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# Producer Organizations, Productivity and Sustainable Intensification Practices in Oil Palm Production

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## Abstract

Oil palm production is expanding in traditional farming and forested areas, especially in West and Central Africa around the Congo Forest Basin and mostly characterized by declining yields and yield gaps. Due to typically non-binding land access, independent producers tend to prioritize extensification over intensification, which has negative environmental consequences. Sustainable intensification (SI) of smallholder production is a guiding paradigm that aims to increase yields while minimizing negative environmental impacts. In this study, we examine the relationship between producer organizations (POs), some sustainable intensification practices (SIPs)—specifically mulching and intercropping, and oil palm yields in independent farmers in Cameroon. We estimate actual and counterfactual associations between POs, SIPs, production, and yields, drawing on farm- and household-level data collected through surveys and interviews with village chiefs and reference farmers. Empirically, we employ various regression techniques, including ordinary least squares, doubly robust estimators, instrumental variable estimators, recursive bivariate probit models, and switching regressions. Our findings reveal a positive association between POs and oil palm production and yields. The actual-counterfactual analysis demonstrates that POs not only benefit their members in terms of yield gains but also have the potential to benefit non-members if they were to join POs. Furthermore, POs are positively associated with the adoption of mulching and intercropping. Our results reveal distinct insights by gender when households are analyzed separately. POs are positively associated with behavioural factors such as perceived self efficacy, locus of control, hope and risks. Overall, our study highlights the potential of POs as institutional mechanisms for facilitating the adoption of SIPs and stirring productivity increases in smallholder oil palm systems.

**Keywords:** oil palm production, yields, sustainable intensification, producer organizations, Cameroon

JEL Classification: C24; D13; Q15; Q18; Q5

## 1. Introduction

Oil palm (*Elaeis guineensis*) is one of the most important tropical crops, significantly contributing to poverty reduction, food security, economic development, and providing livelihoods for millions of rural farm and non-farm households [1,2]. Increasing global demand for palm oil and its by-products has led to the expansion of oil palm cultivation, resulting in the rapid growth of oil palm production in recent years. However, this rapid expansion of oil palm cultivation has been associated with negative environmental and social consequences, including deforestation, biodiversity loss, and conflicts between plantation companies and local communities [1,3,4]. Millions of smallholder farmers in the tropics cultivate oil palm, with smallholders accounting for approximately 40% of cultivate area in Southeast Asia and up to 85% in Africa [1]. However, the yield and production of oil palm among smallholders remain low, prompting expansion at the expense of forests to increase yield through extensification rather than intensification [5,6]. This trend is more prevalent in countries in the Congo Basin, such as Cameroon, where land appears to be a non-binding constraint for oil palm expansion [3,7]. Smallholders encounter numerous challenges and their yields are low due to their limited access to technical knowledge, inputs, and markets [7,8].

In response to these challenges, sustainable intensification (SI) has emerged as a guiding paradigm for reconciling agricultural productivity with environmental sustainability, that is, increasing output from existing farmland while minimizing adverse environmental impacts [3,5,9-11]. Within this paradigm, various agronomic, institutional, and technological strategies can serve as practical pathways to achieve SI. The adoption of sustainable intensification practices (SIPs) such as improved crop management, soil fertility techniques, and biodiversity-friendly practices, represents a key pathway to achieving SI. In particular, applying good agricultural management practices, referred to as SIPs in oil palm plantations, has the potential to increase oil palm productivity and narrow yield gaps [9,10]. For example, mulching involving the use of oil palm residues, has emerged as a promising way to enhance oil palm production and mitigate land conversion and degradation [12]. As a carbon farming practice, mulching also increases soil organic carbon, which contributes to yield increases [13]. Similarly, intercropping, especially with leguminous crops and trees, can improve food and nutrition security, while increasing soil health and fertility [14,15]. However, we acknowledge that yield-enhancing practices may also incentivize area expansion under certain conditions, especially where land is not a binding constraint [16,17]. Despite the advantages and benefits, the use of SIPs in oil palm fields remains understudied [6]. Information constraints and knowledge gaps are widely perceived as major barriers to SIPs adoption. However, empirical evidence on the barriers to oil palm production remains scarce.



Among the strategic pathways to operationalize SI, institutional innovations such as producer organizations (POs) could be key enablers. POs are horizontal institutional mechanisms that have emerged as a promising strategy for promoting SI in smallholder settings [18-21]. POs are collective entities or organizations that represent smallholder farmers' interests and other value chain stakeholders, including processors, traders, and consumers [20,22]. As part of a diverse group of agglomeration models, POs can play a crucial role in promoting SI by offering technical assistance and training, facilitating access to credit and markets, and promoting good agricultural practices [22]. Additionally, they could enhance behavioral and psychological skills, such as aspirations, locus of control, self-efficacy, hopes, and risk management, which have been shown to increase the adoption of sustainable agricultural practices [23,24]. POs play an increasingly important role in organizing and supporting smallholder oil palm producers [25]. In many settings, farmers form or are encouraged to form groups to harness the benefits of collective action. However, the effectiveness of POs in improving oil palm production, yields, and the adoption of sustainable intensification practices (SIPs) remains not well established with some open questions emanating. What are the key characteristics of POs that encourage the application of SIPs, increasing yields in existing plantation areas? What impacts do POs have on smallholder oil palm production and yields? What are the current states of application of SIPs in oil palm fields? What is the relationship between POs and SIPs, such as mulching, and intercropping? Are the significant gender differences in the implications of POs? Is there any association between POs and behavioural factors such as perceived self efficacy, locus of control, hope and risk? Answering these questions is crucial for advancing the extant literature.



In this study, we answer these questions using household- and plot-level data collected in Cameroon through household surveys and informal meetings with village chiefs and reference farmers. Cameroon is an ideal case study due to its status as the largest oil palm producer in Central Africa and its long history of oil palm cultivation [17]. Our study draws on a cross-sectional household survey conducted with 329 smallholder oil palm farmers across five divisions in the South-West region of Cameroon, where oil palm cultivation is most concentrated. The data were collected between August and September 2021 and included both PO members and non-members. We investigate the relationship between smallholder membership in POs and oil palm production and yields, employing various regression techniques and estimation strategies. Additionally, we identify the current use of SIPs and examine the relationship between POs membership and SIPs. We also estimate actual-counterfactual effects to determine whether POs membership generates yield benefits exclusively for current members or could similarly benefit non-members if they were to join. Following this, we perform some gender heterogeneities to understand whether the implications of POs vary by the gender of the household head. We also estimate the association between POs and behavioural factors such as perceived self efficacy, locus of control, hope and risk.

Our study contributes to the empirical literature in two distinct ways, extending current knowledge on POs, SI, and oil palm production. First, while many studies have examined the role of POs in improving agricultural productivity and facilitating the adoption of improved farm practices, these are mostly focused on annual food crops (e.g., maize, rice, banana, cassava) in East Africa and South Asia [26-28]. In contrast, we focus on oil palm, a perennial cash crop, with limited empirical research in the context of smallholder systems in Central Africa. Relatedly, we contribute to the SI literature by analyzing the adoption of specific, context-relevant SIPs (mulching and intercropping) in oil palm fields, providing a crop- and practice-specific lens rarely addressed in the existing body of work. In doing this, we also establish some important heterogeneity analysis along gender lines. We go beyond average treatment effects by employing a counterfactual framework (endogenous switching regression and doubly robust Inverse Probability Weighted Regression Adjustment [IPWRA]) to estimate both the actual and potential outcomes of PO membership. This allows us to examine how non-members might benefit if they were to join POs, an approach that enhances policy relevance. The second contribution relates to providing empirical evidence on the role of POs in stirring and inducing behavioural and pyschological changes which may be important for driving SI adoption and productivity increases [23,24]. We offer original insights from Cameroon, the largest oil palm producer in Central Africa. These contributions collectively provide a nuanced understanding of the institutional pathways through which SI can be operationalized in smallholder oil palm systems. Our findings provide valuable insights into the challenges and opportunities associated with promoting sustainable practices in the smallholder oil palm sector, thereby informing policies and interventions to promote sustainable agriculture and rural development in tropical regions.

