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ORIGINAL ARTICLE

Does simultaneous adoption of drought-tolerant maize varieties and organic fertiliser affect productivity and welfare outcomes? Evidence from rural Nigeria

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Abstract

The promotion of improved maize varieties and chemical fertilisers underscores many policy approaches addressing multiple production risks such as poor soil fertility and drought. However, the unsustainable use of chemical fertilisers has important implications for soil degradation. The synergies between improved maize varieties and sustainable land use management practices such as the use of organic fertilisers (e.g., manure) are poorly documented, despite the role of manure in enhancing soil organic matter. Employing nationally representative household survey data in Nigeria, this study utilises multivalued inverse probability weighted regression adjustment, entropy balancing and a multinomial endogenous switching regression model to determine the effects of the adoption of drought-tolerant maize varieties (DTMVs) and organic fertiliser on farm households' productivity, per capita total expenditure and per capita food expenditure. Controlling for farm households' observables and unobservables, the estimation results of the average treatment effects show that the highest pay-off on productivity and welfare outcomes is achieved when DTMVs and manure are jointly adopted. Also, wealth indicators, access to loans and access to extension services significantly influenced individual and combinatory packages of DTMVs and manure application adoption. This study underlines the significance of the joint adoption of DTMVs and manure application on rural farmers' productivity and welfare and a substantial contribution to achieving sustainable agricultural practices.

KEYWORDS
climate-smart agriculture, drought, improved maize varieties, manure, multinomial endogenous switching regression, multivalued inverse probability weighting regression adjustment, organic fertiliser, sub-Saharan Africa

JEL CLASSIFICATION
O13, Q01, Q54, Q55

1 | INTRODUCTION

In sub-Saharan Africa (SSA), poor soil fertility is one of the major impediments to attaining increased agricultural productivity (Sanchez, 2002; St. Clair & Lynch, 2010). Compared with other agricultural regions, predominant soil types in SSA have high leaching potential, and nearly 40% of soils are low in nutrient capital reserves (Tully et al., 2015). The situation is continuously exacerbated by various climatic and anthropogenic activities. As estimated, 70%–80% of cultivated farmland areas are exposed to continuous degradation with losses of 30–60 kg of nutrients per hectare per year (IPCC, 2017). The maize crop is highly susceptible to problems of poor soil fertility; soil nutrients such as nitrogen and phosphorous are highly limiting, highly mobile and subject to excessive loss (Kamara et al., 2014; Pasley et al., 2020). Extreme climate conditions such as drought are one of the top challenges in maize production, and besides affecting maize crops during important growth stages, it reduces soil nutrient uptake activity which affects the stability of soil organic matter and the soil biological systems (Dimkpa et al., 2020; McCulloch et al., 2021). As reported in empirical findings, about 40% of Africa's maize-growing area faces occasional drought stress, resulting in yield losses of 10%–25%, and about 25% of the maize crop suffers frequent drought, with losses of up to half the harvest (Fisher et al., 2015).

Usually, problems of poor soil fertility and drought translate into multiple challenges to maize farming households, and due to the importance of maize as a major staple crop for food and animal feed in SSA, it is not uncommon for farm households to adopt multiple climate-smart agricultural practices (CSAPs). The drought-tolerant maize varieties (DTMVs) are important components of CSAPs deployed in maize-producing countries in SSA under the Drought Tolerant Maize for Africa (DTMA) project (Wossen, Abdoulaye, Alene, Feleke, Menkir, et al., 2017). The desirability of the DTMVs is linked to their ability to increase yield by 20%–30% under moderate drought, resistance to major diseases, good nitrogen use efficiency, and their superior milling and cooking quality (Fisher et al., 2015). While various findings have, in principle, established the profound impact of DTMVs on reducing drought risks and increasing the productivity and welfare of farm households (Lunduka et al., 2017; Simtowe et al., 2019; Wossen, Abdoulaye, Alene, Feleke, Menkir, et al., 2017), the adoption of a single technology is not likely to be sufficient to imporve overall productivity without adopting other interrelated technologies (Kassie, Teklewold, Jaleta, et al., 2015; Kassie, Teklewold, Marenya, et al., 2015). The above-mentioned impact studies on DTMVs have overlooked the role of other climate-adaptive or mitigating approaches that can both dictate the adoption of DTMVs as well as jointly influence the productivity and welfare of rural farm households. In this study, we consider assessing the joint impact of adopting DTMVs and the application of organic fertiliser (henceforth denoted as ‘manure’). We argue that joint adoption of DTMVs and use of manure provides a greater effect on productivity and on welfare indicators of farm households compared with adoption of one of those practices in isolation. This study addresses the following research questions: (1) What are the determinants of the decision to adopt DTMVs and manure individually, as well as the combination of both practices? (2) Does simultaneous adoption of DTMVs and manure use affect productivity and welfare outcomes? This research further fills the gap as a novel attempt to demonstrate the joint impact of DTMVs and interrelated practices and to motivate policy, and the need to incorporate and promote the complementarity of manure with DTMVs.

Improved maize seeds and chemical fertilisers are notable complementary CSAPs for maize farming communities in SSA (Duflo et al., 2008; Kassie et al., 2013; Kassie Teklewold, Jaleta, et al., 2015; Kassie, Teklewold, Marenya, et al., 2015; Teklewold, Kassie, & Shiferaw, 2013; Teklewold, Kassie, Shiferaw, & Köhlin, 2013), and there have been continuous efforts to increase the adoption of chemical fertilisers, which is still considered low in SSA (Sheahan & Barrett, 2014). The use of chemical fertilisers is however unsustainable, and excessive fertiliser application is one of the top anthropogenic drivers of runoff and infiltration, which affects the quality of surface water and groundwater (Li et al., 2017). There is a need for more sustainable complementary technology and practices to ensure increased food production while sustaining soil organic matter without compromising on environmental needs. Application of manure is an important component of sustainable agricultural practices, which are environmentally non-degrading, soil-conserving, technically appropriate, socially acceptable and economical (FAO, 2015). Manure is important in enhancing soil organic carbon sequestration and improving soil quality (Ibrahim et al., 2020; Olalekan et al., 2021), although, when applied without proper treatment, manure can negatively impact the environment through soil acidification and the build-up of pathogenic microorganisms (De Vries et al., 2012; Kumar et al., 2013). In maize production, experimental evidence has shown that manure improves the physical and biochemical activity of the soil and nicely complements improved maize seeds (Li et al., 2017). Also, where manure is used as a complete substitute for chemical fertiliser in appropriate proportion, it has been found to provide enough nutrients to the soil and increase maize yield while improving the soil environment (Geng et al., 2019). In combination with other CSAPs, such as NPK-based fertilisers, organic fertilizers promote the sustainable uptake of Zn in maize grain (Naveed et al., 2018), increases plant height, number of grains, length of ear, and potassium content in maize and overall support maize growth and productivity (Kandil et al., 2020; Soro et al., 2015). Despite this established evidence, the use of manure has received low attention in terms of promoting them in combination with improved seeds in most agricultural policies in SSA (Cavane & Donovan, 2013).

Nigeria presents an interesting case study to assess the combined effect of adopting DTMVs and manure. Agriculture is central to the Nigerian economy, and according to the World Bank Statistics (2019) estimates, it currently employs 34.97% of the Nigerian population, of which the majority live in rural areas. Prevailing poverty estimates also show that 30.9% of Nigerians lived below the international poverty line of $2.15 per day, and 41% of rural populace are classified poor (Poverty & Equity Brief, 2022). Nigeria is Africa's second largest maize producer, and the 14th largest in the world (PwC Report, 2021), but drought and poor soil fertility are prominent factors limiting production potential. The maize crop is densely grown in a large expanse of arable lands in the Savanna with high sunshine which makes it susceptible to drought issues (Bello et al., 2012). Also, like in most SSA countries, poor soil fertility is a major biophysical factor limiting maize yield in Nigeria (Shehu et al., 2018).

