Received: 8 October 2023 | Revised: 26 January 2024 | Accepted: 25 March 2024

DOI: 10.1111/1477-9552.12582

JAE Journal of Agricultural Economics

ORIGINAL ARTICLE

Are farm input subsidies a disincentive for integrated pest management adoption? Evidence from Zambia

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Funding information
CABI Development Fund (CDF)

Abstract

Input subsidy programmes (ISPs) remain a popular but contentious policy tool to promote agricultural intensification, food security and poverty reduction across Africa. Although previous studies have explored the impact of ISPs on various smallholder outcomes, no studies have analysed the impact of recent ISPs on pest management. This is particularly important given the increasing pest challenges due to climate change and the recent surge in pesticide use in low-income countries and its associated negative consequences for human and environmental health. Thus, this study assessed the effects of ISPs on smallholder adoption of sustainable pest management practices, using data from 1048 smallholder maize plots across major maize-producing zones of Zambia and a control function regression approach. We find consistent evidence that input subsidy receipt is negatively associated with smallholders' adoption of environmentally friendly and sustainable pest management strategies. Participation in the Zambia ISP (particularly the flexible e-voucher system) encourages synthetic pesticide use, at the expense of sustainable practices. We also find that farmers consider synthetic pesticides and biopesticides as substitutes and are more likely to adopt sustainable pest management when they have tenure security and access to financial resources. Given the human and environmental health consequences associated with synthetic pesticide use, it would be important to leverage input subsidy schemes to promote the adoption of safer and more sustainable alternatives to synthetic pesticides. Beyond input subsidies, policies that improve tenure security and financial access for smallholders can promote the adoption of sustainable pest management practices.

KEYWORDS
fall armyworm, farm input subsidies, integrated pest management, pesticides, smallholder farmers, Zambia

JEL CLASSIFICATION
Q12, Q16, Q18

1 | INTRODUCTION

Crop pests cause significant economic losses and pose a serious threat to food security, particularly in low-income food-deficit countries (Pratt et al., 2017; Savary et al., 2019). In maize, for instance, yield losses caused by pests are estimated to be 22.5% at the global level and 30% in sub-Saharan Africa (SSA) (Savary et al., 2019). Pesticides, which include insecticides, herbicides and fungicides, constitute an important input for reducing pest-induced crop losses. Over the past decade, the volume of pesticide use in low-income countries grew by 153% (Shattuck et al., 2023), driven by a combination of factors, including increasing pest pressures, subsidy schemes, lack of advice on alternative methods of pest control, increasing labour costs and falling prices of generic pesticides (Haggblade et al., 2022; Williamson et al., 2008). Although pesticides play a significant role in protecting crop yields, they can cause serious human health and environmental problems (Jepson et al., 2014). For example, it is estimated that 44% of farmers worldwide suffer pesticide poisoning every year (Boedeker et al., 2020).

In the wake of outbreaks of devastating pests, such as fall armyworm (FAW), *Spodoptera frugiperda*, many developing-country governments have gravitated to the provision of synthetic pesticides to farmers through subsidy schemes (Day et al., 2017; Tambo et al., 2020). Given the potential dangers of synthetic pesticides and the limited use of protective equipment by smallholder farmers when handling pesticides, several studies have argued that subsidies for pesticides should be geared towards the promotion of sustainable pest management strategies, such as integrated pest management (IPM) (Bateman et al., 2021; Day et al., 2022; Grovermann et al., 2017; Tambo et al., 2021). IPM involves the use of a combination of pest management techniques, including biological, cultural, mechanical and pest monitoring practices, as well as pesticides, which should be considered as a last resort (Deguine et al., 2021). It has been suggested that governments should never subsidise synthetic pesticides as it may disincentivise farmers from investing in acquiring IPM skills (Pingali & Rosegrant, 2001). This is also underscored in Article 8.1.3 of the International Code of Conduct on Pesticide Management developed by the United Nation's Food and Agriculture Organisation (FAO) and the World Health Organisation (WHO), which states that: 'governments should ensure that any pesticide subsidies or donations do not lead to excessive or unjustified use which may divert interest from more sustainable alternative measures' (FAO & WHO, 2014). However, empirical evidence on whether input subsidy programmes (ISPs) encourage or disincentivise the use of sustainable alternatives to synthetic pesticides for pest control is lacking.

Farm input subsidies have been a major agricultural policy intervention in many developing countries over the past decades and have received renewed attention in recent years, partly due to global food price crisis, reported early successes of Malawi's ISP, political motives and the emergence of innovative subsidy models (so-called 'smart subsidies') (Hemming et al., 2018; Holden, 2019; Jayne et al., 2018; Ricker-Gilbert, Jayne, & Shively, 2013). For instance, it is estimated that 10 SSA countries have together spent up to US$1 billion annually on ISPs in recent years (Jayne et al., 2018). The massive government expenditures on ISPs, coupled with debates about their effectiveness have stimulated a growing body of research aimed at understanding the impacts of ISPs on various outcomes, such as modern input use (largely fertiliser and improved seeds), crop acreages and yields, crop diversification, deforestation, food prices, farmer income, nutrition and rural poverty (e.g., Abman & Carney, 2020; Chibwana et al., 2012; Khonje et al., 2022; Kuntashula & Mwelwa-Zgambo, 2022; Liverpool-Tasie, 2014; Mason et al., 2013; Ricker-Gilbert, Mason, et al., 2013; Takeshima & Liverpool-Tasie, 2015; Wossen et al., 2017). However, no recent studies (that we are aware of) have analysed the impact of ISPs on synthetic pesticide use and pest management more broadly.

Thus, this article aims to contribute to filling this gap in the ISP literature by assessing the effect of Zambia's farmer input support programme (FISP) on farmers' choice of pest management strategies. We also examine the differential effects of two subsidy modalities: a traditional model that provides subsidised fertiliser and hybrid maize seed in fixed proportions and a flexible model that allows beneficiary farmers to choose from a variety of subsidised inputs. We use survey data from 837 Zambian smallholder maize producers who have been contending with FAW, a new invasive pest that is causing substantial damage to maize production in many countries across Africa, Asia and Oceania. Zambia has suffered severe FAW infestation (Stokstad, 2017), with a reported average maize yield loss of 40% in the early years of its outbreak in the country (Day et al., 2017). It is also estimated that if left uncontrolled, the FAW pest has the potential to destroy nearly US$160 million worth of maize annually in Zambia (Rwomushana et al., 2018). Given that maize is the primary food crop in Zambia, it is crucial for farmers to adopt appropriate management strategies to combat the pest.

Our paper makes three main contributions to the literature on farm input subsidies. First, we add to the limited evidence on the effect of ISPs on the adoption of sustainable intensification practices. The existing related literature has primarily focused on whether ISPs promote the use of soil fertility management practices, with mixed findings (Holden & Lunduka, 2012; Khonje et al., 2022; Kim et al., 2021; Koppmair et al., 2017; Morgan et al., 2019). For instance, Khonje et al. (2022) showed that participation in ISPs is significantly associated with the adoption of organic fertiliser and conservation practices in Malawi, while Morgan et al. (2019) found negative effects of ISPs on the adoption of fallowing and intercropping practices in Zambia. By contrast, we focus on ISP effects on sustainable pest management outcomes. This is particularly important because of the recent surge in pesticide use in low-income countries and its associated negative consequences for human and environmental health leading to a call for sustainable approaches to pest management. It is also important given the expected expansion of pest incidence, disease transmission and risk of invasive insect species due to global warming and climate change (Bebber et al., 2013; Deutsch et al., 2018; Diffenbaugh et al., 2008).

