 1). The summary statistics of the use of the various practices are shown in Tables S1 and S2 in the appendix.

Information on practices was asked at the level of each plot. In this case, only those corresponding to the cultivation of cassava were used, and the same farmer could use all the practices or not use any, as well as use it on multiple plots or only on one plot. As can be seen from these tables, the adoption of some of these practices is very low (<1% of farmers are using them). We thus define adoption based on whether every representative farmer is using either one of the soil fertility enhancing practices or soil erosion preventive practices. Under the use of soil fertility enhancing practices, about 80% of farmers are applying chemical fertilizers on their farms. Given that the use of chemical fertilizers is conceptually and technically different from the use of other soil fertility-enhancing techniques which can be mainly considered as the use of organic soil complements, we created a separate adoption category for the use of chemical fertilizers. For instance, it can be argued that the marginal yield response to fertilizers may be different based on either the use of organic fertilizers or chemical fertilizers. Yield increases due to chemical fertilizers may be lower on degraded soils and soils with low soil organic matter as compared to fertile soils (Barrett & Bevis, 2015; Rowe et al., 2006). Thus, we have three categories of adoption as shown in Table 2: use of chemical fertilizers, use of soil fertility practices, and use of soil erosion preventive practices.

TABLE 2 Summary statistics of key variables

Variable	Mean	SD
Age of household head (years)	53.99	10.91
Household head is male (1 = yes)	0.62	0.48
Head has primary education (1 = yes)	0.73	0.44
Spouse has primary education (1 = yes)	0.59	0.49
Household size	3.14	1.37
Working-age adults	2.29	1.16
Credit access (1 = yes)	0.84	0.36
Farm size (hectares)	4.22	3.56
Number of crops grown	2.18	1.47
Distance to markets (km)	31.02	26.15
Yields (tons/ha)	19.69	9.26
Incidence of pests (1 = yes)	0.52	0.49
Incidence of droughts (1 = yes)	0.38	0.48
Incidence of floods (1 = yes)	0.29	0.45
Training (1 = yes)	0.39	0.48
Number of known adopters	2.04	0.35
Gender of adopters ((1 = male)	0.81	0.39
Trust Index	2.28	0.66
Share of farm income (percentage)	79.84	23.57
Asset value (Thai Baht)	319,649.7	649,971.9
Asset Index	2.2 e-09	1.73
Livestock ownership (Thai Baht)	7670.04	43,324.8
Livestock ownership (TLU)	0.26	1.18
Soil fertility (1 = yes)	0.44	0.49
Soil erosion (1 = yes)	0.38	0.48
Chemical fertilizers (1 = yes)	0.80	0.39

Note: 1 Thai Baht = 0.029 $US.

3.2 | Measurement of outcome variables

We test the association between the adoption of soil conservation practices and several welfare indicators. To begin with, yield was measured using the total quantity of cassava produced and divided by the area under production. This information was gotten at the plot level, for which the total amount of production and the corresponding areas for each plot were added and later collapsed at the farmer level. Given that yield increases could translate to other welfare outcomes, we also used proxies for income and asset ownership. Under income, we used the share of farm income obtained from the sales of cassava. Given the increasing relevance of asset-based outcomes as better proxies of rural poverty, as opposed to income and consumption outcomes which are liable to short-term fluctuations, we use the total value of all assets owned by a household (Brockington, 2019; Tabe-Ojong, Hauser, & Mausch, 2022). To obtain a better sense of the actual accumulation of assets, we also consider an alternative asset measure besides the $US value such as the asset index. This index is constructed using principal component analysis. In the absence of active and viable banking and saving services in most rural communities, households usually invest in these assets which they could use in times of shocks as buffers to cater for their liquidity constraints and smoothen their consumption. Another critical asset we consider is livestock ownership where we use the tropical livestock unit as a converting factor to create a livestock index from the various livestock owned by households. The tropical livestock unit is a livestock conversion factor from the Food and Agriculture Organization which attributes different units to livestock based on their live weight. For instance, cattle are 0.7, sheep and goats are 0.1, a pig is 0.2, and chicken is 0.01. As an alternative measure of livestock, we also use the total value of livestock owned by households.