Consequently, this study investigates how the adoption of complementary climate-smart practices can sustainably address drought risks and poor soil fertility issues in Nigeria. The key finding is that joint adoption of DTMVs and manure use has higher effects on the productivity and welfare of farm households compared to DTMVs and manure being independently adopted. The rest of the paper is organised as follows. Section 2 describes the conceptual and econometric framework, while Section 3 describes the data. Section 4 discusses the results and findings. Section 5 concludes the paper with policy implications.

2 | CONCEPTUAL FRAMEWORK AND ESTIMATION STRATEGY

2.1 | Conceptual framework

Nigeria ranks as SSA's second-largest producer of maize after South Africa, with a production exceeding 10 million tonnes, according to FAOSTAT's 2018 data.[1] Nigeria has the largest harvested land area maize in Africa (Figure 1), but the yield per hectare is low, suggesting that Nigeria is still riddled with low productivity in maize production. In an estimate of average yield per hectare over 25 years (1993–2018), Nigeria has the lowest yield (1572 kg/ha) compared with other maize-producing countries in Africa (Figure 2).[2] The yield per hectare has been low despite the adoption of agricultural technology interventions in the past years. In addition, the effects of climate change are evident through increasing temperatures, changes in biodiversity and adverse impacts on agricultural systems (IPCC, 2014). In Nigeria, maize crop production faces a threat from climate change, including changes in the pattern of rainfall, especially in the savannah, where there is large-scale maize production. Drought stress can amount to a reduction in the number of ears per plant by 22% and grain yield by 53% (Olaoye et al., 2009).

This study explores the prospects of promoting sustainable land management practices jointly with improved maize seed technology. In drought-prone maize farming communities, enhancing soil conservation measures is an effective way to improve soil productivity and minimise moisture loss (Murungweni et al., 2016). DTMVs are modified adaptive seed

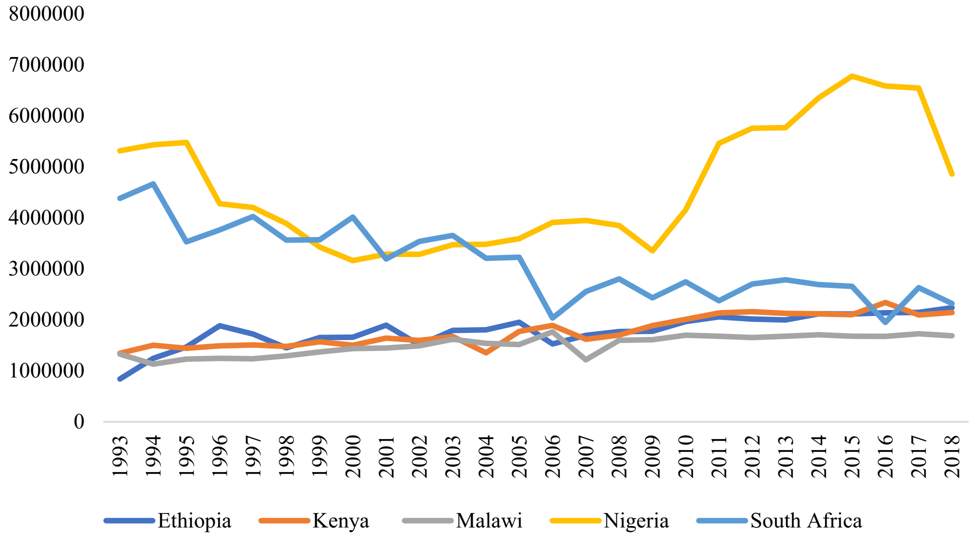

FIGURE 1 Graphical illustration of maize crop area harvested from 1993 to 2018. *Source*: Author's illustration based on data from FAOSTAT 2019. [Colour figure can be viewed at wileyonlinelibrary.com]

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[1] This estimate is subject to maize production in each country as provided in the FAOSTAT database. It is, however, important to note that South Africa adopts genetically modified (GM) maize crops, which impacts its yield and Nigeria produces non-GM crops. Nigeria can be referred to as the largest producer of non-GM crops.

[2] Figure 1 illustrates crop areas harvested in Nigeria and other maize-producing countries. A subsequent report on maize production in Nigeria in the period indicates a consistent decline in 2017 through 2019/2020, this was attributed to some factors such as economic recession and a major currency devaluation which happened in 2016. The immediate impact of this was reduced consumer income and consumption of poultry and fish products. This indirectly impacts demand for maize produce which is an important ingredient in animal feed production (Beillard et al., 2019).

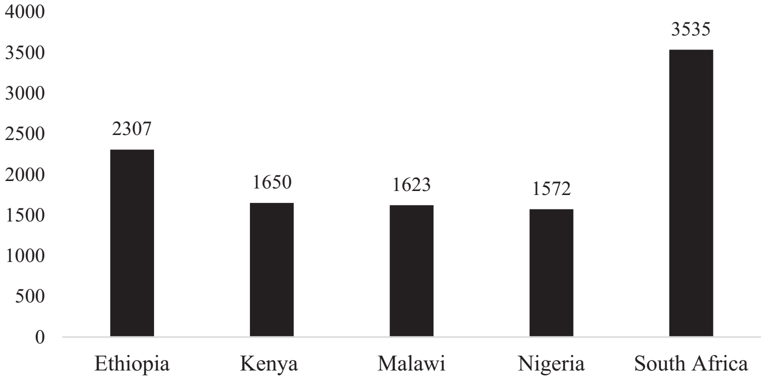

FIGURE 2 Graphical illustration of average maize yield (kg/ha) for 25-year period for selected maize-producing countries in sub-Saharan Africa (SSA). *Source*: Author's illustration based on data from FAOSTAT 2019.

technology that thrives well in extreme drought situations, and when jointly adopted with soil conservation measures such as manure application, farmers are expected to get a better productivity as well as a longer term gain in soil improvements. Increased productivity usually translates to improved access to funds for farming households, enabling them to meet their welfare needs.

In previous studies, the adoption impact of individual climate-smart practices has been established. The DTMVs were maize varieties launched under the DTMA project in SSA. The DTMA project involved the development and dissemination of DTMVs among maize farm households and was launched in 2007 across 13 countries in SSA, including Nigeria (DT Maize 2015). Studies have established the positive impact of DTMVs as climate-smart practices for farming households when adopted independently (Amondo & Simtowe, 2019; Wossen, Abdoulaye, Alene, Feleke, Ricker-Gilbert, et al., 2017). The use of manure has also been found to directly improve maize yield (Githongo et al., 2021). This study evaluates whether the impact is greater when DTMVs and manure application are adopted jointly compared to adopting them in isolation. We also evaluate the determinants of individual or joint adoption of DTMVs and manure application. The joint adoption of DTMV and manure is expected to increase farming households' productivity and welfare while providing long-term sustainable soil conservation. Research findings are expected to establish pathways to jointly promote DTMVs and the use of manure as part of agricultural development in Nigeria.