The remainder of this paper is organized as follows. Section 2 provides a brief overview of the context and background of oil palm production in Cameroon and the role of POs in promoting SI and increasing yields. After describing the data, Section 3 introduces the key variables of interest and outlines the empirical approach. The results are reported and discussed in Section 4, followed by Section 5, which concludes the study and provides directions for future research.

## 2. Context and conceptualization

This section provides a brief overview of the oil palm sector in Cameroon, the role of oil palm production in Cameroon, and its implications for smallholder farmers. We then conceptualize the relationship between POs, SIPs, and yields in oil palm fields.

### 2.1. An overview of the oil palm sector in Cameroon

Oil palm production is crucial to Cameroon's agricultural economy and contributes significantly to rural livelihoods and national export earnings. Smallholder farmers are the dominant oil palm growers in the country [29,30]. In recent years, national oil palm production has increased in Cameroon (Figure 1). Nevertheless, the average national production over the past decade has been significantly below the average in most producing countries and globally. Arguably, much of the increase in oil palm production in recent years can be attributed to area expansion (Figure 1). This improvement in oil palm production has been shown to increase farm income and reduce poverty in Cameroon [29,31,32]. However, smallholder oil palm production in Cameroon has been plagued by challenges such as low productivity, poor oil quality, and limited market access [21,30]. It has also been argued that oil palm production has a long value chain associated with reductions in off-farm activities participation by primary household producers [32]. Part of this long value chain involves milling, which is conducted using artisanal mills associated with increased deforestation [30].

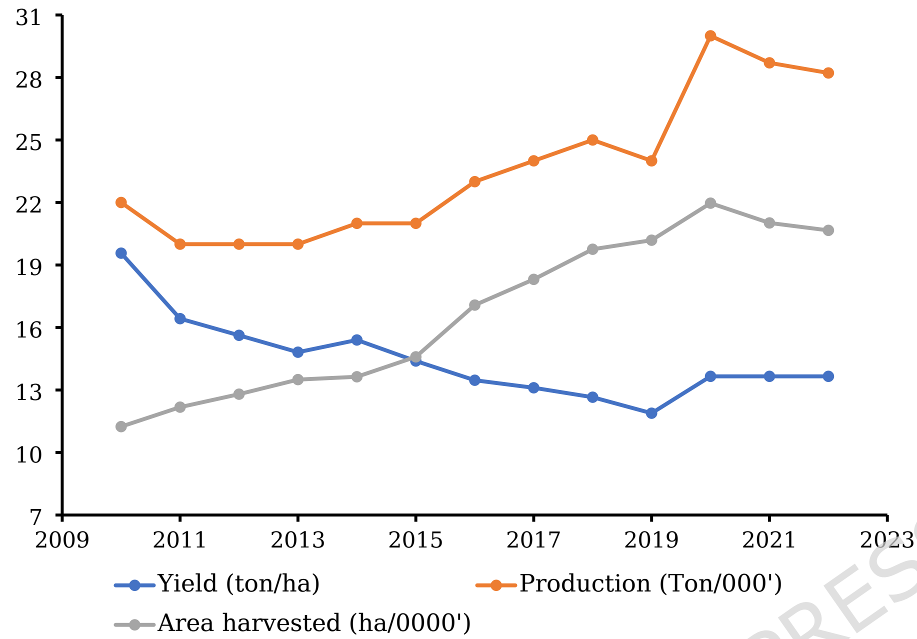


Figure 1. Production, yield, and area harvested of oil palm fruit in Cameroon (2010-2022).

*Source:* Authors' construction based on FAOSTAT (2024).



### 2.2. Sustainable intensification (SI) in practice

SI has emerged as a pivotal approach to address the challenges of increasing agricultural productivity, ensuring food security, and managing environmental impacts [33,34]. Globally, SI refers to farming practices that increase crop production from existing farmlands, while minimizing pressure on the environment and enhancing ecosystem services [35]. This concept is increasingly relevant, as the world grapples with the need to feed a growing population, which is projected to reach nearly 10 billion by 2050, without exacerbating environmental degradation [33-35].

In Africa, the application of SI is crucial. The continent faces unique challenges such as limited agricultural productivity, climate change vulnerabilities, and a rapidly growing population. Studies have shown that SI practices in Africa, such as improved crop varieties, agroforestry, water management, and soil conservation techniques can significantly boost yields while preserving ecological integrity [35,36]. These practices not only contribute to food security but also empower smallholder farmers, who form the backbone of African agriculture.

Cameroon, as a part of the Central African region, demonstrates the potential and challenges of implementing SI. Despite its diverse agro-ecological zones, Cameroon's agricultural sector is underdeveloped, with low yields and high postharvest losses [21]. Efforts to promote SI in Cameroon have focused on enhancing crop productivity through sustainable practices such as integrated pest management, conservation agriculture, and the use of improved seed varieties [31]. However, the adoption of these practices is still limited because of factors such as a lack of access to resources, inadequate extension services, and policy constraints. SI offers a promising pathway to meet global food demand while preserving environmental resources. Its successful implementation requires a holistic approach that integrates technological innovation, and policy support.



### 2.3. Producer organizations and farm performance

Membership in agricultural POs can affect crop production and yield through both direct and indirect channels (Figure 2). We define direct channels as mechanisms through which PO membership affects production outcomes immediately and concretely, such as improved access to inputs, training, technical assistance, and credit. Indirect channels involve more mediated effects, such as peer learning, social capital formation, and behavioral changes resulting from collective action and shared norms.

Improvements in production performance can be directly manifested through membership-induced changes in productivity or crop yields, resulting from enhanced access to modern technologies (improved farming practices and modern inputs) [26,37-39]. POs can help smallholder farmers improve their access to modern inputs, such as high-yielding and disease-resistant seeds, fertilizers, and pesticides, as well as access to markets for their production [40,41]. These actions can reduce transaction costs and increase economies of scale, thereby supporting both production and the adoption of SIPs. For example, POs can boost crop production by creating better linkages to markets, thereby easing supply-side constraints, such as high transaction costs [18,41,42]. POs can aggregate the output of smallholder farmers, enabling them to sell their products in larger volumes to local and international buyers [18,22,42]. This could result in higher prices for smallholder farmers and more stable and predictable markets. POs can provide technical assistance and training to farmers on the proper application of inputs, thereby improving their technical efficiency and effectiveness [40,43]. In this context, and as stated earlier, POs provide training to farmers on sustainable intensification practices (SIPs), including mulching and intercropping in oil palm cultivation.



Additionally, POs can help smallholder farmers comply with market standards and certifications such as the Roundtable on Sustainable Palm Oil (RSPO) certification, which can enhance the marketability of their products and maintain environmental sustainability [1]. POs can stimulate crop production by potentially offering a better market price for their members [28,39,41] and by providing financial support or seasonal credit of inputs, which can relax liquidity constraints in purchasing inputs [18,44]. POs can also facilitate the adoption of sustainable production practices and advocate for smallholder farmers' rights and interests (Meijaard and Sheil, 2019). Sustainable methods, such as integrated mulching and intercropping can enhance the resilience of oil palm plantations and improve the long-term productivity of smallholder farmers [45].

POs can also play a crucial role in advocating the rights and interests of smallholder farmers by representing their collective interests in negotiations with government agencies, private companies, and other stakeholders [19]. Furthermore, they can provide a platform for smallholder farmers to voice their concerns and engage in policy dialogues at various levels [46]. Another notable channel is resource pooling, which can involve aspects of both direct and indirect mechanism of influence. Given its operational role in many POs, resource pooling can be classified as a direct mechanism of influence. However, resource pooling can also be indirectly facilitated by social capital formation and collective norms within POs. In such cases, trust and social cohesion among members enable and sustain these pooling practices, inducing an indirect effect on production performance and SIP adoption.