Second, we contribute to the literature on obstacles to IPM uptake in developing countries. Despite evidence that IPM interventions are associated with positive economic, health and environmental outcomes (Githiomi et al., 2019; Midingoyi et al., 2019; Norton et al., 2019), adoption of the technology among developing-country farmers is still very low (Alwang et al., 2019; Parsa et al., 2014), with lack of favourable government policies and support argued as one of the major factors hindering widespread adoption (Day et al., 2022; Parsa et al., 2014). We analyse empirically whether government policy on input subsidies encourages or discourages IPM adoption. Although some studies conducted several decades ago showed that pesticide subsidy policies affect pesticide use and IPM adoption in developing countries (Farah, 1994; Repetto, 1985), they did not apply rigorous impact assessment methods, as we do in this article. Lessons drawn from this study can be useful in leveraging recent ISPs to promote IPM.

Finally, the large body of literature examining the effects of farm input subsidies in SSA has mostly focused on traditional maize-centric ISPs that provide fertiliser and improved seeds to beneficiary farmers, with evidence of some positive effects (for reviews, see Hemming et al., 2018; Jayne et al., 2018; Ricker-Gilbert, Jayne, & Shively, 2013). Given the increasing recognition that such traditional subsidy schemes are insufficient to achieve sustainable agricultural intensification in SSA, alternative subsidy schemes, such as 'smart' or flexible programmes have emerged (Jayne et al., 2018). However, as noted by Mason et al. (2013) and Ricker-Gilbert, Jayne, and Shively (2013), there is little knowledge on the relative effectiveness of traditional and 'smart' subsidy schemes. To our knowledge, only Mason, Kuteya, et al. (2020) has empirically compared the effectiveness of the two ISP implementation modalities. They found that the traditional FISP in Zambia outperformed the flexible e-voucher programme in terms of timely availability of fertiliser and farmer adoption of hybrid maize seed and fertiliser, but with no differential effects on crop acreage and diversification, at least in the short run. We complement this previous work by assessing how the two FISP modalities in Zambia influence pest management choices.

The rest of the paper is organised as follows. The next section provides a brief background on the FISP in Zambia, and Section 3 describes the data used in this study and the estimation methods. The empirical results are presented in Section 4, including the determinants and effects of FISP participation, as well as the differential effects of the traditional and e-voucher subsidy schemes. The last section concludes by summarising key findings and their implications for policy.

2 | FARMER INPUT SUPPORT PROGRAMME (FISP) IN ZAMBIA

The FISP has been implemented in Zambia since the 2009/2010 agricultural year, building on an earlier large-scale ISP in the country called the Fertiliser Support Programme (2002–2009).[1] The subsidy programme aims to improve access to modern agricultural inputs, increase agricultural productivity and income, improve household food security, and reduce poverty among smallholder farmers (Mason et al., 2013). The FISP is the main agricultural development policy in Zambia, with nearly three-quarters of the country's agricultural sector budget devoted to the programme in 2022 (Mulenga et al., 2021). Around one million farmers benefit from the programme each year. Eligibility criteria for FISP participation include: membership in a registered farmer organisation or cooperative; being a registered smallholder farmer cultivating not more than 5 hectares of land; having the capacity to pay the farmer contribution of 400 ZMW; and not being a beneficiary of any other government support programme (National Assembly of Zambia, 2022).

For several years, Zambia has implemented a traditional FISP model (now referred to as direct input supply) where subsidised fertilisers and improved seeds are delivered to beneficiary farmers through farmer groups or cooperatives. In recent cropping seasons, the FISP participants received a predetermined input pack comprising 10 kg maize seed and 300 kg of inorganic fertiliser under the traditional model. As part of diversification efforts, the beneficiary farmers may also receive seeds of legume crops, such as groundnut, sorghum and soybean. The traditional FISP model is beset by several challenges, including high implementation cost, leakage of fertiliser inputs into commercial channels, crowding out private sector participation, poor targeting of beneficiaries and blanket fertiliser recommendation (Kuteya et al., 2016; Mason et al., 2013).

In response to these challenges, an electronic voucher (e-voucher) system of delivering the FISP was piloted in the country in 13 and 39 districts during the 2015/2016 and 2016/2017 agricultural seasons, respectively, while the remaining districts continued with the traditional FISP. Under the e-voucher modality, beneficiary farmers receive vouchers redeemable at private agro-input shops for the agricultural inputs of their choice. An e-voucher is worth 2100 ZMW, with contributions of 1700 ZMW and 400 ZMW from the government and beneficiary farmer, respectively. The inputs redeemed by the e-voucher recipients include improved maize and legume seeds, fertilisers, pesticides, veterinary drugs and farm equipment (Kuteya

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[1] For a historical overview of Zambia's ISPs, see Mason et al. (2013).

et al., 2016). The e-voucher programme was rolled out nationwide during the 2017/2018 agricultural season. However, due to several implementation challenges, 40% of the FISP beneficiaries were reverted to the traditional model during the 2018/2019 agricultural season. The share of e-voucher beneficiaries was further scaled down in the subsequent agricultural seasons, with even the implementation of only the traditional FISP in the past two seasons. However, the government has committed to rolling out the e-voucher and traditional FISPs in 43 districts and 73 districts, respectively, in the 2023/2024 agricultural season (National Assembly of Zambia, 2023).

Although most studies on the targeting and impacts of farm input subsidies in Africa have focused on Malawi's ISP, Zambia's FISP has also received considerable attention in the literature. On the positive side, studies have shown that farmer participation in Zambia's FISP is significantly associated with higher maize productivity (Mason et al., 2013; Ngoma et al., 2021), greater production and dietary diversity (Kuntashula & Mwelwa-Zgambo, 2022), and increased income and reduced poverty (Mason & Smale, 2013; Mason, Wineman, & Tembo, 2020). On the other hand, other studies have found that the FISP in Zambia crowds out commercial fertiliser and maize seed demand (Mason & Jayne, 2013; Mason & Ricker-Gilbert, 2013; Xu et al., 2009), disincentivises the adoption of sustainable soil management practices (Morgan et al., 2019), and is not cost-effective (Mason et al., 2013). We extend these studies by examining how the FISP influences sustainable pest management decisions.

3 | DATA AND METHODS

3.1 | Data

This study uses survey data collected from a representative sample of 837 households and 1048 maize plots across the three major maize-growing agro-ecological zones (AEZs I, IIa and III) of Zambia.[2] These AEZs also cover seven (Central, Copperbelt, Eastern, Luapula, Lusaka, Muchinga and Northern) of the 10 provinces of Zambia (Figure 1). The data were collected primarily for the purpose of assessing farmers' management of the invasive FAW pest; hence, this influenced the sampling strategy used. Based on the severity of FAW infestation and the importance of maize production, 12, 24 and 14 agricultural camps were selected from AEZs I, IIa and III respectively.[3] Then within each camp, about 10 to 20 households were randomly selected from a list of maize-producing households provided by local extension workers. Overall, our sample consists of 145 (187), 364 (475) and 328 (386) households (maize plots) from AEZs I, IIa and III, respectively.