2.2 | Estimation strategy

2.2.1 | Multivalued inverse probability weighted regression adjustment and entropy balancing technique

Simultaneous adoption of CSAPs is evident in various studies conducted in SSA (Kassie, Teklewold, Jaleta, et al., 2015; Kassie, Teklewold, Marenya, et al., 2015; Onyeneke et al., 2018; Teklewold, Kassie, & Shiferaw, 2013; Teklewold, Kassie, Shiferaw, & Köhlin, 2013; Wainaina et al., 2016). Following these studies, we first establish the possible adoption choices of DTMVs and manure to include (1) adoption of neither DTMVs nor manure (D_0M_0), (2) adoption of DTMVs only (D_1M_0), (3) adoption of manure only (D_0M_1) and (4) adoption of both DTMVs and manure (D_1M_1). Adoption choices can influence expected productivity and welfare gains (per capita total expenditure and per capita food expenditure), of farming households, given the constraints they are facing. Therefore, we model outcomes of productivity and welfare status Y_{ji} as a linear prediction of adoption decisions T_{ji} and farming households' attributes X_{ji} as follows:

$$Y_{ji} = \alpha X_{ji} + \beta T_{ji} + \varepsilon_{ji} \tag{1}$$

where α and β are vectors of parameters to be estimated; ε_{ji} represents identical and randomly distributed errors with mean zero that are assumed to be uncorrelated with X_{ji}.

To estimate the impact of each adoption choice on farm households' productivity and welfare outcomes, we employed the multivalued inverse probability weighted regression adjustment (MIPWRA) approach and entropy balancing. The MIPWRA uses the inverse of estimated probability weights to estimate missing data correction-regression coefficients that are subsequently used to produce robust estimates of the average treatment effects on the treated (ATT). The MIPWRA in the context of this model is estimated in two phases. In the first phase, a multinomial logit model is estimated to generate propensity scores for the adoption of the four possible combinations of DTMVs and manure application, after which the inverse probability of treatment weights is calculated for each of the treatments. In the second phase, using estimated weights, the outcome models (productivity, per capita total expenditure and per capita food expenditure) are fitted by weighted regressions for each treatment level, and treatment-specific predicted outcomes are obtained using the estimated coefficients from this weighted regression model. The model is finally estimated using generalised methods of moments in one step which has the advantage of automatically accounting for the estimation error from the estimated propensity scores when deriving the standard errors. The average treatment effect estimation for each of the treatment combination of DTMVs and manure is as follows:

$$ATT_{lj,\vec{j}} = E\{(y_{\tilde{j}i} - y_{1i}) \mid j = \vec{j}\ \} \tag{2}$$

where y_{ji} is the potential outcome (productivity, per capita total expenditure, or per capita food expenditure) that household i would obtain from jth treatment combinations. In the multivalued treatment case, $\vec{j}$ defines the ATT treatment levels of the treated potential outcome, and $j = \vec{j}$ restricts the expectation to include only those individuals who receive treatment level $\vec{j}$. To keep the discussion brief, we provide only a summary of the MIPWRA. For details, please see Cattaneo (2010) Cattaneo et al. (2013) and Linden et al. (2016).

We further apply the entropy balancing technique, which addresses covariate balancing by using weight functions to adjust for the control units. The approach uses a reweighting scheme that allows balancing on the first, second or a higher moment of covariate distributions in the treatment and reweighted control group (Hainmueller & Xu, 2013). The advantage is that the entropy balancing estimates the weights directly, and following Hainmueller and Xu (2013), the counterfactual mean can be shown as follows:

$$E\left[\widehat{Y(0) \mid D} = 1\right] = \frac{\sum_{\{i|D=0\}} Y_i w_i}{\sum_{\{i|D=0\}} w_i} \tag{3}$$

where w_i are the entropy balancing weights chosen for each control unit. The weights are selected by a reweighting scheme that minimises the entropy distance metric. The *ebalance Stata* command is used to estimate the third model, and the balance constraints are specified as the mean (first moment), the variance (second moment) and the skewness (third moment) (Hainmueller & Xu, 2013). In this study, we specified the balance constraints for each choice category based on the first moment. After reweighting for each choice category, we use the standard ordinary least squares linear regression approach to estimate the impact of adoption on welfare outcomes (per capita total expenditure and per capita food expenditure) for each chosen category.

The limitation of the MIPWRA and the entropy balance is that they only account for observed characteristics. Hence, we further employ the multinomial endogenous switching regression (MESR) to account for the selection issue based on both observed and unobserved characteristics.

2.2.2 | Multinomial endogenous switching regression

Given that farming households endogenously self-select themselves into adoption and non-adoption categories, bias due to observed and unobserved factors may arise. To disentangle this effect, following Kassie, Teklewold, Jaleta, et al. (2015), Kassie, Teklewold, Marenya, et al. (2015) and Martey, Etwire, et al. (2020), Martey, Maxwell, et al. (2020), we apply the Dubin and McFadden model (1984) and Bourguignon et al. (2007) MESR—a selection bias correction based on multinomial logit model. Besides correcting for selectivity bias, the MESR model estimates the effect of CSAPs on outcome equations by allowing for interaction between the choices of alternative CSAPs and farm household attributes (Di Falco & Veronesi, 2014; Mansur et al., 2008). In the first stage of the MESR model, the individual and joint adoption of DTMVs and manure applications are modelled using a multinomial logit specification. The second stage estimates the impact of each adoption choice category on the outcome variables using ordinary least squares with a selectivity correction term derived from the first stage.

The first stage: Multinomial selection model

Based on the random utility framework, we model adoption choices of DTMVs and manure application as a multinomial selection process assumed to be induced by the expected benefits of farming households on their attributes. Given that farming households consider optimisation of input choices and maximisation of utility U_i, by comparing the gains from j choices of DTMVs and manure, it follows that farmer i will choose any of the adoption choices j over any other choice k if $U_{ij} > U_{ik}$, $k \neq j$. The expected utility is modelled as the

$$U_{ij} = X_i \beta_j + \varepsilon_{\text{ij}} \tag{4}$$

where X_i represents farming household explanatory variables, which include socioeconomic, plot, institutional and regional variables. Let Å denotes the farm household's choice of package (combination of DMTV and manure application), such that:

$$\text{Å} = \begin{cases} 1 \text{ if } U_{i1} > \max\left(U_{ik}\right) \text{or } \vartheta_{i1} < 0 \\ \qquad k \neq j \\ \qquad \textit{for all } k \neq j \\ j \text{ if } U_{ij} > \max\left(U_{ik}\right) \text{or } \vartheta_{ij} < 0 \\ \qquad k \neq j \end{cases} \tag{5}$$

Equation 5 describes the ith farmer's decision to adopt package j to maximise his/her expected utility if the expected profit of package j is greater than any other alternatives adoption choices $k \neq j$, that is, if $\vartheta_{ij} = max_{k \neq j} \left(U^*_{ij} - U^*_{ik} \right) > 0$.