Additionally, POs may foster key behavioral and psychological attributes among farmers, such as aspirations, self-efficacy, locus of control, trust, hope, and self-esteem, which have been shown to play a critical role in the adoption of sustainable agricultural practices [23,24,47,48]. Well-established farmer organizations can also improve their members' production performance

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https://www.sciencedirect.com/science/article/pii/S2452292921000655

https://www.sciencedirect.com/science/article/pii/S2214804323001453 through various other indirect mechanisms. Collective action can boost crop production and yield by facilitating agricultural innovation through efficient information flows and farmer-to-farmer technology transfer (spillover effect) [37,39,42,49]. Information asymmetry is a critical constraint faced by smallholder farmers in developing countries [50], but the lack of knowledge on the best production practices and marketing opportunities could be harnessed through cooperative membership. Cooperatives can act as information hubs and crowdsourcing units, where farmers bring information and disseminate information to their peers [51]. Collective actions can also enable resource-poor smallholder farmers to sustainably intensify their crop production by facilitating the pooling of various physical resources [28,41].

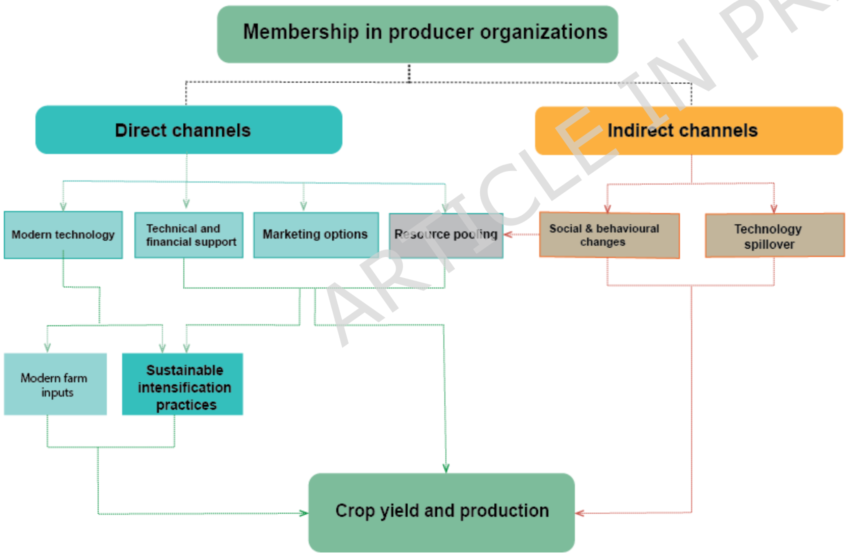


**Figure 2**. Potential effects of POs on oil palm production and yield
Source: Authors' visualisation

## 3. Materials and methods

### 3.1. Farm household survey

We rely on a farm household survey conducted between August and September 2021 in the Littoral region of Cameroon. The Littoral region is one of the hotspots of oil palm production in Cameroon. It has favorable agroecology (natural ecological conditions, like fertile soils, suitable rainfall, and supportive landscape features) and weather that favors oil palm cultivation. The region features forests largely untouched by human activity, along with secondary forests, as well as both old and new oil palm plantations. In this region, oil palm production is in the hands of independent producers and those contracted to large-scale oil palm agro-industries (plantation villages). SOCAPALM (La Société Camerounaise des Palmeraies) is an agro-industry that established resource-saving and marketing contracts with smallholder farmers in the region.

Sampling for the data collection followed a two-stage procedure wherein 39 villages were randomly selected in the first stage following the probability proportional to size sampling framework from the Ngwei and Yabassi districts in the Sanaga Maritime and Nkam divisions of the Littoral region (Figure 3). In the second stage, 13-17 households were randomly selected in each village, giving a total of 582 households. These households were then interviewed by a group of seven enumerators, supervised by the corresponding author. The interviews were conducted using survey-based tablets in both French and English. In some cases, interviews were conducted in the native language of the area. Although the survey successfully covered 582 households as part of a broader research project on both oil palm and non-oil palm farming systems, only 329 households that cultivated oil palm were retained for analysis in this paper, as they are directly relevant to the study's objectives.

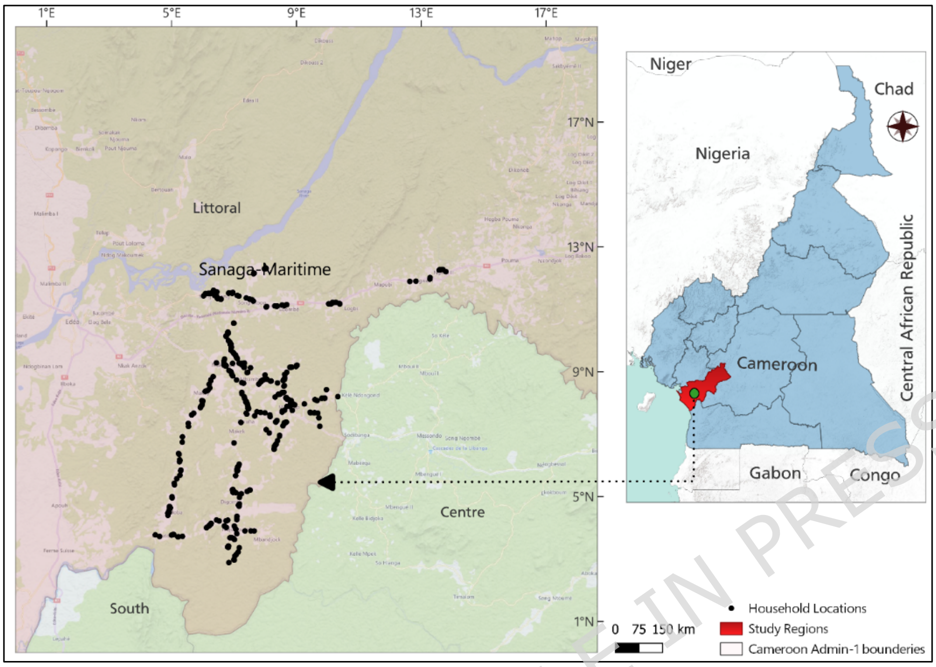


**Figure 3**. Map of study area showing sampled households
*Notes:* The spatial clustering of sampled households along roads reflects the geographic layout of villages in the study area, where settlements and farming communities are typically located near road networks for ease of access, transport, and market connectivity. The map was produced using *QGIS 3.34*.



The survey captured structured data at both household and farm levels. At the household level, socioeconomic characteristics such as age and education level of the household head, household size, and labor availability, and institutional variables such as access to extension and credit, use of mobile money, cooperative membership, income, and asset measures, were collected. Information on exposure to various shocks was also collected. At the farm level, we collected data on the inputs used (fertilizers and pesticides), outputs harvested, and the use of some SIPs. Informal interviews and open discussions were conducted with opinion leaders and village chiefs to obtain anecdotal insights at the village level.

### 3.2. Measurement of key variables

Our independent variable of interest is membership in POs, which is non-random, as households self-select into these groups based on their interests. It is measured as a dummy, taking *1* for households that participate in POs, and *0* otherwise. Furthermore, we have four outcomes of interest: oil palm production, yields, mulching, and intercropping. Some of the crops intercropped with oil palm especially when young are legume crops and trees which offer both livelihood and welfare opportunities for the farmers. They also offer agronomic benefits such as improving soil health and fertility conditions which greatly benefits oil palm fields.

While production measures total farm output, yields (also known as land productivity) take into account the area under cultivation. Production was measured as the total weight (in kilograms) of fresh fruit bunches (FFBs) harvested over the previous 12 months. Given that oil palm is a non-seasonal crop with continuous harvesting, farmers were asked to report the number of FFBs harvested per month and the average weight per bunch. These figures were aggregated across months to compute total annual production. Yield is calculated using the standard method commonly accepted in agricultural research and practice (i.e., total production divided by area) [33]. Both production and yield contain zero values for households that reported no harvest in the last calendar year. To effectively manage these zeros, we applied an inverse hyperbolic sine transformation, which is an efficient way of handling right-skewed variables by transforming them [52]. To measure SI, we rely on two primary practices commonly used by oil palm farmers in Cameroon: mulching and intercropping. Farmers practice mulching using fronds and residues from the vegetative parts of oil palm (fresh fruit bunches) to increase soil organic carbon [13]. Mulching is also important for preventing soil water erosion and land degradation [12]. Intercropping is an important component of the SIPs. Farmers are also cultivating food crops on oil palm fields in Cameroon to maximize the use of existing land and diversify their livelihood portfolios [15]. This is greatly encouraged, as oil palm is associated with lower dietary diversity and food insecurity in forest environments [53]. Intercropping also captures some aspects of crop diversification that are important for food security and income increases [15]. These two variables are captured as dichotomous variables (*1* and *0*) for households using them or not, respectively.