4 | MATERIALS AND METHODS

A preferred empirical strategy to understand the association between soil conservation, farm performance, and welfare outcomes would be to leverage an estimation strategy like the difference in difference technique using a multi-wave data set or better still panel data methods that can control for unobserved time-invariant heterogeneity and establish some dynamics. However, it is impossible to reconstruct a baseline for this study. This makes it hard to observe the impacts of soil conservation on welfare. That notwithstanding, we make use of the cross-sectional data to understand the association between soil conservation and welfare. In doing so, we control for observed confounding factors and employ some rigorous estimation techniques in establishing this association.

We use the doubly robust multivalued treatment effect estimator (Cattaneo, 2010; Cattaneo et al., 2013; Tabe-Ojong & Nshakira-Rukundo, 2021) that takes into consideration the different soil conservation practices used by farmers and can control for observed heterogeneities in the use of these practices. More specifically, we employ the 'doubly robust' augmented inverse probability weighting (AIPW) estimator that models both the adoption of soil conservation and the outcome variables within the same framework. The advantage of using this estimator as opposed to ordinary least squares and other matching estimators is that even under misspecifications of either the treatment or outcome models, it would still produce unbiased estimates (Linden et al., 2016). According to Linden et al. (2016), the AIPW is operationalized in three main steps: (1) the parameter estimates of the generalized propensity score are estimated with the computation of inverse probability weights, (2) different regression models of the outcomes are estimated for the three treatments which lead to the generation of different treatment-specific predicted outcomes and (3) unconditional means are then estimated using the estimated generalized propensity scores with the conditional mean functions.

Consider the following regression model depicting the potential outcome framework (Rubin, 1974):

$$Y_i = \sum_{t=0}^{3} D_{ic}(C_i) Y_{ic} \tag{1}$$

Where: Y_i refers to the outcome variables (farm performance and welfare indicators), C_i is the multivalued treatment variable which take on integer values between 0 and 3 where 1 represents the use of soil erosion practices, 2 is soil fertility practices, 3 is the use of chemical fertilizers and 0 is non adoption. Y_{ic} represents the potential outcome for every household i for which $C_i = c$. For each household, only one of the potential outcomes is observed, depending on the adoption of the soil conservation practice. $D_{it}(C_i)$ is an indicator for adopting any soil conservation practice, c by a representative household i and is represented as

$$D_{ic}(C_i) = \begin{cases} 1, \text{if } C_i = c \\ 0, \text{otherwise} \end{cases} \tag{2}$$

More formally, the treatment model and the outcome models can be represented as

$$\Pr(C_i = 1, 2, 3, 0) = f(\boldsymbol{X}_i, \beta) + u_i \tag{3}$$

$$Y_i = h(C_i, \delta) + v_i \tag{4}$$

$\boldsymbol{X}_i$ is a vector of control variables thought to determine the adoption of soil conservation practices. β and δ are the parameter estimates of the control variables correlated with the adoption of soil conservation practices and the association of soil conservation and on-farm performance and welfare indicators respectively. The AIPW estimator is a selection on observables estimator and hinges on observable covariation to reduce selection bias. Given that unobservable factors such as skills and motivation may be driving the adoption of soil conservation, our analysis could be biased by unobserved heterogeneity. Conditioning on a rich set of covariates may help to reduce selection bias due to unobserved heterogeneity (Imbens & Wooldridge, 2009). We, therefore, added a rich set of control variables in this regard, but guard against implying any causality from the analysis. Some of the included control variables include the gender of the household head, age and educational level of the household head, educational level of a spouse, household size, number of working-age adults, access to credit facilities, size of landholding, number of crops cultivated, the incidence of pest and diseases, drought shock, flood shock, training, and number of known adopters of soil conservation.