The surveys were conducted between August and September 2019 and covered the 2018/2019 agricultural season of Zambia. The data were collected by trained enumerators through face-to-face interviews with the sampled households using tablet-based questionnaires. The questionnaires included modules on household demographic characteristics, plot-level characteristics, maize production decisions, FAW infestation and management practices, and access to institutional support services, including farm input subsidies.

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[2] There are four AEZs in Zambia. AEZ I: hot and drought-prone region (annual rainfall <800 mm); AEZ IIa: soils and rainfall are more favourable for farming (annual rainfall = 800–1000 mm); AEZ IIb: sandy soils with annual rainfall of 800–1000 mm; and AEZ III: high rainfall area (annual rainfall >1000 mm).

[3] A camp is the lowest level of agricultural administration in Zambia (i.e., province, district, block and camp).

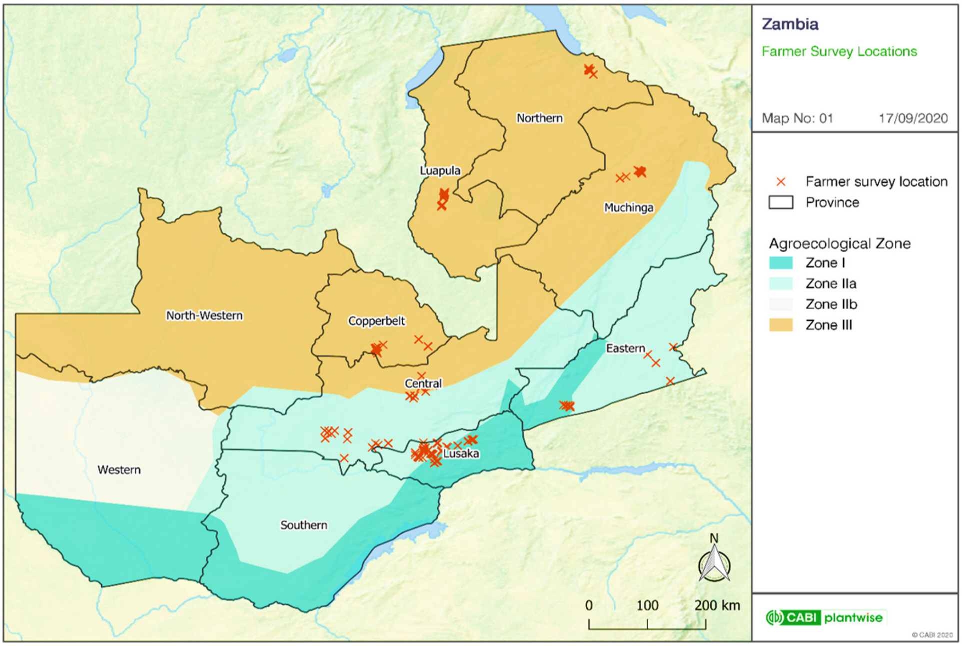

FIGURE 1 Map of Zambia showing the survey locations.

3.2 | Empirical approach

As mentioned earlier, the goal of this study is to estimate the effect of Zambia's FISP on the adoption of sustainable crop protection practices. There are several mechanisms through which FISP can possibly influence farmers' choice of pest management strategies. For instance, when faced with an invasion of a serious pest such as FAW, FISP participants may be inclined to redeem their vouchers for a subsidised package of inputs including synthetic pesticides for immediate control of the pest, at the expense of adopting sustainable non-chemical pest control options. It is also possible that the FISP beneficiaries may invest the money saved from not buying fertilisers and improved seeds at market prices on synthetic pesticides or environmentally friendly substitutes to pesticides. Subsidised fertilisers can provide the nutrients needed for the growth of healthy plants that can withstand pest attack, potentially reducing the need for pesticides. However, extensive and inappropriate use of fertilisers can result in reduced pest resistance or increased pest damage (Altieri & Nicholls, 2003; Harrison et al., 2019), which can spur the demand for pest-control products.

Given that farmers are encouraged to use complementary pest management practices for FAW control in line with the principles of IPM (Day et al., 2017; Harrison et al., 2019), we first examine FISP effects on the extent of adoption of management practices against FAW. This can be expressed as:

$$N_{ip} = \alpha_0 + \alpha_1 FISP_i + \boldsymbol{\alpha_2 P_p} + \boldsymbol{\alpha_3 H_i} + \alpha_4 A_p + \varepsilon_{ip} \tag{1}$$

where N_{ip} represents the number of IPM practices adopted by household i on plot p against FAW. The FAW management practices adopted included: (1) timely planting to limit FAW infestation; (2) monitoring of FAW infestation; (3) regular weeding to remove alternative host plants; (4) fertilisation to support healthy plant growth so that the maize plants can withstand pest infestations; (5) intercropping with non-host legume crops; (6) crop rotation to disrupt the pest cycle; (7) trap cropping to attract FAW away from the maize crop; (8)

handpicking/crushing of the pest; (9) uprooting and destruction of infested plants; (10) application of ash or sand on the FAW larvae; (11) use of biopesticides; and (12) application of synthetic pesticides. Thus, N_{ip} ranges from 0 to 12.

FISP is a dummy variable that is equal to 1 if the household participated in FISP during the 2018/2019 agricultural season, and zero otherwise. Thus, the main coefficient of interest is α_1, which measures the average effects of FISP on the adoption of IPM practices. $\boldsymbol{P}$ is a vector of plot-level covariates, such as plot size, plot tenure security, distance of plot from homestead, and perception of plot steepness and quality. $\boldsymbol{H}$ represents household-level characteristics, such as the number of children and adults in the household; age, gender, education level of household head; household asset wealth; as well as access to institutional support services, such as credit, farmer group, extension, and input suppliers. A captures differences in agro-climatic conditions. α is a vector of coefficients associated with the explanatory variables, and ε is the random error term. A description of the explanatory variables can be found in in Table 1. We estimate Equation (1) with a negative binomial regression model, given the count nature of the dependent variable.

We are particularly interested in investigating how the FISP influences the adoption of pest management categories, including monitoring, cultural control, mechanical or physical control, and pesticides. These pest management strategies are among the major components of IPM (Dhawan & Peshin, 2009).[4] Monitoring involves regular scouting of crops after germination to check for signs and symptoms of pest to aid in better pest management decision-making. Cultural control involves the use of any of the following practices: timely planting, regular weeding, fertilisation, legume intercropping, crop rotation or trap cropping. Mechanical control includes handpicking of larvae and egg masses, destruction of infested plants or the application of ash or sand. In terms of pesticides, we distinguish between synthetic pesticides and biopesticides. Biopesticides are lower-risk crop protection products (compared to synthetic pesticides), and they include natural plant derivatives or extracts (such as neem and pyrethrum) or microbial pest control agents (such as bacteria and virus) (Bateman et al., 2021).