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We assessed behavioural factors - self-efficacy, locus of control (LOC), hope, and risk - using established scales from the literature [24,54]. Self-efficacy was measured with three Likert-scale items relying on well established statements measuring self-efficacy (1–5, strongly disagree to strongly agree); LOC with seven statements (1–7); hope with six statements (1–10); and risk with four items assessing willingness to take risks (1–5). We then used principal component analysis to aggregate the scores for each measure.

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We also include socioeconomic and farm-level controls in our regressions. Some of these controls include age, gender, educational level of the household head, household size, farm experience, off-farm activities participation, years lived in the village, extension contact, credit access, livestock ownership, farm size, number of crops cultivated, and the use of hired labor. The selection of relevant control variables is informed by earlier studies examining the effects of cooperative membership on farm production and productivity in developing and emerging economies [19,27,38,49,51].

### 3.3. Empirical strategy

We are interested in understanding the relationship between POs, production, and yields on oil palm farms and the relationship between POs and SIPs. We are also interested in the relationship between POs and behavioural factors such as perceived self-efficacy (PSE), locus of control, hope and risks. Given this, we estimate regression models of the form:

$$Y_i = \beta_0 + \beta_1 PO_i + \beta_2 X_i + u_i \qquad (1)$$

where $Y_i$ represents the outcome variables (production, yields, SIPs, PSE, locus of control, hope and risk) for household $i$, $PO_i$ is, the variable of interest, membership in POs. Our parameter of interest is $\beta_1$ which indicates the association between membership in POs and oil palm production levels and yields. A positive coefficient implies that POs are positively associated with production and likely to increase yields. By contrast, a negative association indicates a possible yield-reducing effect of PO membership. This is also the case for the SIPs and the behavioural factors, where a positive coefficient signifies increased adoption (and improved behaviour and agency for behavioural factors) and otherwise. The vector $X_i$ represents a vector of explanatory variables that are thought to influence smallholder production and yields. The parameter estimates of the vector $X_i$ indicates the relationship between the various explanatory variables and yields and the SIPs. Finally, $u_i$ is the stochastic error term.

We can estimate Equation (1) using the ordinary least squares (OLS) estimator, but it does not address the issue of selection bias. For instance, membership in POs is not random, and households self-select themselves in these organizations based on different observable and unobservable characteristics. In this case, estimating an OLS model would lead to biased estimates. Matching and weighting estimators have been shown to reduce selection bias; however, they are not without their own limitations. Beyond matching households based on their observable characteristics and minimizing selection bias, these estimators may still be biased when specified incorrectly. Other variants of this weighting estimator, the doubly robust estimators, have been shown to relax this limitation of matching and weighting estimators by imposing fewer restrictions on the functional form of the model. In this regard, we use Inverse Probability Weighted Regression Adjustment (IPWRA), a doubly robust estimator, to estimate the relationship between membership in POs, oil palm production, yields, and SIPs.

The IPWRA works in three distinct but interrelated steps: (1) the probability of households participating in POs is modeled using nonlinear models such as probit and logit models; (2) inverse probability weights obtained from the non-linear model are used to fit weighted outcomes to obtain the predicted outcomes for both members and non-members of POs, as in Equation [2]. It is worth mentioning that the outcome models are fitted based on the nature of the outcome variables. In our case, linear models are estimated, and (3) the means of the predicted outcomes are used to estimate the average treatment effect on the ATET, which signifies the association between POs and oil palm production and yields. These can be represented as:

$$Y_i = f(PO_i,\ \beta_1) + v_i \quad (2)$$

$$Pr(PO_i = 1,0) = H(X_i, \beta_2) + e_i \quad (3)$$

$$ATET = E(Y_{1i}|PO_i = 1) - E(Y_{0i}|PO_i = 0) \quad (4)$$

The same notation is used as described above. Additionally, *E*(.) represents the expectation operator $Y_{1i}$ representing the oil palm production and yield of households that are members of POs and $Y_{0i}$ the production and yield levels of non-members of POs.

### 3.4. Additional identification strategies and robustness checks



Despite being robust to functional form misspecification, IPWRA only controls for the observed characteristics. It fails to control for unobservable characteristics, which may indeed be correlated with both membership in POs and relevance to yield increases and the use of SIPs. These unobserved characteristics include risks, preferences, managerial abilities, and other variables that are usually difficult to capture in household surveys. We do not have experimental data or a panel to effectively control for this unobserved heterogeneity. However, we explore two variants of instrumental variable estimators to control for these unobserved characteristics. We use two-stage least squares (2SLS) and endogenous switching regression (ESR) models [55]. Because the SIPs are binary outcomes, we also use the recursive bivariate probit model. These models require the specification of an instrumental variable (IV), which is usually difficult to obtain, especially in nonexperimental settings. Notwithstanding, we use membership in POs at the village level as an instrument. Our instrument is a village-level variable also known as the Village PO membership rate. It simply shows the number of households in POs in the village. It is constructed by counting the number of farmers who belong to a PO, excluding the representative farmer itself and then dividing by the total number of households.

The use of this variable as an IV is motivated by the literature on social learning and neighborhood effects. Households tend to follow the decisions and choices of their members, particularly when they observe positive benefits [49,51,56]. This variable could serve as a reasonable proxy for information access and flow, which is relevant for membership in POs, as we show in the results. Moving away from instrument relevance to exogeneity, we do not think of any possible relationship between our IV and yields except through membership in POs. Nevertheless, our instrument may not be perfect, given possible aggregation bias and issues of omitted variable bias [57,58]. In light of this limitation, we conduct some falsification tests and follow Oster [59] to perform coefficient stability and omitted variable bias tests, where we show that omitted variable bias does not seem to bias our estimated coefficients. We also follow and explore the test of Diegert, et al. [60], which relaxes some of the assumptions of Oster [59] but, most importantly, allows for endogenous controls. The Oster approach relies on the exogenous controls assumption, which is restrictive as it is based on the premise that omitted variables are uncorrelated with the included control variables. Thus, the approach of Diegert, et al. [60] allows the included controls to be endogenous, which reflects reality to a great extent.

Given that we include many controls that may be endogenous (access to credit and fertilizer use), this novel framework estimates how large the selection of unobservable needs to be relative to the selection of observables to explain the estimated results (interested readers should refer to Diegert, et al. [60] for a detailed discussion). Although the 2SLS and ESR models rely on valid exclusion restrictions, they offer two different results that can be used for robustness checks. While 2SLS, like OLS and IPWRA, provides different variants of the treatment effect model based on intercept shifts, the ESR model examines slope shifts, making it possible to differentiate between members and non-members of POs, and by doing so, obtain actual and counterfactual associations [51].

### 3.5. Ethical considerations

The authors confirm that the household survey was carried out in accordance with relevant guidelines and regulations. The study was also approved by the Center for Development Research Ethics Committee at the University of Bonn and was found to be ethically sound. All methods were carried out in accordance with relevant guidelines and regulations. Our study complies with the relevant institutional, national, and international guidelines and legislation, especially the IUCN Policy Statement on Research Involving Species at Risk of Extinction and the Convention on the Trade in Endangered Species of Wild Fauna and Flora. Additionally, informed consent was obtained from all interviewed households prior to the start of the survey.



## 4. Results and Discussion

### 4.1. Characterizing the sample and data

Table 1 presents the descriptive insights of the selected variables. As shown in column (3) of Table 1, oil palm production and yield averages 8758 kg and 4262 kg/ha, respectively. Regarding the use of SIPs, we find that 40% of households practice mulching, and 64% practice intercropping. About 36% of oil palm farmers are members of POs. On average, household heads are mostly middle-aged, and 78% of them are males. Households have spent about ten years of informal schooling and have nearly 23 years of farming experience. Farm households cultivate oil palm on about three hectares of farmland and other crops. These include cocoyam, legumes (groundnuts and beans), maize, and vegetables. Livestock ownership is relatively low, indicating that farming in the study area is crop-dominated. Many households rely on family labor for farm production purposes and have an average size of five members.