An important assumption of doubly robust estimators is that conditional on the specified control variables, each observation has a non-negative probability of being an adopter. This assumption, also known as the overlap assumption, creates a counterfactual adoption observation for each adopting observation. The violation of this assumption may lead to less precise estimates. The tolerance level for the probability of being an adopter ranges between 0 and 1. We observe sufficient overlap in the probability of adopting soil conservation. We also perform some balance checks to assess pre-estimation balancing between treated and control units. As shown in the supplementary material, few of the weighting variables have a standardized difference greater than 0.25, which is within the conventional thresholds without reducing our sample size (Imbens & Wooldridge, 2009). The variance ratios are also close to one. We also perform some overidentification tests where we examine the null hypothesis that covariates are balanced. The test statistics are $\chi^2(15) = 1.049$ with $p > \chi^2 = 1.00$. This suggests that the weighted samples are well balanced. All these checks provide sufficient credence to our estimated coefficients.

5 | RESULTS AND DISCUSSION

5.1 | Descriptive results

Table 2 presents the summary statistics of some of the key explanatory variables used in the regression framework. Households have an average age of 54 years and 62% of these household heads are males.

Around 73% of the household heads have achieved some level of primary education with 59% of spouses having the same. Households in the study area have household sizes of about three members but just two of these members are in the working-age category. Approximately 85% of households have access to credit from a financial institution such as a bank, microfinance, or other informal groups. Households practice mixed farming and cultivate about two crops per production cycle. They also have landholdings of about four hectares.

As earlier noted, households are mainly into cassava cultivation and report an average yield of about 20 t ha^{-1}. Households are faced with both flood and drought shocks which greatly affect their production. In terms of household income, farm income contributes about 80% of farm income. Households report an asset value of 319,649.7 Thai Baht.[3] They also have livestock holdings amounting to 7670 Thai Baht with an equivalent livestock unit of 0.26 based on the tropical livestock unit conversion scale of the Food and Agriculture Organization (FAO).

In terms of the use of soil conservation practices, 44% of households adopt soil fertility practices, 38% use soil erosion practices and about 80% of households use chemical fertilizers.

TABLE 3 Estimates of soil conservation and yields, income, and off-farm income

	Yields	Income
Soil erosion	0.213*** (0.033)	0.561*** (0.014)
Soil fertility	0.236*** (0.034)	0.568*** (0.016)
Chemical fertilizers	0.234*** (0.036)	0.565*** (0.014)
Additional controls	Yes	Yes
Number of clusters	60	60
Observations	600	600

Note: Additional controls include the gender of the household head, age and educational level of the household head, educational level of a spouse, household size, number of working-age adults, access to credit facilities, size of landholding, number of crops cultivated, the incidence of pest and diseases, drought shock, flood shock, training and number of known users of soil conservation practice. Robust standard errors in parenthesis
*$p < 0.1$
**$p < 0.05$
***$p < 0.01$

5.2 | Regression results

Here, we present the results of the multivalued treatment effect model for the various welfare outcomes: yields, income, asset value, and index as well as livestock value and index.

5.2.1 | Soil conservation, yields, and income

Estimating the relationship between soil conservation and on-farm performance outcomes like yields and farm income, we observe intuitive and expected results as shown in Table 3. Adoption of soil erosion practices is associated with yield increases of about 21%. This is also very similar to the adoption and use of soil fertility enhancing practices and chemical fertilizers which are associated with yield increase of approximately 24% and 23% respectively. Yield increase from the use of these soil conservation practices is expected given that these measures are not only meant to retain and maintain soil nutrients but also to add soil nutrients in the case of soil enhancing measures like the application of organic and chemical fertilizers. Previous empirical analysis (Adams et al., 2020; Adolwa et al., 2019; Nunes et al., 2018; Xiong et al., 2018) found similar results on the positive association between the adoption of soil conservation and yields. In some cases, the adoption of soil conservation practices such as the use of organic soil amendments has been shown to be associated with food security (Tabe-Ojong, Fabinin, et al., 2022). For the more specific case of Thailand, earlier analysis from this same project area found substantial yield increases because of the farmer participatory research and extension approach (Dalton et al., 2011).