We use a multivariate probit (MVP) model to estimate the effects of FISP on the adoption of the five different FAW management strategies. Unlike univariate models such as probit and logit, the MVP model accounts for potential interdependence between the five binary outcomes by estimating them jointly (Greene, 2012). Thus, the MVP model estimates the influence of the FISP and other covariates on the adoption of the five FAW management options simultaneously, while accounting for the possibility that adoption of any particular strategy could be correlated with adoption of the other four strategies. This can be specified as:

$$\begin{gathered} y^*_{ipk} = \alpha_0 + \alpha_1 FISP_{ik} + \boldsymbol{\alpha_2 P_{pk}} + \boldsymbol{\alpha_3 H_{ik}} + \alpha_4 A_{pk} + \varepsilon_{ipk}; k = 1, 2, \ldots, 5 \\ y_{ipk} = 1 \text{ if } y^*_{ipk} > 0 \text{ and } 0 \text{ otherwise} \end{gathered} \tag{2}$$

where y^*_{ipk} indicates farm household i's latent propensity to use FAW management strategy k on plot p, and y_{ipk} represents the actual adoption of FAW management strategy k by household i on plot k. ε_{im} is a vector of multivariate normally distributed error terms. The rest of the symbols are as earlier defined. The MVP model also generates an error term correlation matrix, which gives an indication of whether any two FAW management strategies used by the farmers are complements (positive correlation) or substitutes (negative correlation) to each other.

In estimating Equations (1) and (2), we recognise that FISP participation was not based on random assignment. Hence, it is possible that some unobservable factors such as motivation

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[4] Other IPM components include host-plant resistance and biological control using parasitoids or predators. However, these options were not available for adoption by Zambian farmers as at the time of the study.

TABLE 1 Descriptive statistics for study variables.

Variable	Description	Mean	SD
Years in the village	Number of years household has lived in the village	27.72	15.35
Age	Age of household head (years)	50.60	13.01
Gender	Gender of household head (1 = male)	0.70	0.46
Education	Years of formal education of household head	7.83	3.39
Children	Number of children in the household	3.29	2.14
Adults	Number of adults in the household	4.00	2.12
Maize area	Size of maize plot (hectares)	1.39	1.77
No. of maize plots	Number of maize plots cultivated by household	1.50	0.80
Plot distance	Distance from household to maize plot (km)	1.77	3.87
Sloped plot	Plot is sloped (1/0)	0.47	0.50
Fertile plot	Plot is perceived to be of good quality (1/0)	0.33	0.47
Tenure security	Household has secure rights over the plot (1/0)	0.91	0.28
Off-farm activity	Household member has off-farm job (1/0)	0.48	0.50
Credit access	Household has access to credit (1/0)	0.12	0.32
FISP participation	Household participates in FISP (1/0)	0.80	0.40
Asset index	Household asset index using principal component analysis	0.00	1.60
TLU	Household livestock holding in Tropical Livestock Unit (TLU)	3.27	5.40
Distance to agro-shop	Distance from household to the nearest agro-input shop (km)	15.24	13.54
Extension access	Household has access to extension services (1/0)	0.85	0.35
Farmer group	A household member belongs to a farmer group (1/0)[a]	0.88	0.32
AEZ I	Household is located in agro-ecological zone I	0.17	0.38
AEZ IIa	Household is located in agro-ecological zone IIa	0.44	0.50
AEZ III	Household is located in agro-ecological zone III	0.39	0.37
Observations	Number of observations	1048	

[a] Farmer groups include farmer associations and cooperatives.

and entrepreneurial ability influence both the decision to participate in FISP and our outcome variables. Thus, using negative binomial regression and MVP models to respectively estimate Equations (1) and (2) may yield biased estimates. We applied a control function approach to test and address this potential selection bias problem (Terza et al., 2008; Wooldridge, 2015). The control function approach follows two steps. First, a probit model for FISP participation is estimated to obtain the generalised residual. In the second step, Equations (1) and (2) are estimated using negative binomial regression and MVP models, respectively, while including the generalised residual from the first-stage regression as an additional covariate. A statistical significance of the generalised residual variable implies that the FISP participation decision is endogenous.

Thus, the FISP effects are estimated using negative binomial regression and MVP models combined with the control function approach. In estimating Equation 2, we used bootstrapping to adjust the standard errors for the two-step estimation procedure. Moreover, we used the number of years that the household head has lived in the village as an exclusion restriction in the control function approach. A similar instrumental variable has been used in several studies examining the impact of farmer participation in input subsidy programmes in Africa (Bezu et al., 2014; Chibwana et al., 2012; Ngoma et al., 2021; Ricker-Gilbert et al., 2011; Wossen et al., 2017). The argument is that the number of years of living in a village improves social capital, which can enhance access to FISP. The first-stage regression results in Table 3 show that the number of years a household has lived in a study village variable significantly affects FISP participation, but it is not statistically significant when included as an additional covariate in the outcome regressions (see Table S1). This provides some support to the validity of our exclusion restriction variable (Di Falco et al., 2011). Nonetheless, given the challenge of establishing causality with cross-sectional data, we interpret our regression results as associations rather than causal effects.

4 | RESULTS AND DISCUSSION

4.1 | Descriptive results

Table 1 reports summary statistics of the control variables in our regression models. A typical household in our sample consists of four adults and three children and is headed by a middle-aged male farmer who has lived in the study village for nearly three decades. The sample comprises smallholder maize-growing households who cultivate roughly two maize plots, with an average size of 1.40 hectares per plot. A majority of the households have secure rights over their maize plots, and only a third of the plots are deemed to have good soil fertility. Approximately half of the households engage in off-farm income earning activities, while only 12% of them had access to credit during the agricultural year 2018/2019. Eighty percent of the households participate in the FISP, which is our main variable of interest. Additionally, over 80% of the households have access to agricultural extension services and are members of farmer groups or associations.

Table 2 presents the descriptive statistics for the outcome variables, disaggregated by FISP participation and whether the household is located in an e-voucher or a traditional FISP district. On average, households implemented three different fall armyworm (FAW) management practices on a maize plot. This is noteworthy, as smallholder farmers are encouraged to combine different practices to tackle FAW, in line with the tenets of IPM (Day et al., 2017; Harrison et al., 2019). This is also consistent with previous evidence showing that Zambian maize farmers have adopted a mix of pest management practices in the wake of the FAW pest outbreak in the country (Kansiime et al., 2019; Tambo et al., 2020). The most common IPM techniques include cultural and mechanical control practices, which were implemented on at least half of

TABLE 2 Descriptive statistics for outcome variables.

Outcome	Full sample ($n=1048$)	FISP[a] ($n=841$)	Non-FISP ($n=207$)	E-voucher[b] ($n=746$)	Traditional ($n=302$)
No. of IPM practices used (0–12)	3.17	3.21	3.04	3.16	3.21
Use of pest monitoring (%)	42.46	42.57	42.03	42.76	41.72
Use of cultural control (%)	51.34	52.32	47.34	50.80	52.65
Use of mechanical control (%)	52.19	51.37	55.56	47.05***	64.90
Use of synthetic pesticides (%)	33.59	35.08**	27.54	35.52**	28.81
Use of biopesticides (%)	31.20	32.10	27.54	31.50	30.46

[a] FISP participants are compared with non-FISP participants.