The errors ε are assumed to be identically and independently Gumbel distributed. The probability that farm household i with attributes X will select an adoption choice j is modelled in a multinomial logit framework (McFadden & Train 2000) specified below:

$$P_{ij} = \Pr\left(\vartheta_{ij} < 0 | X_i\right) = \frac{\exp\left(X_i \beta_j\right)}{\sum_{k=1}^{j} \exp\left(X_i \beta_k\right)} \tag{6}$$

The second stage: The MESR model

The second stage, MESR, estimates the impact of each category of adoption choices of DTMVs and manure on outcome variables. The base category, D_0M_0 (non-adoption), is denoted as $j = 1$. The rest of the combinationsD_1M_0, D_0M_1 and D_1M_1 are denoted as $j = 2, 3$ and 4, respectively. Of these, at least one of the choice categories is adopted. To evaluate the productivity and welfare implications of the adoption of each choice category, we define the following regimes.

$$\begin{cases} \text{Regime 1:} \quad Q_{1i} = \beta_1 X_{1i} + \mu_{1i} \\ \text{Regime } j\text{:} \quad Q_{ji} = \beta_j X_{ji} + \mu_{ji} \end{cases} \quad j = 2, 3, 4 \tag{7}$$

where Q_{ji} is the outcomes of productivity and welfare outcomes of the ith farming household in regime j. X is the vector of all explanatory variables, β is the vector of parameters of explanatory variables to be estimated, and μ denotes the error term with mean zero $E(\mu) = 0$. Q_{ji} is observed only if package j is selected, under which $U_{ij} > \max_{k \neq j}\left(U_{ik}\right)$. The model, however, assumes that the error terms are independent. If the error terms are not independent, the ordinary least square estimation will be biased. This is a limitation of the endogenous switching regression model estimates. This model also assumes that the error terms are jointly normally distributed, otherwise, when added with the inverse mills ratio (IMRs) as shown below, will not correct for selection bias (Tucker, 2010).

A consistent estimation requires the inclusion of selection correction terms, which are the IMRs computed from estimated probabilities in stage 1. The MESR model is illustrated as follows:

$$\begin{cases} \text{Regime 1:} \quad Q_{1i} = \beta_1 X_{1i} + \phi_1 \mathcal{H}_{1i} + \mu_{1i} \\ \text{Regime } j\text{:} \quad Q_{ji} = \beta_j X_{ji} + \phi_j \mathcal{H}_{ji} + \mu_{ji} \end{cases} \quad j = 2, 3, 4 \tag{8}$$

where ϕ_j is the covariance between error terms and $\mathcal{H}_{ji}$, which represents the IMRs of regime j.

The inclusion of the IMRs provides consistent estimates and due to this inclusion from the first stage selection model, the standard errors can be bootstrapped to account for heteroscedasticity (Khonje et al., 2018). For a more robust identification, we adopt the use of exclusion restriction or instrument, that is, to include regressors in the treatment equation that are excluded from the outcome equations. This may not be strictly necessary in the case of multinomial treatment effects because the parameters of the model can be identified using the non-linearity of the model (Teklewold, Kassie, & Shiferaw, 2013; Teklewold, Kassie, Shiferaw, & Köhlin, 2013). Following Kassie, Teklewold, Jaleta, et al. (2015), Kassie, Teklewold, Marenya, et al. (2015), Manda et al. (2016), Ng'ombe et al. (2017) and Martey, Etwire, et al. (2020), and Martey, Maxwell, et al. (2020), we include the *access to extensive training on improved production practices*, a dummy variable, that takes a value of one if farm households had access to training on improved production practices and zero if they had no access. Access to training on production practices among maize farming households suggests that farming households are likely to have information on climate-smart practices that are yield-enhancing. In similar studies, access to information on sustainable agricultural practices was adopted as an instrument (Manda et al., 2016); also, extension access and contacts were significant instrumental variables (Martey, Etwire, et al., 2020; Martey, Maxwell, et al., 2020). The admissibility of the identified instrument (*access to extension services on improved production practices*) is established through a falsification test (Di Falco et al., 2011). We show that our instrument is significantly correlated with the adoption of individual and combinations of DTMVs and manure application, but does not have any direct effect on outcomes of productivity and welfare of non-adopters (see Table S1 in the appendices).

2.2.3 | Estimation of the average treatment effects on the treated

To estimate the ATT due to the adoption of individual and joint adoption of DTMVs and manure application, outcome values of adopters and non-adopters in each category are compared in both actual and counterfactual scenarios. The actual and counterfactual expected outcomes of adopters are respectively specified as follows:

$$E\left(\mathrm{Q}_{ji} \mid U = j, \mathrm{X}_{ji}, \mathcal{H}_{ji}\right) = \beta_j \mathrm{X}_{ji} + \phi_j \mathcal{H}_{ji} \tag{9a}$$

The counterfactual expected outcome of adopters had they not adopted is:

$$E\left(\mathrm{Q}_{1i} \mid U = j, \mathrm{X}_{1i}, \mathcal{H}_{1i}\right) = \beta_1 \mathrm{X}_{ji} + \phi_1 \mathcal{H}_{ji} \tag{9b}$$

The counterfactual Equation (9b) represents the outcome for what adopters of package j would have obtained if the coefficients of characteristics ($\mathrm{X}_{ji}, \mathcal{H}_{ji}$) were similar to the coefficients of characteristics of non-adopters. To measure ATT, we compute the difference between (9a) and (9b) (Kassie et al., 2017; Khonje et al., 2018) as follows:

$$ATT = E\left(\mathrm{Q}_{ji} \mid U = j, \mathrm{X}_{ji}, \mathcal{H}_{ji}\right) - \mathrm{E}\left(\mathrm{Q}_{1i} \mid U = j, \mathrm{X}_{1i}, \mathcal{H}_{1i}\right) = \mathrm{X}_{ji}\left(\beta_j - \beta_1\right) + \mathcal{H}_{1i}\left(\phi_j - \phi_1\right) \tag{10}$$

In Equation (10), the first term on the right-hand side represents the expected change in adopters' mean outcome supposing adopters' attributes had the same return as non-adopters (Teklewold, Kassie, & Shiferaw, 2013, Teklewold, Kassie, Shiferaw, & Köhlin, 2013). The second term (ϕ_j) is the selection term that captures all potential effects of differences in unobserved variables, such as individual ability.

3 | DATA AND DESCRIPTION OF VARIABLES

In this study, we used nationally representative farming household survey data collected by the International Institute of Tropical Agriculture (IITA) between November 2014 and February 2015 from 18 major maize-producing States in Nigeria. The process of data collection was through a multi-stage sampling technique. The first stage involved dividing the 36 states in Nigeria into five subgroups based on the total land areas allocated to maize production. From the five subgroups, 18 states were randomly selected (Figure 3). Within the 18 intervention states, enumeration areas (EAs) were generated from local government areas (LGAs) in each state. Based on this, five maize farm households were randomly selected per EAs per LGAs for interviews. A total of 2305 farm households form the sample.

Table 1 below presents possible combinations (D_0M_0, D_1M_0, D_0M_1 and D_1M_1) and their distribution among maize farming households. As shown, only 14.3% of farming households

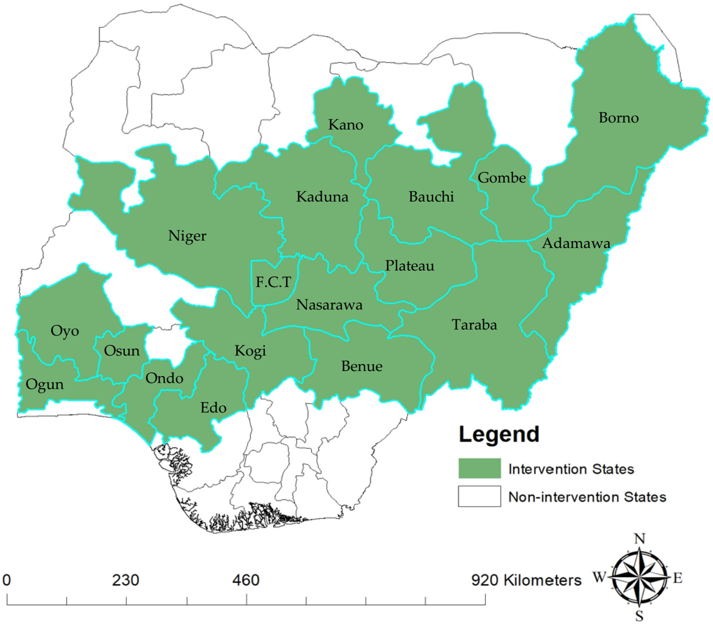

FIGURE 3 Map of Nigeria showing Drought Tolerant Maize for Africa (DTMA) intervention and non-intervention states. (DTMA Bulletin, 2016; Abdoulaye et al., 2018). [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 1 Adoption of combinations of DTMVs and manure.