**Table 1**. Mean differences based on membership in POs

| | (1) Non-members | (2) Members | (3) Total | (4) p-value |
|---|---|---|---|---|
| Production (Kg) | 7601.539 | 10798.775 | 8757.986 | 0.558 |
| | [2895.528] | [5136.698] | [2617.364] | |
| Yields (Kg/ha) | 4603.294 | 3660.117 | 4262.145 | 0.809 |
| | [2857.018] | [1193.490] | [1872.393] | |
| Age of household head (years) | 53.714 | 51.000 | 52.733 | 0.092* |
| | [1.004] | [1.183] | [0.773] | |
| Household head is male (1/0) | 0.795 | 0.739 | 0.775 | 0.246 |
| Educational level (years) | 9.890 | 10.445 | 10.091 | 0.239 |
| | [0.269] | [0.407] | [0.226] | |
| Household size (number) | 5.195 | 5.277 | 5.225 | 0.881 |
| | [0.331] | [0.429] | [0.262] | |
| Experience (years) | 24.395 | 20.008 | 22.809 | 0.008*** |
| | [1.083] | [1.089] | [0.803] | |
| Off-farm activities participation (1/0) | 0.262 | 0.277 | 0.267 | 0.762 |
| Years lived in the village (years) | 26.133 | 20.739 | 24.182 | 0.006*** |
| | [1.263] | [1.280] | [0.939] | |
| Extension access (1/0) | 0.252 | 0.269 | 0.258 | 0.743 |
| Credit access (1/0) | 0.186 | 0.252 | 0.210 | 0.156 |
| Livestock ownership (TLU) | 0.042 | 0.068 | 0.052 | 0.293 |
| | [0.010] | [0.027] | [0.012] | |
| Farm size (hectares) | 30.739 | 19.033 | 26.505 | 0.046** |
| | [3.830] | [3.821] | [2.822] | |
| Area under oil palm (hectares) | 3.324 | 2.640 | 3.077 | 0.124 |
| | [0.302] | [0.251] | [0.214] | |
| Number of crops cultivated | 2.357 | 2.748 | 2.498 | 0.047** |
| | [0.118] | [0.155] | [0.094] | |
| Hired labor (1/0) | 0.557 | 0.630 | 0.584 | 0.197 |
| Mulching (1/0) | 0.324 | 0.529 | 0.398 | 0.000*** |
| Intercropping (1/0) | 0.571 | 0.765 | 0.641 | 0.000*** |
| Fertilizer use (1/0) | 0.276 | 0.277 | 0.277 | 0.983 |

| | | | | |
|---|---|---|---|---|
| Perceived self-efficacy | -0.117 | 0.209 | 1.49e-08 | 0.039** |
| | [0.107] | [0.091] | [0.076] | |
| Locus of control | -0.279 | 0.486 | -2.33e-08 | 0.002*** |
| | [0.165] | [0.153] | [0.120] | |
| Hope | -0.200 | 0.357 | -2.76e-09 | 0.009*** |
| | [0.140] | [0.140] | [0.104] | |
| Risk | -0.170 | 0.293 | -1.19e-08 | 0.026** |
| | [0.131] | [0.149] | [0.100] | |
| Number of observations | 210 | 119 | 329 | |

*Notes:* Means are presented with standard errors in brackets. Column (4) shows the p-values of the t-tests for equality of the means. The values displayed for the t-tests are p-values. ***, **, and * indicate significance at the 1, 5, and 10 percent critical levels. Table A1 presents the drivers of cooperative membership. Table A2 presents the first stage model of participation in POs. Table A3 presents the Balance tests showing the standardized differences and variance ratio of the covariates.

About 58% of households employ hired labor, which is seasonal in most cases, indicating that family labor is limited in handling more technical and skilled processes in oil palm production, such as harvesting. About 27% of farmers participate in off-farm income-generating activities. Regarding the other village-level covariates, 26% and 21% of the sample households have access to extension and financial credit services, respectively.

In columns (1) and (2), we provide insights into some observed differences between households that are members of POs and those that are not. For our variables of interest, we did not observe any statistical difference in the means for both oil palm production and yields or crop rotation when we considered membership in POs. Nevertheless, members of POs are more likely to practice mulching and intercropping than non-members of the POs. For other socioeconomic and farm-level controls, we observe varying relationships. Specifically, PO members are younger and less experienced than their non-member counterparts. Compared to non-members, cooperative members have smaller farm sizes and are more diverse in their crop production. It is important to mention that although some of these results make intuitive sense, they do not control for other confounding factors in a formal regression setup. Moreover, no attempt has been made to control for selection bias in POs.

### 4.2. Regression results

In this section, we present and discuss the insights from the empirical investigation of the relationship between membership in POs and oil palm production and yields. We begin by presenting the baseline OLS results (Figure 4). The full OLS estimates are reported in the Appendix (Table A5). The OLS estimates obtained without adding household- and farm-level controls indicate that membership in POs is positively associated with oil palm production and yield. However, after controlling for other factors, we maintain a positive relationship only with oil palm yield. Thus, members of POs are observed to have greater yields than non-members by about 61 percent. The fact that controlling for other observables and weighting for probability of participation produces positive estimates of membership on yields suggests that lower productivity farmers are more likely to be members, on average. This is an interesting finding as it commonly assumed that farmers with greater farming skills are more likely to join POs, which does not seem to be the case here. As stated earlier, OLS estimates are only suggestive, as they may lead to biased estimates and subsequent inferences regarding the relationship between POs, production, and yields due to potential selection bias.



In the following section, we examine the treatment effect estimates for POs using alternative estimation techniques that can control for the selection bias arising from the non-random nature of membership in POs.

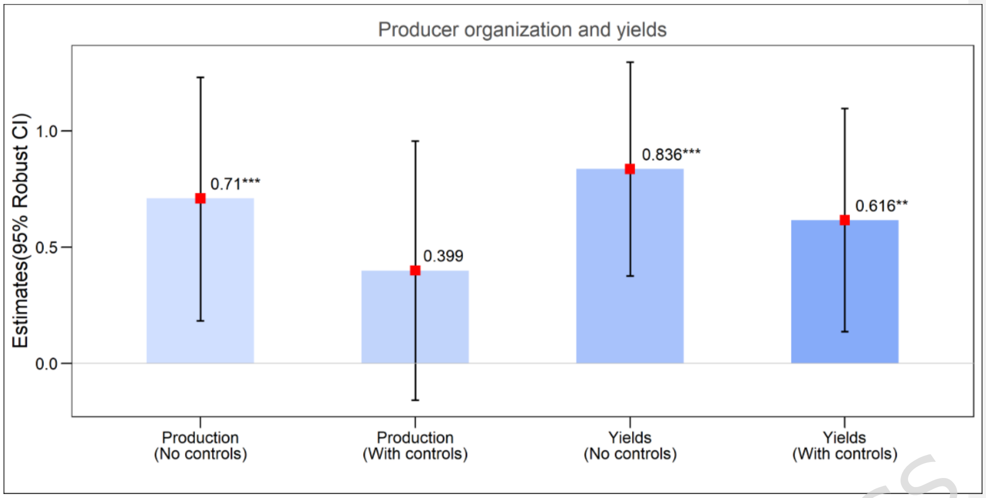


**Figure 4**. Producer organization, oil palm production, and yields
Notes: Full results are presented in Table A5 in the Supplementary Material. *, **, and *** represent statistical significance at the 10%, 5%, and 1% levels, respectively. The models are estimated with other controls such as age, gender, educational level of the household head, household size, farm experience, off-farm activities participation, years lived in the village, extension contact, credit access, livestock ownership, farm size, number of crops cultivated, use of hired labor, crop rotation, mulching, intercropping, soil and water conservation, minimum tillage, forest expansion, fertilizer use, and pesticide use.

*4.2.1. Membership in producer organizations, oil palm production, and yields*

Tables 2 and 3 show the estimates for the relationship between membership in POs and oil palm production and yields estimated using different quasi-experimental regression techniques and estimation strategies. Table 2 reports the results estimated after correcting for selection bias using Equation (4) within the IPWRA framework. Table 3 presents the results on the relationship between POs and yields, estimated based on the ESR specifications—one of the two alternative estimators we use to verify the robustness of the IPWRA estimates. Overall, these additional results estimated using the ESR model are very similar to the IPWRA results, bolstering the robustness of our estimated coefficients.