[b] Households located in e-voucher FISP districts are compared with those located in traditional FISP districts.

***$p<0.01$; **$p>0.05$; $p<0.1$.

TABLE 3 Determinants of FISP participation.

	Coefficients	Standard error	Marginal effect
Years in the village	0.009**	0.004	0.002
Age	0.008*	0.004	0.001
Gender	−0.036	0.127	−0.007
Education	0.001	0.018	0.001
Children	0.006	0.025	0.001
Adults	−0.025	0.028	−0.005
Maize area	0.128**	0.052	0.023
Number of maize plots	0.132***	0.037	0.024
Off-farm income	0.004	0.109	0.001
Credit access	0.284	0.189	0.052
Asset index	0.045	0.043	0.008
TLU	−0.007	0.012	−0.001
Distance to agro-shop	0.004	0.004	0.001
Extension access	0.113	0.148	0.021
Farmer group	2.185***	0.160	0.401
AEZ IIa	−0.243	0.163	−0.044
AEZ III	−0.072	0.171	−0.012
Constant	−2.064***	0.396	
Observations	1048		
LR chi^2	334.85***		

Note: Probit regression results. Dependent variable = FISP participation (1/0).

***$p<0.01$; **$p>0.05$;*$p<0.1$.

the maize plots in our sample. Synthetic pesticides and biopesticides, which are relatively more costly control options, were each applied on about a quarter of the plots. The level of adoption of the specific FAW management practices is presented in Table S2.

The results in Table 2 also show that pesticides were sprayed on a greater number of plots of FISP participants than of non-participants, with statistically significant differences in terms of the use of synthetic pesticides. Similarly, a significant number of maize plots of households located in e-voucher FISP districts received synthetic pesticides, as compared to plots of households residing in traditional FISP districts. On the other hand, mechanical control measures, such as handpicking of FAW larvae, were performed more in traditional FISP districts than in e-voucher districts. Overall, these unconditional summary statistics may be suggestive that the FISP beneficiaries, particularly participants of the flexible e-voucher scheme, are more likely to use synthetic pesticides for maize pest control. The econometric evidence for these potential effects of FISP is presented in Section 4.3.

4.2 | Determinants of FISP participation

Table 3 shows the first-stage probit regression results on the determinants of household participation in the FISP. We find that the number of years a household has lived in a study village is significantly and positively correlated with participation in the FISP, suggesting that our instrument is relevant. This finding is in line with previous studies on input subsidy participation in Malawi (Bezu et al., 2014; Chibwana et al., 2012; Ricker-Gilbert et al., 2011), Nigeria (Wossen et al., 2017) and Zambia (Ngoma et al., 2021). The results also show that the likelihood of participation in FISP increases with the age of household head, which may also be reflective of the effect of social capital. None of the financial capital and wealth-related factors (off-farm job, credit, asset index and livestock holding) is significantly associated with FISP participation, indicating that resource-rich and resource-poor households are equally likely to participate in the programme. Similarly, the input subsidy programme is inclusive of both male and female-headed households, which is consistent with evidence from Zambia and several other African countries (Jayne et al., 2018).

The results in Table 3 also indicate that the number of maize plots cultivated and maize plot size exert significant effects on FISP participation. This suggests that participation in the FISP is higher among households for whom maize production is of particular economic importance. This is expected, as the Zambia FISP is largely a maize-centric intervention, especially the traditional FISP where beneficiary farmers receive subsidised maize inputs. In their review of empirical literature on input subsidy programmes in Africa, Jayne et al. (2018) also found that households with more land are more likely to benefit from input subsidies. Finally, the results show that farmer group membership has the strongest effect on FISP participation. This is not surprising because farmer group or cooperative membership is a key eligibility criterion for farmer participation in the FISP (Mason et al., 2013).

4.3 | FISP effects on adoption of IPM practices

Table 4 displays the results of the negative binomial regression model performed with the control function approach, which show the effects of FISP participation on the number of IPM practices used. We find that after controlling for potential confounding factors, the FISP participants adopt roughly four less IPM practices, compared to their non-participant counterparts. This implies that the FISP intervention disincentivises the use of multiple IPM practices, which is troubling given the calls for the promotion of IPM as a sustainable approach to the management of FAW and other crop pests in smallholder farming systems (Day et al., 2017; Hruska, 2019). This result resonates with the finding of Morgan et al. (2019) that the FISP in Zambia discourages the use of sustainable intensification practices among smallholder farmers in the country.

TABLE 4 FISP effects on the number of IPM practices used.

	Coefficients	Robust SE	Marginal effect
FISP participation	−1.243**	0.483	−3.954
Age	0.001	0.002	0.003
Gender	0.004	0.057	0.012
Education	0.01	0.008	0.032
Children	0.019*	0.011	0.061
Adults	0.007	0.012	0.023
Maize area	0.040*	0.021	0.127
Distance to maize plot	−0.008	0.008	−0.025
Sloped plot	−0.035	0.047	−0.111
Fertile plot	0.085*	0.048	0.272
Tenure security	0.188**	0.076	0.597
Off-farm job	0.144***	0.045	0.460
Credit access	0.215***	0.074	0.684
Asset index	−0.008	0.017	−0.025
TLU	−0.001	0.005	−0.002
Distance to agro-shop	0.004**	0.002	0.013
Extension access	0.547***	0.092	1.738
Farmer group	0.801**	0.351	2.546
AEZ IIa	−0.442***	0.068	−1.547
AEZ III	−0.327***	0.067	−1.207
Generalised residual	0.685***	0.261	2.178
Constant	0.665***	0.198	
Observations	1048		
LR test of alpha = 0	172.71***		

Note: Results from a negative binomial regression model performed with the control function approach. Dependent variable is the number of IPM practices adopted, ranging from 0 to 12.

***$p < 0.01$; **$p > 0.05$; *$p < 0.1$.

The results for the control variables in Table 4 are informative. We find that a greater number of IPM practices are likely to be adopted on larger and fertile maize plots, albeit the effects are significant only at the 10% level. Results also show that having a secure right over a plot is significantly associated with the adoption of 0.60 additional IPM practices. This is possibly because the tenure secure households may be more likely to care about the future benefits from their plots by investing in sustainable agricultural practices (such as IPM) that can generate yield benefits even in the long term. The positive role of tenure security in agricultural investment has been documented in several studies (e.g., Gebremedhin & Swinton, 2003; Tambo & Mockshell, 2018).

We also find that access to credit and off-farm activities, which can help households to relax their financial constraints, are strongly significantly correlated with IPM adoption. In particular, households with access to off-farm activities and credit respectively adopt 0.46 and 0.68 additional IPM practices on their maize plots. An interesting finding is that households living far from agro-input dealers are more likely to adopt a higher number of IPM practices. In other words, being in closer proximity to agro-input dealers where farmers obtain pesticides reduces the likelihood of IPM adoption. This is likely because profit-driven agro-input dealers tend to provide crop health advice and sell pesticide products to farmers, which may decrease the incentive to apply alternatives to chemical pest control. This also lends support to arguments that pesticide industry interference and heavy promotion of pesticides by salespeople undermine efforts to promote IPM in developing countries (Parsa et al., 2014). Conversely, access to agricultural extension services (a key source of agricultural information), is significantly associated with the adoption of roughly two additional IPM practices. Farmer group, another source of information, enhances the adoption of nearly three additional IPM practices. These results give credence to the assertion that lack of information is a major obstacle to IPM adoption among smallholders in low-income countries (Alwang et al., 2019; Parsa et al., 2014).