Adoption of soil conservation (including soil erosion, soil fertility, and the use of chemical fertilizers) also depicts a positive correlation with increases in farm income. This result corroborates the findings from Hörner and Wollni (2021) who found the adoption of soil conservation practices to increase smallholder incomes in Ethiopia. Of course, one would immediately imagine that an increase in farm income could stem from higher yields. However, there could be other pathways mediating this relationship. Income increases could also stem from a reduction in farm production costs arising from the use of cheaper farm inputs and technologies such as the use of soil erosion and soil fertility practices. Most of these practices impose little or no costs on farmers as they are usually farmer-led and produced on their farms with other farm resources.

5.2.2 | Soil conservation and assets

Moving from farm performance indicators and short-term measures of welfare to longer-term welfare outcomes such as the accumulation of assets and livestock ownership, we use both the value of the assets as well as an index generated from principal component analysis for the case of assets. For livestock ownership, we used livestock units adopting the livestock conversion unit of FAO. The use of the index measure serves as a robustness check for the asset values. In all these measures, we again obtain a positive association between soil conservation and asset accumulation as shown in Table 4. Since the adoption of soil conservation practices leads to the accumulation of assets on smallholder farms and increased livestock ownership, this may suggest some long-term welfare implications given that assets and livestock ownership represent rural wealth to a considerable extent (Tabe-Ojong, Hauser, & Mausch, 2022). In the case of livestock, it may also signify some form of rural diversification. Households may view both cassava production and livestock rearing as complementary activities where the gains from each activity can be invested in the other activity to increase its sustenance and make it profitable.

TABLE 4 Estimates of soil conservation and assets

	Assets		Livestock	
	Value (Thai Baht)	Index	Value (Thai Baht)	TLU
Soil erosion	0.922*** (0.011)	1.044*** (0.054)	1.043*** (0.011)	1.026*** (0.005)
Soil fertility	0.914*** (0.011)	1.021*** (0.063)	1.042*** (0.027)	1.027*** (0.013)
Chemical fertilizers	0.912*** (0.011)	0.883 (0.051)	1.019*** (0.009)	1.011*** (0.004)
Additional controls	Yes	Yes	Yes	Yes
Number of clusters	60	60	60	60
Observations	600	600	600	600

Note: Additional controls include the gender of the household head, age and educational level of the household head, educational level of a spouse, household size, number of working-age adults, access to credit facilities, size of landholding, number of crops cultivated, the incidence of pest and diseases, drought shock, flood shock, training, and number of known users of soil conservation practice. Robust standard errors in parenthesis

*$p < 0.1$

**$p < 0.05$

***$p < 0.01$

5.2.3 | Correlates of the adoption of soil conservation

Now that we have established the positive association between soil conservation, farm performance, and welfare outcomes, we are interested to know and understand the correlates of the use of these various farm practices that not only conserve the soil but have implications for nutrient increases and soil fertility. Our use of the doubly robust multivalued treatment estimator makes it possible to easily obtain correlation as shown in Table 5. The education of a household's spouse is positively correlated with the adoption of soil erosion practices while the occurrence of a flood is negatively correlated with the use of soil erosion practices. Moving to soil fertility practices, the education of the household head matters as educated households may easily understand the benefits of using such soil enhancing techniques than uneducated household heads. Given that the application of various soil fertility measures is energy driven and time-consuming, it is no surprise that households with greater family sizes are more likely to adopt these techniques. Like with the use of soil erosion, the occurrence of floods also depicts a negative association with the adoption of soil fertility practices. In contrast, households faced with the incidence of pests and diseases are more likely to use soil fertility enhancing practices.