		DTMVs (D)		**Manure (M)**		
Choice (*j*)	**Combination**	**D_1**	**D_0**	**M_1**	**M_0**	**Frequency (%)**
1	D_0M_0		√		√	54.7
2	D_1M_0	√			√	8.6
3	D_0M_1		√	√		22.4
4	D_1M_1	√		√		14.3

Note: The combination column represents a possible combination of DTMVs and manure. Each element in the combination is a binary variable for CSAPs: drought-tolerant maize varieties DTMVs(D), manure (M). In addition to statistics in this table, our data show that on the average 92.4% of sample under study adopts NPK fertilisers, 36.6% adopts organic manure and 30.6% jointly adopts organic manure and inorganic fertilisers. Please note that there are earlier established complementarity of organic and inorganic fertilisers (e.g., see. Ayoola et al., 2006). Basically, this study further shows additional complementarity with DTMVs. The use of organic matter (manure) in addition to improvement in soil fertility increases water/moisture retention, thus making the DTMVs more productive with access to more moisture.

Source: Own computation using the IITA DTMA survey.

adopted both CSAPs (D_1M_1), while the majority 54.7% did not adopt any of the CSAPs on their plots (D_0M_0). Based on past empirical studies (Kassie, Teklewold, Jaleta, et al., 2015; Kassie, Teklewold, Marenya, et al., 2015; Martey, 2018; Ng'ombe et al., 2017; Teklewold, Kassie, & Shiferaw, 2013; Teklewold, Kassie, Shiferaw, & Köhlin, 2013), farming household characteristics considered include (gender, age, family size, farm experience, years of residence in the village, total livestock unit (TLU)), land and farm factors (land ownership, land rental, farm

TABLE 2 Description and summary statistics of the variables used in the analysis.

Variables	Description	Mean	SD
Outcome variables			
Productivity	Maize yield per hectare in the past agricultural season	1990.15	6510.18
Per capita total expenditure	Per capita total expenditure of farm household	43,900.17	637,243.90
Per-capita food expenditure	Per capita food expenditure of farm household	5601.657	11,460.35
Other covariates			
Gender	1 = if household head is male, 0 otherwise	0.88	0.33
Age	Age of household head in years	47.45	13.97
Education	Household head education in years	7.62	6.64
Household size	Family size (number)	6.93	2.98
Farm experience	Farming experience in years	27.88	14.94
Village residence	Number of years household head lived in the village	40.74	17.57
Land ownership	1 = owned plot, 0 otherwise	0.84	0.37
Land rental	1 = if land is on rental contract, 0 otherwise	0.08	0.28
Farm size	Farm size in hectares	11.01	173.26
Hired labour	Cost of hired labour in the last agricultural season measured in Nigerian Naira (NGN)	62,509.44	95,750.41
Risk	1 = yes if farmers are willing to adopt new maize varieties at first availability without considering potential risks, 0 otherwise	72.5	44.6
Tropical Livestock Units (TLU)	Tropical livestock units, calculated from cattle, goats, sheep, poultry, pigs, and donkeys	2.28	15.51
Loan	1 = yes if farm household received a loan in the past agricultural season	0.49	0.50
Membership	=1 if household head is a member of input supply and farm cooperatives, 0 otherwise	0.62	0.48
Urea	Quantity of urea used in kg/ha	122.70	215.13
NPK fertilizer	Quantity of NPK fertiliser used kg/ha	283.43	442.54
Weather information	=1 if household head received regular information on expected rainfall and temperature, 0 otherwise	0.55	0.50
North West	=1 if farm household is in North-West, 0 otherwise	0.35	0.48
South-South	=1 if farm household is in South–South, 0 otherwise	0.05	0.21
South East	=1 if farm household is in South-East, 0 otherwise	0.04	0.20
North Central	=1 if farm household is in North-Central, 0 otherwise	0.27	0.44
North East (yes = 1, no = 0)	=1 if farm household is in North-East, 0 otherwise	0.05	0.21
Instrumental variable			
Access to extension training on improved production practices (yes = 1, no = 0)	= 1 if the household head had access to extension training on improved production practices in the past agricultural season, 0 otherwise	0.09	0.29

Source: Own computation using the survey.

size, Urea and fertiliser used); climatic information (temperature and rainfall), institutional factors (membership, credit access and extension training) and regional delineation (North-West, South-South, South-East, North-Central, North-East and South-West). The description of variables and summary statistics is presented in Table 2.

Following previous impact studies on improved maize varieties (Abdoulaye et al., 2018; Olagunju et al., 2020; Wossen, Abdoulaye, Alene, Feleke, Ricker-Gilbert, et al., 2017), the productivity outcome variable is measured as maize crop yield per hectare in the agricultural season. The welfare outcomes are proxied by the per capita total expenditure and per capita food expenditure. The per capita total expenditure is the total sum of food and non-food expenditure divided by the household size. The distribution of each package based on the outcome variables is presented in Figures 4–6. As shown, in all categories of outcomes, returns are higher for adopters of at least one CSAP compared with non-adopters of both CSAPs, except for the per capita food expenditure outcome, where only adopters of DTMV on its own, reported greater per capita food expenditure then non-adopters.

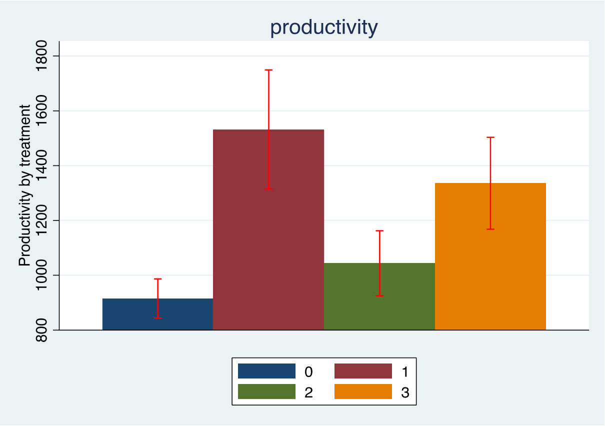

FIGURE 4 Graphs of productivity outcome by their treatment status. Where 0 = D_0M_0 (non-adopters); 1 = D_1M_0 (adopts drought-tolerant maize varieties (DTMVs) only); 2 = D_0M_1 (adopts organic manure only); 3 = D_1M_1 (adopts DTMVs and organic manure). [Colour figure can be viewed at wileyonlinelibrary.com]