The results also show that agro-climatic conditions are significantly related to the uptake of IPM practices. Maize plots in AEZ IIa and AEZ III are less likely to have multiple IPM practices, compared to those in AEZ I. A plausible explanation is that AEZ I is a low-rainfall and drought-prone region; hence, households located in this zone may be more likely to adopt certain IPM practices to protect their yield from weather and pest shocks. Given that FAW infestation rates tend to be higher in low-rainfall environments (Early et al., 2018; Varella et al., 2015), farmers located AEZ I are more likely to experience the devastating effects of the pest, which may increase their likelihood of implementing multiple management practices. Lastly, the statistical significance of the generalised residual variable confirms the endogeneity of the FISP variable (Wooldridge, 2014).

The results for the effects of FISP on the uptake of various IPM strategies, which were estimated using a multivariate probit model combined with the control function approach, are presented in Table 5. We find that households that participate in FISP are about 106 percentage points less likely to monitor their fields for signs of pest infestation. This is a disturbing finding because regular field inspection or scouting for pest incidence and severity of infestation is a highly important IPM practice that help farmers to decide whether management is needed, and to act at the right time to limit the spread of pests. Similarly, the results show that FISP beneficiary households are 125 percentage points less likely to adopt cultural controls, which are good agronomic practices that double as sustainable pest prevention methods, such as timeliness in planting, disrupting pest cycle through crop rotation, intercropping of maize with non-host leguminous crops, and removal of alternate pest host plants through regular weeding. This result is also in line with evidence that Zambia's FISP crowd out the use of sustainable soil management practices, including crop rotation and maize-legume intercropping (Morgan et al., 2019), but contrasts with the finding of Koppmair et al. (2017) that farmer adoption of natural resource management practices is generally unaffected by Malawi's FISP.

The results also show that FISP participation is not significantly related to the adoption of mechanical control methods and biopesticides. On the other hand, participation in FISP has a significantly positive effect on the use of synthetic pesticides for FAW control. In particular, the FISP participants have a 67 percentage points higher probability of controlling FAW using synthetic pesticides. Unfortunately, synthetic pesticides are associated with adverse effects on animal, human and environmental health; hence, the need to reduce farmer reliance on synthetic pesticides by promoting the use of a combination of non-chemical pest management practices, in line with IPM. Overall, the results in Table 5 demonstrate that the FISP incentivises the use of synthetic pesticides, at the expense of environmentally friendly and sustainable pest management strategies. Further analysis shows that during the 2018/2019 agricultural season, the average number of pesticide applications against FAW by FISP participants was 2.6 times more compared to non-participants, possibly suggesting that FISP beneficiaries are more likely to use pesticides intensively (see Table S3).[5]

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[5] Due to data limitations, we are unable to estimate FISP effects on the quantity of pesticide used per unit area, which is a more appropriate measure of pesticide use intensity.

TABLE 5 Effect of FISP on adoption of different IPM strategies.

	Monitoring		Cultural control		Mechanical control		Synthetic pesticides		Biopesticides	
	Marginal effect	Robust SE	Marginal effect	Robust SE	Marginal effect	Robust SE	Marginal effect	Robust SE	Marginal effect	Robust SE
FISP participation	−1.056***	0.308	−1.247***	0.298	−0.095	0.289	0.672**	0.264	0.383	0.251
Age	0.001	0.001	0.001	0.001	0.000	0.001	−0.002	0.001	−0.001	0.001
Gender	0.010	0.036	−0.023	0.036	−0.005	0.036	0.040	0.034	−0.050	0.034
Education	0.005	0.005	0.002	0.005	0.006	0.005	0.005	0.005	0.007	0.005
Children	0.013*	0.007	0.015**	0.007	−0.002	0.007	0.001	0.007	−0.005	0.007
Adults	−0.007	0.007	0.003	0.008	0.014*	0.008	−0.003	0.007	0.005	0.007
Maize area	0.018	0.013	0.033**	0.013	0.009	0.006	0.008	0.008	−0.005	0.007
Distance to maize plot	−0.006	0.004	−0.006	0.004	−0.003	0.005	−0.006*	0.004	0.002	0.003
Sloped plot	−0.038	0.029	0.000	0.030	−0.001	0.030	0.039	0.028	−0.016	0.028
Fertile plot	0.035	0.031	0.056*	0.031	0.027	0.032	0.026	0.030	0.091***	0.029
Tenure security	0.099*	0.052	0.091*	0.052	0.046	0.055	0.021	0.051	−0.136***	0.051
Off-farm activity	0.076**	0.030	0.052*	0.030	0.087***	0.030	0.043	0.029	0.069**	0.028
Credit access	0.077*	0.047	0.141***	0.049	−0.010	0.048	−0.025	0.044	0.022	0.044
Asset index	−0.009	0.012	−0.004	0.012	−0.015	0.012	0.005	0.011	0.006	0.011
TLU	0.000	0.003	0.002	0.003	−0.006*	0.003	0.002	0.003	0.004	0.003
Distance to agro-shop	0.001	0.001	0.003**	0.001	0.001	0.001	−0.000	0.001	0.000	0.001
Access to extension	0.204***	0.044	0.245***	0.043	0.100**	0.044	0.301***	0.048	0.037	0.041
Farmer group	0.755***	0.228	0.864***	0.218	−0.010	0.213	−0.454**	0.194	−0.288	0.185
AEZ IIa	−0.319***	0.043	−0.282***	0.042	−0.098**	0.046	−0.062	0.044	0.054	0.043
AEZ III	−0.258***	0.045	−0.175***	0.043	0.124***	0.047	−0.088**	0.044	−0.092**	0.042
Generalised residual	0.557***	0.167	0.698***	0.164	0.030	0.156	−0.359**	0.140	−0.174	0.132
Observations	1048		1048		1048		1048		1048	

Note: All the five dependent variables are binary outcomes, and the parameters were jointly estimated using a multivariate probit model performed with the control function approach.

Abbreviation: SE, standard error.

$^{***}p < 0.01$; $^{**}p > 0.05$; $^{*}p < 0.1$.

TABLE 6 Pesticides used for fall armyworm control.