**Table 2.** Doubly Robust Estimates of the relationship between producer organization and yields

| | Production | | Yields | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| Producer organisation (1/0) | 0.710** | 0.537** | 0.836*** | 0.735*** |
| | (0.289) | (0.271) | (0.276) | (0.261) |
| Additional controls | No | Yes | No | Yes |
| Number of clusters | 31 | 31 | 31 | 31 |
| Observations | 329 | 329 | 329 | 329 |

Notes: Robust standard errors are reported in the parentheses. *, **, and *** represent statistical significance at the 10%, 5%, and 1% levels, respectively. Other controls include age, gender, educational level of the household head, household size, farm experience, years lived in the village, extension contact, credit access, livestock ownership, farm size, asset index, number of crops cultivated, use of hired labor, use of fertilizer, and forest expansion



The reported estimates of the association between POs, production, and yields are generally consistent across all estimation strategies and are statistically significant with and without controlling for other factors that would affect oil palm production and yield. Given the estimated slope coefficients, this is even more the case for the ESR model, where we capture the actual-counterfactual relationships between POs and yields. Our estimates, based on the IPWRA specification, align with the OLS model, which shows that membership in POs has a positive association with oil palm production and yields. The results presented in Column 2 of Table 2, estimated after controlling for other factors, show that membership in POs is associated with a 53 percent increase in oil palm production. Similarly, controlling for other factors, we find that membership in POs is associated with a 74 percent increase in yields. The ESR model estimates (Table 3) show both the actual (ATT) and counterfactual (ATU) effects of POs. The results from the ATT estimates suggest that membership in POs is associated with increases in oil palm yield by 2.45 percent among PO members, respectively. The ATU estimates also point to potential positive effects, even for non-members of POs. Table 3. ESR estimates of POs and yields

| | PO member | Non-member | |
|---|---|---|---|
| | | | **ATT** |
| Yields | 7.19 | 11.81 | 4.62*** |
| | (0.09) | (0.06) | |
| | | | **ATU** |
| Yields | 12.10 | 6.34 | 5.76*** |
| | (0.06) | (0.05) | |
| Heterogeneity effects (Yields) | -4.91 | 5.47 | -1.14 |

Notes: Yield is transformed using inverse hyperbolic sine transformation. ATT stands for the Average Treatment Effect on the treated and ATU stands for the Average Treatment Effect on the untreated. Heteroskedasticity robust standard errors are shown in parentheses. ***, **, and * indicate statistical significance at the 1, 5, and 10 percent critical levels, respectively.

We also show at the bottom of Table 3 that significant heterogeneity effects make members and non-members of POs different. The transitional heterogeneity for yields is negative, implying that the effect of POs on yields is greater for non-members than for members. This is an important insight as it shows that POs have the potential to benefit non-members if they were to join. Transition heterogeneity provides information about the counterfactual, that is the potential effect of POs on the outcomes of non-members. This is clearly hypothetical and based on the actual counterfactual framework. In this case, non-members would experience higher gains than members based on their existing characteristics. If these households were to join POs with their existing backgrounds and resource endowments, they could adopt SIPs more and see large increases in their productivity. While this is an important finding in itself, it also points to the important role of POs for yield increases.

These findings generally support the widely held notion that effectively promoting rural collective action through POs can serve as an important institutional vehicle to boost the smallholder farming sector. Our results are largely consistent with the findings of earlier studies that have focused on both food and cash crops. Numerous studies have examined the role of membership in rural farmer organizations on farm performance and productivity in developing and emerging economies [19,27,38,40,49,61]. For example, focusing on banana production in China, Ma, et al. [27] show that cooperative membership increases banana yield by 3%. Using farm-level data from tomato farmers in Nepal, Mishra, et al. [61] reveal that contract farming through cooperatives is positively associated with tomato yields. Most existing studies have documented a positive association between POs and farm performance. These studies look at crops such as maize [19,49], banana [42], and cocoa [62]. However, as evidenced by a comprehensive meta-analysis of primary studies in developing countries, empirical evidence of the effects of POs on crop yields remains mixed [38]. For instance, while Shumeta and D'Haese [63] find little effect of POs on coffee yields, Fischer and Qaim [42] find an adverse effect on banana yields. Such heterogeneity in the relationship between membership in farmer organizations and farm performance could be likely due to differences in scope across studies, especially when different crops and farming systems are considered. This gives credence to the role of context in understanding household-level analyses.

Notwithstanding, our results show consistent estimates across different estimation techniques, underscoring the important role of POs in increasing oil palm production and yields. Given that oil palm is both a food and cash crop in Cameroon, with significant income gains for smallholder households [32], our results suggest that further strengthening and promoting POs can make the sector more profitable, with implications for development in rural and forested areas.

#### *4.2.2. Producer Organizations and SIPs*

We are also interested in understanding the relationship between POs and SIPs. The insights here would either confirm or refute some of the conceptualizations we highlighted earlier. Beyond increasing oil palm production and yields, POs could also stir the adoption of SIPs. If this is the case, one could argue that our results on the association with SIPs could represent the pathways through which POs increase oil palm production and yield in Cameroon. Intuitively, the observed increase in production and yields could arise from some of the benefits of POs, such as better access to modern inputs, improved agency and psychological skills, technical support, and the provision of inputs such as fertilizers and pesticides [26,38,39]. The observed production and yield-enhancing effect of POs can also be attributed to technology transfer through the farmer-to-farmer spillover effects [37] and efficient information flows [42]. POs could also increase production and yields by relaxing supply-side constraints and transaction costs in accessing productivity-enhancing inputs [18,41,42], facilitating the pooling of various resources (e.g., labor and credit) among members [28,49], and relaxing liquidity constraints in purchasing modern inputs by providing seasonal credit of inputs [18,26,44].

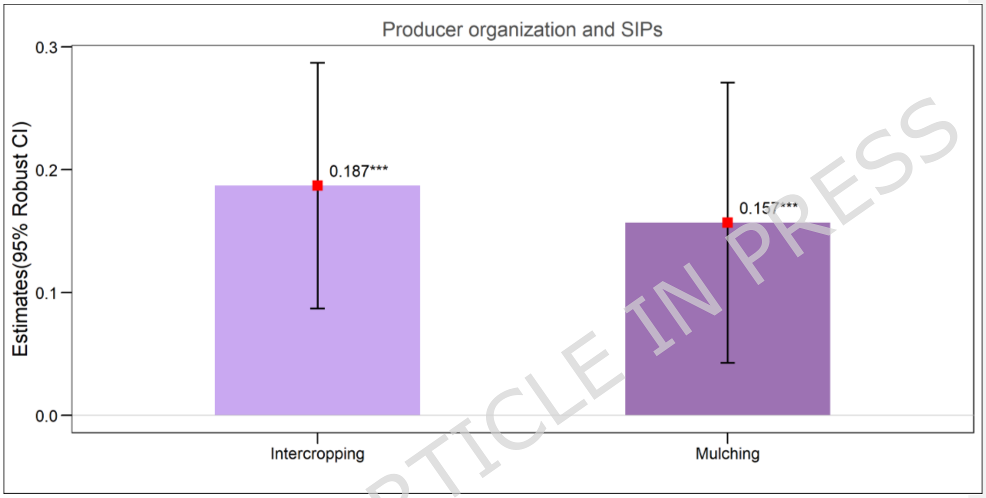



Figure 5. POs and SIPs

Notes: Full results are presented in the supplementary material, Table A4. *, **, and *** represent statistical significance at the 10%, 5%, and 1% levels, respectively. The models are estimated with other controls such as age, gender, educational level of the household head, household size, farm experience, years lived in the village, extension contact, credit access, livestock ownership, farm size, asset index, number of crops cultivated, use of hired labor, use of fertilizer, and forest expansion.