For the case of chemical fertilizers, older farmers are more likely to apply chemical fertilizers on their plots than their younger counterparts. This could be due to their large social networks and build of experience. Of course, older farmers have navigated various problems in their agricultural production more broadly, which could have made them more willing and receptive to techniques that have the promise of increasing their production levels while conserving the environment. Male-headed households are observed to have a positive correlation with the use of chemical fertilizers. This correlation could be explained in two directions. In the first place, chemical fertilizers are expensive to purchase and given that men usually control the resources of a household, they may be more likely to purchase chemical fertilizers than women who are usually on the low when it comes to access to resources. In the second place, like every technology, adoption critically depends on networks and who you observe using a particular technology. In this case, men are usually more connected with greater networks than women in most societies, which could further explain this positive association. To confirm this insight, we also observe a positive correlation between the number of known adopters of soil conservation and the adoption of chemical fertilizers. This is an earlier confirmed finding that farmers learn from others in their social networks (Krishnan & Patnam, 2014).

Our results on the correlates of the adoption of soil conservation speak to the role of information access, knowledge, and peer effects in driving the use of these soil enhancing and nutrient increasing practices (Tabe-Ojong, 2022). These findings are largely in line with previous analyses that evaluated the impact of participatory research in increasing the adoption of soil conservation and fertility management innovations in Southeast Asia (Dalton et al., 2011). Participatory research here refers to the use of various active learning approaches, such as on-farm experimentation of farmer-developed innovations, training courses, peer-to-peer exchanges, and learning (Agrifood Consulting International, 2004). Many years after, adoption is somewhat maintained with visible implications on various farm performance and welfare outcomes. To this end, there is the sustained use of some of the soil conservation innovations, introduced and disseminated earlier on by the Nippon Foundation, with some positive implications, which have in part led to the sustainability of cassava-based cropping systems in Thailand.

5.3 | Limitations of the analysis

Our analysis has some limitations that could be taken up in future research endeavors. In the first place, we refer to the estimated

TABLE 5 Factors correlated with the use of soil conservation practices

	Soil erosion	Soil fertility	Chemical fertilizers
Age of household head (years)	−0.043 (0.059)	0.096 (0.070)	0.151** (0.066)
Household head is male (1 = yes)	1.674 (1.169)	−0.155 (1.510)	2.503** (1.230)
Head has primary education (1 = yes)	2.355 (1.729)	4.514** (1.889)	1.717 (1.400)
Spouse has primary education (1 = yes)	2.829* (1.572)	−0.706 (1.837)	1.350 (1.628)
Household size	0.248 (0.582)	1.405*** (0.674)	−0.812 (0.947)
Working age adults	−0.082 (0.790)	−0.899 (0.870)	0.726 (0.760)
Credit access (1 = yes)	−2.751 (1.960)	−0.463 (1.604)	1.074 (1.582)
Farm size (hectares)	−0.120 (0.243)	0.085 (0.191)	−0.239 (0.262)
Number of crops grown	0.569 (0.457)	−0.610 (0.641)	0.463 (0.653)
Incidence of pests (1 = yes)	−1.898 (1.579)	2.840** (1.458)	−1.793 (1.325)
Incidence of droughts (1 = yes)	−0.730 (1.491)	−1.687 (1.517)	−2.062 (1.287)
Incidence of floods (1 = yes)	−2.168* (1.163)	−3.669** (1.691)	−1.826 (1.451)
Training	1.892 (1.254)	2.008 (1.442)	1.850 (1.161)
Number of known adopters	−0.346 (1.506)	1.666 (2.435)	5.795*** (2.265)
Constant	20.159*** (5.596)	6.252 (6.411)	−2.942 (6.232)
Observations	600	600	600