Active ingredient	WHO toxicity class[a]	Full sample ($n=505$)	FISP ($n=417$)	Non-FISP ($n=88$)
Azadirachtin	N	42.77	43.17	40.91
Cypermethrin	II	18.22	18.47	17.05
Lambda-cyhalothrin	II	10.50	11.51	5.68
Abamectin	II	6.14	5.28	10.23
Monocrotophos	Ib	4.36	4.55	4.31
Profenofos + Cypermethrin	II	3.37	3.60	2.27
Dimethoate	II	2.18	2.40	1.14
Chlorpyrifos + Cypermethrin	II	2.18	2.40	1.14
Lambda-cyhalothrin + Thiamethoxam	III	1.98	1.92	2.27
Chlorothalonil	U	1.58	1.92	0.00
Emamectin Benzoate	N	1.58	1.92	0.00
GS-omega/kappa-Hxtx-Hv1a	N	1.39	1.44	1.14
Profenofos	II	1.19	0.96	2.27
Alpha-cypermethrin	II	0.79	0.96	0.00
Flubendiamide	N	0.99	1.19	0.00
Atrazine	III	0.79	0.72	1.14
Chlorantraniliprole + Lambda-cyhalothrin	II	0.79	0.96	0.00
Dichlorvos	Ib	0.79	0.96	0.00
Emamectin Benzoate	N	0.59	0.72	0.00
Malathion	III	0.59	0.48	1.14
Methamidophos	Ib	0.40	0.48	0.00

Note: Values are percentages of pesticide users.

[a] WHO recommended classification of pesticides (WHO, 2020): Ia = extremely hazardous; Ib = highly hazardous; II = moderately hazardous; III = lightly hazardous; U = unlikely to present acute hazard; N = not classified.

Table 6 reports the types of pesticides sprayed against FAW by the pesticide users in our sample. The most commonly used pesticide is azadirachtin, which is a biopesticide. We find that most of the synthetic pesticides used are moderately hazardous, as classified by the World Health Organisation, based on acute risk to human health (WHO, 2020). Alarmingly, about 5% of the pesticide users applied highly hazardous pesticides such as methamidophos, dichlorvos and monocrotophos, which can have acute and severe or irreversible effects on human and environmental health. Unfortunately, some of the pesticide users do not wear standard personal protective equipment (PPE) when spraying these hazardous pesticides (Table 7). For instance, around half of the pesticide users in our sample did not wear masks, gloves or coverall when handling or spraying pesticides, and only 24% of them wore goggles. Table 7 shows that about 12% of the farmers who sprayed pesticides did not wear any protective apparel when working with pesticides. The high use of hazardous pesticides without the necessary protective gear underscores the importance of leveraging the FISP to promote the use of sustainable, non-chemical alternatives or a shift from synthetic pesticides to biopesticides, which are considered less toxic to health and the environment (Bateman et al., 2021).

The error term correlation matrix of the multivariate probit model, which gives an indication of complementarities and trade-offs between the five IPM options, confirms that the

TABLE 7 Use of PPE items.

PPE	Full sample ($n = 505$)	FISP ($n = 417$)	Non-FISP ($n = 88$)
Goggles	23.76	23.50	25.00
Mask	49.11	49.40	47.73
Gloves	50.69	49.40	56.82
Coverall	51.09	51.56	48.86
Rubber boots	75.84	76.98	70.45
None	12.08	10.79	18.18

Note: Values are percentages of pesticide users.

promotion of biopesticides may reduce the demand for synthetic pesticides (Table 8). We see a negative and significant correlation between the use of synthetic pesticides and biopesticides, suggesting that farmers perceive substitutability between these two groups of pesticides. Thus, farmers who use biopesticides are less likely to opt for synthetic pesticides for FAW control. Tambo et al. (2020) reported a similar finding for Ghana. The results in Table 8 also show complementarities between the monitoring of pest infestation and the use of cultural and mechanical control practices, as well as synthetic pesticides for FAW control. The integration of different pest management tactics is consistent with the expectation of the IPM paradigm. However, it is hoped that synthetic pesticides will be used as a last resort, and if pesticide used is required, farmers will select the products with the lowest risk to human and environmental health.

4.4 | Differential effects by FISP modality

Finally, we examine the heterogeneous effects of the FISP by differentiating households according to the type of FISP operating in their districts. As mentioned earlier, there are two FISP modalities in Zambia: a flexible e-voucher programme and a traditional FISP or direct input supply model. Unlike the traditional FISP where the government distributes a fixed package of maize seed and fertiliser to beneficiary farmers, the participants of the e-voucher programme are allowed to choose inputs of their choice from registered agro-dealers. During the 2018/2019 season, 45 of the 116 Zambian districts were under the traditional FISP, and the rest were under the e-voucher programme. Table 9 summarises the estimation results of the FISP effects on the adoption of IPM strategies, based on whether a household is located in an e-voucher or a traditional FISP district.[6] The full estimation results of the multivariate probit model with control function approach are presented in Tables S4 and S5.

The results show that FISP participation has a negative and significant effect on the adoption of the IPM options of regular monitoring and cultural control in both the e-voucher and traditional FISP districts. In other words, the FISP beneficiaries are less likely to regularly monitor their fields for pest infestation or adopt cultural control techniques, irrespective of the type of Zambia's FISP they are exposed to. However, the marginal effects suggest that households located in traditional FISP districts have a greater probability of not adopting these two IPM practices than those located in the e-voucher FISP districts. Specifically, FISP participants in e-voucher districts are about 51 and 73 percentage points less likely to implement

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[6] Given that a district in Zambia can only participate in either the traditional or e-voucher FISP modality, but not both in an agricultural season, the district location of a FISP beneficiary household reflects participation in the FISP modality that is being implemented in that district.

TABLE 8 Complementarity and substitutability of the IPM options.

	Monitoring	Cultural control	Mechanical control	Synthetic pesticide	Bio pesticide
Monitoring	1				
Cultural control	0.850 (0.021)***	1			
Mechanical control	0.458 (0.043)***	0.442 (0.044)***	1		
Synthetic pesticide	0.104 (0.052)**	0.070 (0.051)	0.180 (0.051)***	1	
Biopesticide	0.010 (0.053)	0.028 (0.052)	−0.003 (0.052)	−0.790 (0.032)***	1

Note: Results in this table are the correlation matrix generated from the multivariate probit model estimates in Table 5.
***$p < 0.01$; **$p > 0.05$; *$p < 0.1$.

TABLE 9 Differential effects by two FISP types.

	(1) E-voucher FISP districts		(2) Traditional FISP districts	
IPM strategy	**Marginal effect**	**Robust SE**	**Marginal effect**	**Robust SE**
Monitoring	−0.731**	0.293	−1.472***	0.419
Cultural control	−0.506*	0.293	−1.454***	0.439
Mechanical control	−0.018	0.296	−0.523	0.412
Synthetic pesticides	0.596**	0.301	0.325	0.350
Biopesticides	0.490	0.316	−0.459	0.324
Observations	746		302	

Note: The results in columns 1 and 2 are based on data from maize plots in districts under the e-voucher and traditional FISP programme, respectively. Each column presents results from a multivariate probit model performed with the control function approach. Each row represents a binary outcome variable. The treatment variable is FISP participation (1/0). The full regression results can be found in Tables S4 and S5.

***$p<0.01$; **$p>0.05$; *$p<0.1$.

cultural controls and field monitoring, respectively, while their counterparts in the traditional FISP districts are nearly 150 percentage points less likely to adopt these two IPM options. It is possible that participation in the FISP (particularly the traditional model) leads to greater use of inorganic fertilisers (Jayne et al., 2018; Mason, Kuteya, et al., 2020), which can influence pest populations (Altieri & Nicholls, 2003; Harrison et al., 2019). Given that monitoring and cultural control are pest prevention practices, farmers may have less incentive to implement them on plots with high pest infestation and damage levels. More use of inorganic fertilisers is also labour intensive, and thus households might be reducing the time spent on monitoring and other cultural control practices to give more time for fertiliser application and associated practices.