As shown in Figure 5, we use the linear probability model to estimate a positive association between membership in POs and the use of mulching and intercropping. We see that membership in POs is associated with 18 and 16 percentage point increase in intercropping and mulching, respectively. These results are consistent with the two-stage least squares estimation and the recursive bivariate probit model used to estimate the relationship between POs and SIPs (Supplementary Material Tables A6 and A7). In terms of what may explain these differences, Tabe-Ojong [51] highlighted how membership in POs may lead to the adoption of SIPs: (1) POs could act as hubs for sharing and exchanging information; (2) PO could also act as small-scale lending institutions, providing loans to their members which relaxes liquidity constraints for farming purposes; (3) Related to the above, POs may benefit from economies of scale due to their size and strength. Their size may also attract rural extension services: (4) Finally input access and market access also matter especially given that intercropping requires the cultivation of different crops which may require significant input and market access.

#### *4.2.4 Gender heterogeneity*

After showing the positive association between POs and the adoption of mulching and intercropping as well as production and yields, we are interested to understand some heterogeneities along gender lines given that approximately 22% of households in the study area are headed by women. In this regard, we perform some gender disaggregated analysis differentiating between male and female-headed households. Table 4 shows the disaggregated results. For male-headed households. The main insights are maintained for mulching, intercropping, production and yields with some little changes in magnitudes and statistical significance. For female headed households, we only find a positive association between POs with mulching and intercropping. For production and yields, we find negative associations although these are not statistically significant. These different results may suggest that membership in producer organizations have gendered implications. For instance, for male headed households, POs are positively associated with production and yields while they are not for female headed households. For mulching and intercropping, we obtain similar insights across different households but a look at the magnitudes suggests that the female-headed households tend to benefit more from POs in terms of the use of mulching and intercropping.

Table 4: Producer organizations, SIPs and productivity by gender of household head

| | (1) Mulching | (2) Intercropping | (3) Production | (4) Yields |
|---|---|---|---|---|
| **Male headed households** | | | | |
| Producer organization (1/0) | 0.120* | 0.142** | 0.631* | 0.725** |
| | (0.070) | (0.059) | (0.354) | (0.277) |
| | (0.083) | (0.066) | (0.459) | (0.439) |
| Constant | 0.364** | 0.363* | 6.128*** | 6.260*** |
| | (0.132) | (0.209) | (1.215) | (1.228) |
| Observations | 255 | 255 | 255 | 255 |
| R-squared | 0.208 | 0.289 | 0.105 | 0.099 |
| Additional controls | Yes | Yes | Yes | Yes |
| | | | | |
| **Female headed households** | | | | |
| Producer organization (1/0) | 0.253** | 0.428*** | -0.481 | -0.026 |
| | (0.117) | (0.103) | (0.609) | (0.646) |
| Constant | 0.501 | 0.563 | 6.396*** | 6.488*** |
| | (0.385) | (0.535) | (2.068) | (1.952) |
| Observations | 74 | 74 | 74 | 74 |
| R-squared | 0.320 | 0.291 | 0.373 | 0.437 |
| Additional control | Yes | Yes | Yes | Yes |

Notes: Robust standard errors are reported in the parentheses. *, **, and *** represent statistical significance at the 10%, 5%, and 1% levels, respectively. Additional controls include age, gender, educational level of the household head, household size, farm experience, years lived in the village, extension contact, credit access, livestock ownership, farm size, asset index, number of crops cultivated, use of hired labor, use of fertilizer, and forest expansion. Full results are in Tables A11 and A12.

### *4.2.5 Producer organizations and behavioural factors*

As has been previously documented, POs often play a significant role in the provision of targeted training on the use of sustainable farming practices such as mulching and organic soil amendments, which have the potential to increase yields and food security while ensuring environmental sustainability [27,38,51,64]. These trainings and enhanced interactions could improve agency and build behavioral and psychological skills. Moreover, in these POs, members may be exposed to role models and reference farmers who may be instrumental in altering their behaviours and improving their agency and mental models [24]. We test this formally in a regression setting where we examine the association between POs and perceived self-efficacy, locus of control, hope and risk. Table 5 shows these results where we show a positive association between producre organizations and perceived self efficacy, locus of control, hope and risks (Table A9 in the Supplementary Material). These behavioral traits have been shown to be associated with the adoption of sustainable agricultural practices [23,24].



Table 5: Producer organizations and behavioral factors

| | (1) PSE | (2) LOC | (3) Hope | (4) Risk |
|---|---|---|---|---|
| Producer organization (1/0) | 0.378*** | 0.687*** | 0.410** | 0.299* |
| | (0.110) | (0.229) | (0.194) | (0.162) |
| Constant | -0.478 | -2.161*** | -1.271 | -1.742** |
| | (0.456) | (0.670) | (0.763) | (0.751) |
| Observations | 328 | 326 | 328 | 324 |
| R-squared | 0.192 | 0.347 | 0.174 | 0.401 |

| Additional control | YES | YES | YES | YES |
|---|---|---|---|---|

Notes: PSE is perceived self efficacy, LOC is locus of control. Robust standard errors are reported in the parentheses. *, **, and *** represent statistical significance at the 10%, 5%, and 1% levels, respectively. The models are estimated with other controls such as age, gender, educational level of the household head, household size, farm experience, off-farm activities participation, years lived in the village, extension contact, credit access, livestock ownership, farm size, number of crops cultivated, use of hired labor, crop rotation, mulching, intercropping, soil and water conservation, minimum tillage, forest expansion, fertilizer use, and pesticide use.Full results are in Tables A9.

#### *4.2.6 Results of the robustness and sensitivity checks*

As mentioned in the empirical strategy above, we employ several estimation strategies to confirm the empirical findings on the relationship between POs, SIPs, and oil palm production and yields. First, we estimate and present the results of the bivariate probit model and ESR model that show the relationship between POs, SIPs, and oil palm production and yields, respectively. Beyond these estimators, we also employ the 2SLS method, which is a nuanced variant of some of the above-estimated models. All models rely on specifying an IV or exclusion restriction. Figure 6 shows the estimated coefficients based on the 2SLS method. Most of the estimated coefficients are consistent in terms of sign, magnitude, and direction.



For the next robustness exercise, we present the results of the coefficient stability test, following Diegert, et al. [60] and Oster [59]. Both tests are informative about omitted variable bias, as discussed in the Methods section. Table 6 presents the beta-adjusted coefficients and delta values. The beta-adjusted coefficient indicates how the estimated coefficient would change if the omitted variable bias is as strong as the included controls. On the other hand, the delta value indicates how large the omitted variable bias needs to be relative to the included controls to explain the estimated relationship. In our case, the omitted variable bias is expected to be approximately 14 times that of the included controls to annul the estimated relationship between POs and yields.

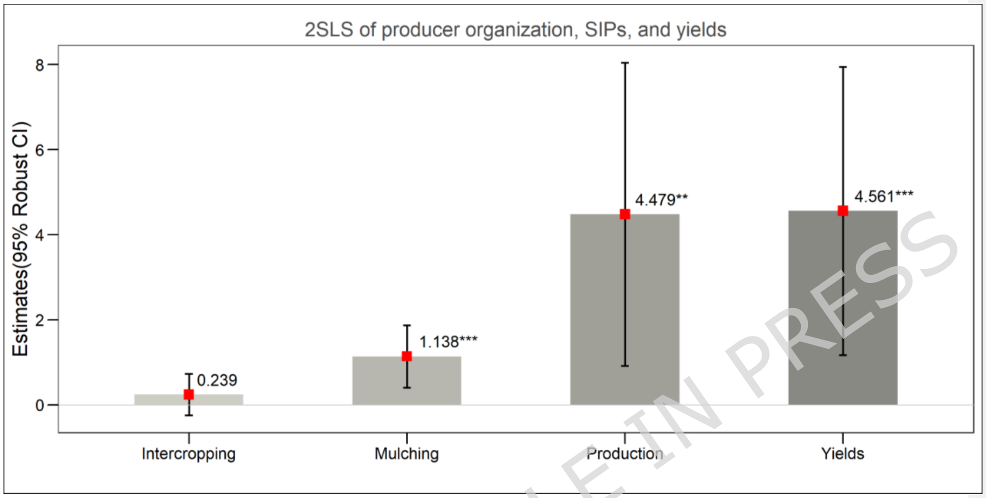


Figure 6. 2SLS estimates of the relationship between POs, SIPs, and yields
Notes: Full results are presented in the supplementary material, Tables A6 and A8. Table A10 also shows the falsification test on the instrumental variable. *, **, and *** represent statistical significance at the 10%, 5%, and 1% levels, respectively. The models are estimated with other controls such as age, gender, educational level of the household head, household size, farm experience, off-farm activities participation, years lived in the village, extension contact, credit access, livestock ownership, farm size, number of crops cultivated, use of hired labor, use of fertilizer, and conversion of forest land.