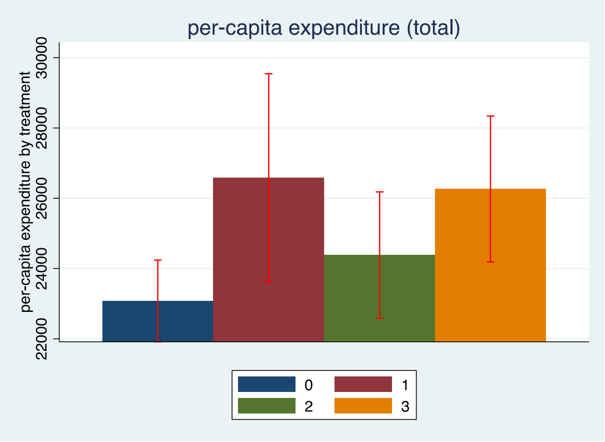

FIGURE 5 Graphs of per capita total expenditure outcome by their treatment status. Where 0 = D_0M_0 (non-adopters); 1 = D_1M_0 (adopts drought-tolerant maize varieties (DTMVs) only); 2 = D_0M_1 (adopts organic manure only); 3 = D_1M_1 (adopts DTMVs and organic manure). [Colour figure can be viewed at wileyonlinelibrary.com]

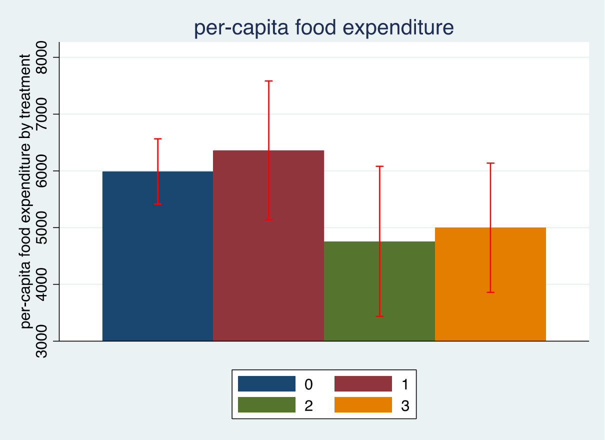

FIGURE 6 Graphs of per capita food expenditure outcome by their treatment status. Where $0 = D_0M_0$ (non-adopters); $1 = D_1M_0$ (adopts drought-tolerant maize varieties (DTMVs) only); $2 = D_0M_1$ (adopts organic manure only); $3 = D_1M_1$ (adopts DTMVs and organic manure). [Colour figure can be viewed at wileyonlinelibrary.com]

4 | RESULTS AND DISCUSSION

4.1 | Multinomial logit estimation of the determinants of combinatory adoption of DTMVs and manure

Table 3 presents parameter estimates of the multinomial logit model of adoption packages. The base category is the non-adoption of both DTMVs and manure (D_0M_0). The model fits the data reasonably well and the Wald test that all regression coefficients are jointly equal to zero is rejected $\left[\chi^2(69) = 873.65; p = 0.000\right]$. The result further shows that the estimated coefficients differ substantially across alternative packages. For farming households that received a loan in the previous agricultural season, the decision to adopt the CSAPs is positive for D_1M_0 (DTMVs only) and D_1M_1 (DTMVs and manure). This finding underscores the importance of fund availability in the adoption of CSAPs, especially DTMVs. On the other hand, receiving a loan in the previous season does not increase the likelihood of adopting D_0M_1 (manure only). These findings are consistent with Ng'ombe et al. (2017), where access to credit did not have an overall positive effect on adoption of all CSAPs.

Adoption of all categories of choice packages is positive and significant ($p < 0.01$) for households with higher TLU. Livestock is a capital asset and is defined as something that has been produced but not yet used up but is capable of providing returns in terms of increased income or welfare in the future (Upton, 2004). The TLU in this study was calculated based on the metric developed by the Food and Agriculture Organization (FAO), which allows for the combination of multiple species of livestock into a weighted measure representing total body weight and potential market value (Mosites et al., 2015). In this study, we calculated the TLU index based on cattle, sheep, goats, poultry and pigs. As such, increasing TLU indicates higher capital worth and in this respect, influenced the adoption of all packages of CSAPs (D_1M_0, D_0M_1 and D_1M_1). One can conclude that increasing livestock ownership has a propensity effect on the adoption of CSAPs.

Access to extension services on improved production practices influenced the adoption of all packages D_1M_0, D_0M_1 and D_1M_1. This may be due to the endogeneity of extension services in the promotion of CSAPs, and these packages are usually knowledge-intensive and require reassurance on use and techniques in management. Also, this further confirms the validity of this variable as an instrumental variable in the MESR model.

TABLE 3 Parameter estimates of adoption packages—multinomial logit model.

Variables	D_1M_0	D_0M_1	D_1M_1
Gender	0.120	−0.278	−0.205
	(0.490)	(0.392)	(0.484)
Age	0.011	−0.013	0.022*
	(0.011)	(0.010)	(0.013)
Education	0.024	−0.004	−0.035*
	(0.015)	(0.013)	(0.018)
Family size	−0.006	0.056**	0.117***
	(0.037)	(0.027)	(0.036)
Farming experience	−0.015	−0.001	−0.021*
	(0.010)	(0.009)	(0.011)
Village residence	0.000	0.003	−0.031***
	(0.008)	(0.007)	(0.010)
Own land	−0.602*	0.392	0.755
	(0.344)	(0.287)	(0.564)
Rent land	−0.396	0.302	0.316
	(0.417)	(0.288)	(0.482)
Farm size (log)	0.067	0.145	0.024
	(0.117)	(0.092)	(0.126)
Hired labour (log)	0.108	−0.078	0.040
	(0.090)	(0.069)	(0.089)
Risk	0.513*	−0.692***	−0.208
	(0.268)	(0.187)	(0.238)
Total Livestock Units	0.076***	0.069***	0.081***
	(0.027)	(0.026)	(0.027)
Loan	0.458**	0.161	0.952***
	(0.218)	(0.162)	(0.221)
Membership	0.156	0.248	0.014
	(0.246)	(0.190)	(0.239)
Urea	0.001	0.001***	0.001**
	(0.001)	(0.000)	(0.001)
NPK	0.000	0.000	0.000*
	(0.000)	(0.000)	(0.000)
Weather information	0.034	0.355**	−0.057
	(0.222)	(0.163)	(0.219)
North-West	1.758***	3.176***	6.263***
	(0.330)	(0.357)	(1.121)
South-South	0.418	−13.596	−10.877
	(0.678)	(781.790)	(1003.406)
South-East	3.507***	4.675***	8.627***
	(0.755)	(0.749)	(1.280)

TABLE 3 (Continued)

Variables	D_1M_0	D_0M_1	D_1M_1
North-Central	−0.437	2.293***	3.148***
	(0.333)	(0.332)	(1.132)
North-East	−1.936**	1.038**	−10.911
	(0.762)	(0.455)	(496.262)
Access to extension training on improved production practices	0.731** (0.326)	0.910*** (0.275)	1.149*** (0.366)
Constant	−4.493***	−2.739***	−7.877***
	(1.158)	(0.898)	(1.576)
Number of observations	1425	1425	1425
LR chi^2(69)	873.65***		
Prob > chi^2	0.000		
Log-likelihood	1243.1374		

Note: Standard errors are in parentheses.

*, ** and *** represent significance at 10%, 5% and 1% levels, respectively.

The result also shows that older farmers have a higher likelihood of adopting both packages D_1M_1 (DTMVs and manure); this may be due to farmers' accumulation of physical and social capital over the years, which enables them to meet joint adoption demands (Manda et al., 2016). On the other hand, farmers' years of experience and number of years of residence in the village negatively and significantly influenced the joint adoption of both packages (D_1M_1) at $p < 0.1$ and ($p < 0.05$), respectively. Access to regular weather information significantly increased the likelihood of adoption by 35.5% for manure only (D_0M_1). In contrast, a similar study by Ng'ombe et al. (2017) finds that access to climate information negatively influenced the adoption of packages of conservation farming practices. The results further show variation in the impact of households that adopt NPK and Urea, for example, while household adoption of NPK fertiliser increases the likelihood of adopting both DTMVs and manure (D_1M_1), the use of urea increases the likelihood of adopting both D_0M_1 and D_1M_1.