Table 9 also indicates that FISP participation is significantly associated with the use of synthetic pesticides only among households who can benefit from the e-voucher model. In particular, beneficiary households in the e-voucher FISP districts have a 60 percentage points higher likelihood of spraying synthetic pesticides to control FAW. Furthermore, the estimation results in Table S3 show that the average number of pesticide sprays per season by FISP participants in the e-voucher districts is 4.5 times more significantly higher than their non-participant counterparts, whereas there is no statistically significant difference in pesticide spray frequency between FISP participants and non-participants in the traditional districts. These results are intuitive because the e-voucher FISP beneficiaries have the possibility of redeeming their vouchers for a wide range of subsidised farm inputs, including pesticides, whereas the traditional FISP participants have to purchase the pesticides, which can be prohibitively expensive for many Zambian smallholders who are used to receiving other inputs at subsidised rates. Overall, these results may be suggestive that the e-voucher programme, which allows farmers access to subsidised pesticides, crowds out the use of environmentally friendly pest prevention practices.

5 | CONCLUSION

Input subsidy schemes are a popular but contentious policy tool used by several African governments in efforts to promote agricultural intensification and achieve food security and poverty reduction goals. This study has assessed the effects of input subsidies on smallholder adoption of sustainable pest management practices, which is important because increasing pest pressure has fostered widespread and indiscriminate use of synthetic pesticides that pose high risks to human and environmental health. Specifically, we examined whether Zambia's farmer input support programme (FISP) influences the use of sustainable integrated pest management (IPM) practices against fall armyworm (FAW)—an invasive pest that is causing massive economic damages to maize production in many African and Asian countries in recent years. We used data from 1048 smallholder maize plots across the major maize-producing zones of Zambia.

Regression results based on control function approaches showed that FISP participation significantly reduces the likelihood of a household adopting IPM practices. More specifically, households that participate in FISP are about 106 percentage points less likely to regularly monitor their farms for early detection pest infestation and are 125 percentage points less likely to adopt preventative cultural measures, such as intercropping and rotation with non-host plants, field sanitation and trap cropping. Moreover, while FISP participation is significantly associated with a 67 percentage points higher probability of a household controlling FAW using synthetic pesticides, it is not significantly related to the adoption of biopesticides, which are considered a safer and low-risk alternative to synthetic pesticides. Worryingly, some of the pesticide-using farmers do not wear protective clothing against pesticide exposure, even though most of the synthetic pesticides used are moderately and highly hazardous. We also found evidence that farmers consider synthetic pesticides and biopesticides as substitutes, suggesting that the promotion of biopesticides is likely to discourage the use of synthetic pesticides.

A disaggregated analysis suggested that the significant effects of FISP on increased use of synthetic pesticides is likely driven by the flexible e-voucher programme where beneficiary farmers can redeem vouchers for a wide range of subsidised farm inputs, including synthetic pesticides, from registered agro-dealers. Being located in a traditional FISP area, where the government distributes a fixed package of maize seed and fertiliser at subsidised rates to beneficiary farmers, has no significant effect on pesticide use. We also found heterogeneous effects of the subsidy programmes on the adoption of non-chemical IPM practices. Results also showed that households with access to secure land tenure, credit and off-farm income earning activities, as well as those in low rainfall environments, where FAW infestation tend to be greater, are more likely to invest in IPM practices.

Overall, the findings imply that the receipt of input subsidies through the Zambia FISP (flexible e-voucher system, in particular) encourages the use of synthetic pesticides, at the expense of environmentally friendly and sustainable pest management strategies. The findings underscore arguments that while ISPs can raise crop yields in the short run, they may inadvertently discourage the adoption of sustainable intensification practices and consequently undermine long-term yield and income gains (Jayne et al., 2018; Morgan et al., 2019). Moreover, the increased synthetic pesticide use induced by subsidies can have immediate and long-term effects on human health (such as respiratory, reproductive and neurological disorders), non-target species and biodiversity (Rani et al., 2021).

Given the human and environmental health consequences associated with synthetic pesticides, it would be important to leverage the FISP to promote safer and more sustainable alternatives to synthetic pesticides. For example, the FISP beneficiaries who choose to redeem their vouchers for pesticides could be required to opt for biopesticides rather than synthetic pesticides. Alternatively, higher subsidy amounts could be offered to those using biopesticides to encourage adoption. A good example that might be worth emulating is China's 'Green Pest Control' policy that provides subsidies on lower-risk crop protection products, including biopesticides (Wei et al., 2019). However, such a strategy can only be effective in Africa if biopesticide products are made readily available—for instance, by addressing registration bottlenecks (Constantine et al., 2020; Day et al., 2022; Srinivasan et al., 2019). Another potential strategy is to ensure that the array of items redeemable through the FISP include PPE items and non-chemical pest management inputs, such as biocontrol agents, pheromone traps and pest tolerant varieties. In addition, extension workers and agro-input dealers from whom smallholder farmers tend to receive pest management information should be trained to offer advice on sustainable pest management and safe pesticide use.

Our findings also suggest that beyond input subsidies, policies that improve tenure security and access to financial resources for smallholders (e.g., via improved access to credit and off-farm employment) can contribute to stimulating the adoption of sustainable IPM practices. For future research, it would be interesting to employ panel data approaches to investigate the long-term effects of FISP in terms of adoption of pest management strategies and related outcomes, given that our cross-sectional study was conducted in the early years of the outbreak of FAW during which some farmers may have limited knowledge on the various alternatives to pesticides for its control. It is possible that farmer participation in FISP can trigger behavioural changes, and the effects may take several years to materialise. Moreover, due to data limitation, we were not able to assess the direct contribution of the traditional and e-voucher FISP programmes to sustainable pest management. This is another important area for further research.

ACKNOWLEDGEMENTS

This work was supported by the CABI Development Fund (CDF) and the PlantwisePlus programme. CABI is an international intergovernmental organisation, and we gratefully acknowledge the core financial support from our member countries (and lead agencies) including the United Kingdom (Foreign, Commonwealth & Development Office), China (Chinese Ministry of Agriculture), Australia (Australian Centre for International Agricultural Research), Canada (Agriculture and Agri-Food Canada), Netherlands (Directorate-General for International Cooperation), and Switzerland (Swiss Agency for Development and Cooperation). See www.cabi.org/about-cabi/who-we-work-with/key-donors/ for full details. This study was also made possible with support from the US Department of Agriculture National Institute of Food and Agriculture and Michigan State University AgBioResearch, MICL12077. We also thank the Editor and two anonymous reviewers for their helpful feedback and comments.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no competing interests.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

INFORMED CONSENT STATEMENT

Before starting an interview, a consent statement was read to each respondent. Only those who gave their consent were interviewed.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Tambo, J.A. & Liverpool-Tasie, L.S.O. (2024) Are farm input subsidies a disincentive for integrated pest management adoption? Evidence from Zambia. *Journal of Agricultural Economics*, 00, 1–24. Available from: https://doi.org/10.1111/1477-9552.12582