Note: Robust standard errors in parenthesis
*$p < 0.1$
**$p < 0.05$
***$p < 0.01$

results as associations or correlates of farm performance and welfare outcomes. Although we have employed double robust weighting estimators to identify the association of soil conservation and welfare, we cannot claim strict causality here as the double robust estimator is a selection on observables estimator that only hinges on correcting selection bias based on observable factors. It could be the case that unobservable factors are present and could be driving the relationship between soil conservation and welfare, and we have not sufficiently mitigated for that although the selection of observables can be informative about the selection of unobservables. Although we cannot claim causality, our analysis shows preliminary evidence of the association of soil conservation with farm performance and welfare outcomes and calls for further analysis that could move in the line of establishing causality. Models like switching regressions for multi-treatments could be used to control for these unobservables, but these models are based on the use of valid exclusion restrictions to identify the impacts of treatments on outcomes. We did not have any valid exclusion restrictions to address and reduce selection bias based on unobservables. Future studies may benefit from using panel data and experimental methods to account for these unobservables and move towards establishing causal effects. In the second place, despite the observed correlations between soil conservation and welfare, we guide against generalizations of our study findings as context always matters. That notwithstanding, given that the conditions in Thailand are not very different from other countries in Southeast Asia where cassava is produced as well as some countries in Africa, one may cautiously generalize the findings to such production zones and cassava-based systems. Finally, our aggregation and bundling of various soil conservation practices are not perfect and may mask important heterogeneities in these practices. Of course, we categorized these practices into three broad groups to reduce the homogenous groupings. However, these classifications and groupings assume that these practices are equally evaluated with regards to the outcome and adoption happens at similar times. This may not be the case, but our one-period dataset prevents us from exploiting such heterogeneity, both in space in time as well as the functionality of the practices.

6 | CONCLUSIONS

In this study, we examine the relationship between soil conservation, farm performance, and welfare outcomes in cassava-based production systems in Thailand. Adoption of various soil conservation practices such as soil erosion reducing practices, and soil fertility enhancing practices have been promoted and disseminated to farmers as part of the Nippon Foundation Project in Vietnam, Thailand, China, and Indonesia between 1993 and 2003. We return to these sites in Thailand approximately close to two decades later to understand the adoption of these soil conservation practices and their association with on-farm performance outcomes such as yields and farm income, as well as rural diversification outcomes such as off-farm income and livestock ownership and longer-term measures of poverty such as asset accumulation.

Leveraging a farm household survey of 602 smallholder farmers in Thailand and employing a doubly robust augmented inverse probability weighting multivalued estimator, we report the positive correlation between soil conservation and yields. Such yield increases could explain income increases which could also be translated to investments in livestock accumulations. Investments in livestock represent rural diversification to a considerable extent and offer some insights into the complementary gains inherent in the adoption of soil conservation. We also report a positive correlation between the adoption of soil conservation and asset ownership which not only represent rural wealth in most farming settings but can also be considered to represent longer-term measures of poverty more fully.

Based on the above results which underscore the positive short and long-term welfare implications of the adoption of soil conservation. Our analysis gives credence to the promotion, distribution, and diffusion of both soil erosion preventing practices and soil fertility enhancing practices as they can be both pro-poor and environmentally friendly especially in the context of land degradation and soil erosion. In such difficult zones, the cultivation of a shrubby tuber crop like cassava is important as it not only survives in such difficult soil conditions and marginal soils but also is less costly in terms of the required inputs to increase productivity and close existing yield gaps. Hence, cassava can be regarded as a crop that is attractive to resource-poor farmers. Despite this, some opponents of the crop have it that the cultivation of cassava could also further degrade the soil and lead to soil erosion through its means of harvesting which critically disturbs the soil. While this may be true, the adoption of soil conservation practices in cassava-based production systems could address these concerns and offset these environmental losses.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in Dataverse at https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/W5V2TC.

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ENDNOTES

[1] For these kinds of technologies, benefits may only be observed under a long-term period (Beaman & Dillon, 2018).

[2] In other parts of the world, like in sub-Saharan Africa and South America, cassava is an important food crop.

[3] 1 Thai Baht is equivalent to 0.029 $US (06.2017)

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