Farmers' willingness to take risks may influence their decision to adopt agricultural innovations (Spiegel et al., 2018). From our result, the parameter estimates show that the adoption of D_1M_0 (DTMVs only) is higher for farmers who are willing to take risks of adopting newly improved maize varieties. Adoption of improved seeds comes with uncertainties, and farming households that are risk-takers tend to adopt improved technologies (Kee, 2017). In contrast, farming households that are risk-averse to adopting improved maize varieties are more likely to adopt manure only (D_0M_1). In line with Chen et al. (2018), risk-averse farmers are more likely to invest in organic fertilisers. The coefficient of D_0M_1 and D_1M_1, respectively, increased for households with large family sizes. This is likely linked to large family households having an available labour supply for production activities, especially the ability to meet the high demand for labour in the case of conservation practices, such as the use of manure (Ndiritu et al., 2014). The result further shows that regional preferences apply in the decision to adopt CSAPs and requires policies targeting preferences accordingly. Significant adoption of all packages (D_1M_0 D_0M_1 D_1M_1) is apparent in the North-West and South-East region. Also, the adoption of D_0M_1 and D_1M_1 packages is more likely in the North-Central region. In the North-East region, farmers show preferences for D_0M_1 (manure only) and are less likely to adopt D_1M_0 package practices.

4.2 | Impact of adoption of DTMVs and manure packages using MIPWRA and entropy balancing approaches

Table 4 presents the MIPWRA estimates for all outcomes. The estimates show a positive and significant ($p < 0.01$) impact of the adoption of each combination of DTMVs and manure on all outcome variables for each of the adoption categories. For each outcome variable, the gain in the adoption of DTMVs only (D_1M_0) is higher than other adoption categories: (D_0M_1) and (D_1M_1). To highlight, the adoption of DTMVs (D_1M_0) only shows a productivity gain of approximately 1523 kg/ha compared with 1043 kg/ha and 1335.61 kg/ha for adopters of manure only (D_0M_1) and joint adopters of DTMVs and manure only (D_1M_1), respectively. Similarly, considering households per capita total expenditure, adopters of DTMVs only (D_1M_0) gained NGN 26,587.69 (33.81 USD or 53.30 AUD),[3] which is higher compared with NGN 24,384.62 (31.01 USD or 48.88) and NGN 26,261.64 (33.40 USD or 52.64 AUD), respectively, for adopters of manure only (D_0M_1) and joint adopters of DTMVs and manure (D_1M_1).

Entropy balancing estimates presented in Table 5 are consistent with MIPWRA results in some adoption categories for productivity, per capita total expenditure and per capita food

TABLE 4 Multivalued inverse probability weighted regression adjustment (MIPWRA) estimates for all adoption choice categories.

Outcomes	DTMVs and organic manure packages	Coefficients	Standard errors	z. Stat.
Maize yield (kg/ha)	D_1M_0	1532.03***	110.30	13.89
	D_0M_1	1043.67***	60.52	17.24
	D_1M_1	1335.61***	85.29	15.66
Per-capita total house expenditure	D_1M_0	26,587.69***	1503.529	17.68
	D_0M_1	24,384.62***	915.67	26.63
	D_1M_1	26,261.64***	1056.92	24.85
Per-capita food expenditure	D_1M_0	6361.50***	621.70	10.23
	D_0M_1	4757.897***	673.53	7.06
	D_1M_1	4997.90***	580.06	8.62

Source: Own computation from the IITA DTMA Survey.

***Significance at 1% level.

TABLE 5 Entropy balancing estimates.

Outcome variable	Adoption categories	Coefficients	Standard errors	R^2	F.Stat
Maize yield (kg/ha)	D_1M_0	218.73***	70.05	0.11***	$F(23, 1333) = 7.46$
	D_0M_1	54.62	69.41	0.14***	$F(23, 1333) = 9.77$
	D_1M_1	88.78	69.89	0.17***	$F(23, 1333) = 12.24$
Per-capita total house expenditure	D_1M_0	−29.90	816.03	0.48***	$F(23, 1396) = 56.50$
	D_0M_1	1842.78**	837.23	0.43***	$F(23, 1396) = 45.90$
	D_1M_1	2763.04***	793.89	0.45***	$F(23, 1396) = 51.67$
Per-capita food expenditure	D_1M_0	673.71***	159.28	0.25***	$F(23, 1417) = 20.14$
	D_0M_1	−267.71*	152.96	0.24***	$F(23, 1417) = 19.44$
	D_1M_1	−144.84	143.32	0.21***	$F(23, 1417) = 16.59$

*, ** and *** represents significance at 10%, 5% and 1% levels, respectively.

Source: Own computation from the IITA DTMA Survey.

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[3] The exchange rates are based on the current (October 2023) exchange rates: 1 USD = 786.35 NGN and 1 AUD = 498.78 NGN.

expenditure outcome. The results show that adopters of DTMVs only (D_1M_0) had significantly higher productivity than other adoption categories. For per capita total expenditure, joint adopters (D_1M_1) significantly gained more than other choice categories: (D_1M_0) and (D_0M_1). In contrast, adopters of DTMVs only significantly gained more in terms of per capita food expenditure than other choice categories.

Estimates from the MIPWRA and entropy balancing may, however, be biased as they do not account for farm households' endogenous attributes. The MESR accounts for this bias, and the result is further presented in Section 4.3.

4.3 | Impact of adoption of DTMVs and manure packages from the MESR

The second-step regression estimates of the MESR are presented in Tables S2–S4. For the outcome of per capita total expenditure, the estimates of adoption of both DTMVs and manure application show decreasing per capita total expenditure for households with larger household sizes. We found a similar significant effect for D_0M_0, D_1M_0 and D_0M_1 packages in the per capita food expenditure model and D_0M_1 in the productivity model. This implies that a larger household size puts pressure on resource needs which can result in poor welfare status (Anyanwu, 2014; Oyetunde-Usman et al., 2021). Also, for per capita total expenditure outcome estimation, increasing the log of hired labour cost is significantly associated with higher per capita total expenditure for packages D_1M_0 and $D_0M_{1.}$ The result surprisingly shows an increasing log of hired labour cost for non-adopters of any of the packages; this could mean that the cost of labour is likely related to other agricultural activities.

The coefficients of willingness to take risk are quite mixed for the outcome of per capita total expenditure; while it reduces for adopters of the D_1M_0 package only, it increases for adopters of the D_0M_1 package only. The result further shows a significant increase in per capita total expenditure of agricultural households that adopt D_0M_1 only and are residents in the South–South region. Also, the adoption of other yield-enhancing techniques, such as Urea, significantly increased per capita total expenditure for farm households of non-adopters (D_0M_0) and increased the productivity of joint adopters of D_1M_1. The coefficient of total livestock unit for adopters of D_0M_1 varies for per capita food expenditure and productivity outcomes, while it shows an increasing effect on households' per capita food expenditure, it reveals decreasing impact on productivity outcome. The coefficient of membership of input supply groups significantly increased productivity outcomes for joint adopters D_1M_1. This agrees with findings on the linkage between group membership and improved welfare (Haddad & Maluccio, 2003; Mmbando et al., 2015).