Table 6. Coefficient stability test (Oster 2019)

| | (1) | (2) |
|---|---|---|
| Beta adjusted coefficients | 0 | 0.79 |
| Delta | 13.71 | 1 |
| $R^2$ max | 0.115 | 0.115 |

Notes: In specification (1), the degree of omitted variable bias is calculated after setting the estimated coefficients to zero. In specification (2), the omitted variable bias is assumed equal to the additional controls used, from which the bias-adjusted beta coefficients are estimated. Robust standard errors are in parentheses. ***p < 0.01, **p < 0.05, and *p < 0.1.

Turning to the results of the Diegert, et al. [60] framework, we obtain results that first confirm insights from the Oster bounds. Figure 7 provides further insights from the coefficient stability test. As observed, the baseline estimate is around 0.8. Given this, the main question remains whether this estimate reflects omitted variables rather than a true relationship between POs and yields. The *cbar* = 1 case in Figure 8 shows that the bounds cross the horizontal axis at zero at around 0.75, or 85%. This indicates that the results are robust to omitted variables, up to 85%, as important as observables. The figure also considers the case in which restrictions are imposed on the relationship between observed and omitted variables. In this case, even assuming that they are exogenous, does not change the point at which the bounds intersect the horizontal axis.

Figure 7 shows the intersection point as a function of the *cbar*. Because this is slightly decreasing, though somewhat flat, we see that robustness conclusions generally do not depend on the assumptions we make about *cbar*. We conclude that our results are robust to omitted variables given that we have a 50% rule of thumb.

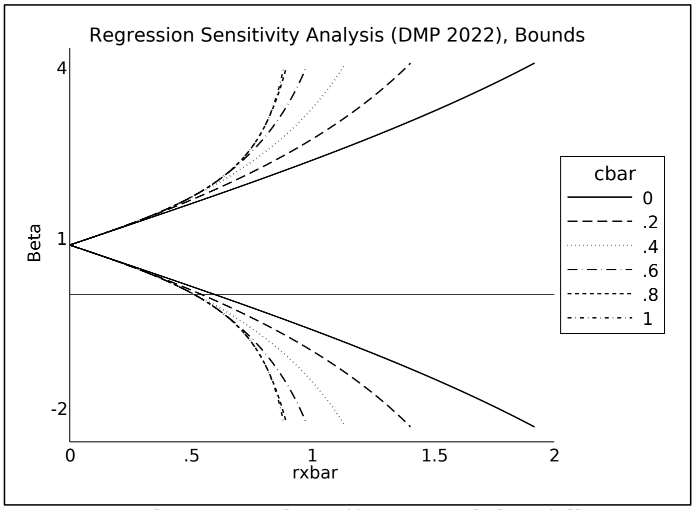


Figure 7. Selection and coefficient stability following Diegert, et al. [60].
Notes: This figure shows the results of the coefficient stability tests when endogenous controls are included. The *cbar* represents different line patterns indicative of different levels of potential endogeneity between the omitted variables and included controls. The dotted line represents the least conservative setting in which full endogeneity is assumed. The intersection here lies at about 0.70.

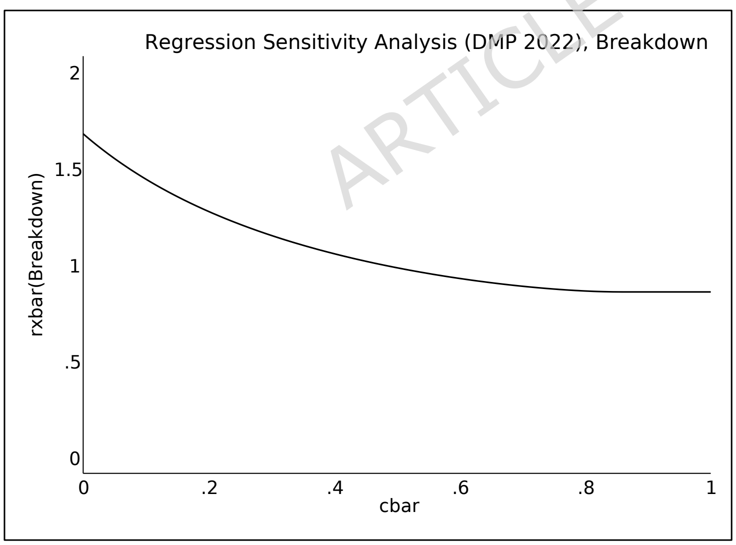


Figure 8. Selection and coefficient stability following Diegert, et al. [60].

## 5. Conclusion

Promoting the SI of smallholder oil palm production is a promising strategy for increasing yields and reducing environmental challenges. In this study, we have investigated the relationship between POs membership and SIPs in oil palm production in Cameroon. We have used farm- and household-level data from surveys of farm households, and discussions and interviews with village chiefs and model farmers. We have employed different regression techniques to estimate the actual and counterfactual effects of POs on oil palm production and yield. We have shown that membership in POs is significantly associated with increases in production and yield. Using actual-counterfactual estimation approaches, we have further demonstrated that POs benefit not only members in terms of yield gains but also non-members should they be members of POs, which is vital for policy formulation. Additionally, we have provided insights into a positive association between POs and intercropping and mulching. In the interest of understanding some heterogeneities, we further showed that our findings are gendered with slightly different implications along gender lines. Finally, we establish a positive association between POs and behaviora factors such as perceived self-efficacy, locus of control, and hope.

Taken together, our findings underscore the importance of promoting POs and SIPs to increase oil palm production and yield, while maintaining environmental sustainability. Our findings can inform policy interventions to promote sustainable agriculture and rural development in developing countries by suggesting that POs can serve as vehicles for the promotion of SI, with implications for agricultural productivity and environmental sustainability. Our findings also have wider implications for intensification, land sparing, and deforestation, which have been linked to the expansion of oil palm plantations in Cameroon and other tropical regions of Africa due to the proliferation of informal mills. The application of SIPs offers immense promise in increasing oil palm production and ensuring environmental sustainability. We emphasize that the success of POs depends on their capability to effectively manage resources, ensure transparency and accountability, and build members' trust and confidence, which are critical problems in developing economies.

We conclude by outlining some limitations of the study that could be taken up in further research endeavors. First, we have made efforts to control for endogeneity and various confounding factors, but we refer to our estimates as associations since we use cross-sectional data, and we cannot fully control for unobserved heterogeneity. Moreover, measurement error in some of our key variables such as production and yield cannot be ruled out. It could also be argued that we relied on binary measures for intercropping and mulching, ignoring potential variability in how intensively these practices are used by farmers. The use of panel data and more accurate measurement methods may help control better for some of these concerns. Second, our sample size is small, and we recognize that this may admittedly affect the extrapolation of the estimates. Thus, larger surveys from different contexts may improve the quality of estimates. Third, and related to the above, we refrain from an absolute generalization of this work as context matters. Although our findings could, in principle, be generalized to other oil palm hotspots in West and Central Africa, such as Ghana, Nigeria, Cote d'Ivoire, and Sierra Leone, given the similarities in the sector, they may not apply to other hotspots from Asia such as Indonesia and Malaysia. Despite these perceived similarities and differences, it would be interesting to analyze in these lines to improve learning on SI in oil palm production.

**Data Availability**

Data and codes used for the analysis would be shared by the corresponding author upon request.



**Author contributions**

**Martin Paul Jr. Tabe-Ojong:** Conceptualization, Data curation, Methodology, Software, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Abebayehu G. Geffersa:** Conceptualization, Methodology, Software, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Kibrom Sibhatu:** Conceptualization, Methodology, Software, Formal analysis, Investigation, Writing – original draft, Writing – review & editing.

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