The second stage estimates the effect of the adoption of individual and joint choices of DTMVs, and manure application is presented in Tables 6 and 7. The results present estimates of the average treatment effect on treated calculated from the actual and counterfactual outcomes of farm households when the instrumental variable is included (Table 6) and when it is excluded (Table 7).

For the productivity outcome, the results show that, on average, joint adopters of DTMVs and manure application (D_1M_1) gained 340 kg/ha more maize output, which translates to 30% returns on adoption. Compared with other choice categories (D_1M_0 and D_0M_1), returns on productivity are 304.88 kg/ha and 198.77 kg/ha more, which translates to a 13% and 19% increase, respectively, for adopters of DTMVs only (D_1M_1) and manure only (D_0M_1). Returns on welfare outcomes also show that gains from joint adoption are significant and equally higher than in single adoption choice cases. As illustrated in Table 6, for per capita total expenditure, welfare gains on the average for joint adopters of DTMVs and manure application (D_1M_1) are almost twice (25%) that of adopters of DTMVs only (D_1M_0) (13%) and 6% higher than adopting manure only (D_0M_1). The result further indicates that per capita food expenditure

TABLE 6 Impact of adoption of CSAPs on productivity and welfare outcomes.

Outcome variables	Adoption package	Outcome by adoption status: Actual outcome if farm household adopt.	Outcome by adoption status: Counterfactual outcome if farm household did not adopt.	ATT	*t*-Value	Sig. % diff.
Maize yield (kg/ha)	D_1M_0	1393.45 (51.74)	1088.56 (32.22)	304.88*** (52.90)	5.76	28%
	D_0M_1	1245.06 (38.93)	1046.29 (14.17)	198.77*** (37.74)	5.27	19%
	D_1M_1	1460.46 (54.27)	1120.38 (19.23)	340.08*** (50.77)	6.70	30%
Per-capita total household expenditure	D_1M_0	31,155.70 (1578.29)	27,505.13 (1442.33)	3650.57*** (807.26)	4.52	13%
	D_0M_1	27,886.72 (848.34)	23,341.27 (966.68)	4545.446*** (492.98)	9.22	19%
	D_1M_1	29,262.65 (873.95)	23,411.49 (1204.73)	5851.16*** (599.91)	9.75	25%
Per-capita food expenditure	D_1M_0	4613.78 (184.53)	4248.75 (632.71)	365.03 (633.84)	0.58	9%
	D_0M_1	3466.00 (103.46)	3305.42 (111.08)	160.58*** (56.99)	2.81	5%
	D_1M_1	3225.81 (85.53)	2969.65 (124.19)	256.16*** (93.28)	2.75	9%

Note: Standard error in parentheses.

***Significance at 1% level, respectively.

Source: Own computation from the IITA DTMA Survey.

equally increased for joint adopters of DTMVs and manure application (D_1M_1) and adopters of DTMVs only (D_1M_0) by 9%, but it is only significant at $p < 0.01$ for joint adopters of DTMVs and manure application (D_1M_1). Also, per capita food expenditure of adopters of manure only (D_0M_1) increased by 5%, and it is significant at $p < 0.01$. Consistent with Manda et al. (2016) and Martey, Etwire, et al. (2020), Martey, Maxwell, et al. (2020), the adoption of improved maize varieties with CSAPs; in this case, maize-legume rotation and row-planting, respectively, impact productivity and welfare outcomes. Also, in line with past studies, the combination of CSAPs yields better results in terms of productivity and welfare than when adopted in isolation (Kassie, Teklewold, Jaleta, et al., 2015; Kassie, Teklewold, Marenya, et al., 2015; Ng'ombe et al., 2017; Teklewold, Kassie, & Shiferaw, 2013; Teklewold, Kassie, Shiferaw, & Köhlin, 2013).

To check the effect of the instrumental variable in the MESR model, we estimate the MESR model without instrumental variables and present it in Table 7. The results are consistent with the findings above in that the joint adoption package (D_1M_1) significantly impacts both productivity and welfare outcomes, except for per capita food expenditure outcomes. In the case of productivity, comparing actual with the counterfactual result, joint adopters of DTMVs and manure application (D_1M_1) gained 368 kg/ha of maize, translating to 34% more productivity returns. Returns on productivity for joint adopters (D_1M_1) are more than twice that of adopters of manure only (D_0M_1) and 5% more returns than adopters of DTMVs only (D_1M_0). Equally, joint adopters of DTMVs and manure application (D_1M_1) are better off with a 25% increase in per capita total expenditure compared with single-choice adoptions in which the returns are 13% and 18% for adopters of the DTMVs only package (D_1M_0) and manure application only package (D_0M_1), respectively. The result for the per capita food expenditure, however, varies

TABLE 7 Estimating impact excluding instrumental variable.

		Outcome by adoption status.				
Outcome variables (log)	**Adoption package**	**Actual outcome if household adopt.**	**Counterfactual outcome if household did not adopt.**	**ATT**	***t*-Value**	**Sig. % diff**
Maize yield (kg/ha)	D_1M_0	1391.61 (53.55)	1080.40 (30.55)	311.21*** (53.62)	5.80	29%
	D_0M_1	1242.60 (37.88)	1070.17 (14.57)	172.42*** (35.82)	4.81	16%
	D_1M_1	1466.33 (53.42)	1098.10 (20.46)	368.24*** (50.80)	7.25	34%
Per-capita total household expenditure	D_1M_0	31,109.75 (1589.73)	27,501.43 (1433.12)	3608.33*** (811.73)	4.44	13%
	D_0M_1	27,757.38 (858.17)	23,502.33 (960.99)	4255.048*** (514.22)	8.27	18%
	D_1M_1	29,238.35 (883.26)	23,438.88 (1199.06)	5799.47*** (622.29)	9.32	25%
Per-capita food expenditure	D_1M_0	4607.81 (165.95)	3903.30 (352.29)	704.51** (347.15)	2.03	18%
	D_0M_1	3469.16 (103.01)	3107.87 (114.33)	361.29 (53.82)	6.71	12%
	D_1M_1	3230.17 (85.87)	2814.67 (117.02)	415.50 (82.73)	5.02	15%

Note: Standard error in parentheses.

*, ** and *** represent significance at 10%, 5% and 1% levels, respectively.

Source: Own computation from the IITA DTMA Survey.

with the exclusion of the instrumental variable and in contrast with the above findings, however, shows that adopters of DTMVs only (D_1M_0) gained 3% higher returns than joint adopters of DTMVs and manure (D_1M_1). This is significant at $p < 0.05$. Similar to Ng'ombe et al. (2017), the adoption effect varied among conservation farming practices, and the highest return is not realised from adopting all packages.

5 | SUMMARY AND CONCLUSION

In Nigeria, as in most sub-Saharan African countries, poor soil fertility and drought conditions are among the major challenges in maize crop production. With increasing food demand and population growth, promoting sustainable approaches in the agricultural food systems will not only target improved productivity but also need to ensure sustainable land management. To address persistent issues of poor soil fertility and drought, there is a need to encourage complementary practices that are soil-conserving. In this study, we considered complementary practices that address drought and poor soil fertility among maize farming households by assessing manure as a complementary practice in a package with DTMVs. We assessed the adoption impact of single and joint adoption choices of DTMVs and manure application and argued that the adoption impact is higher for joint adoption of DTMVs and manure application compared with the adoption of one of those practices in isolation. To complement previous impact studies on DTMVs in Nigeria, we used data from a nationally representative farm household survey from 18 major maize-producing States in Nigeria. We first estimate the determinants of individual and joint multinomial choice categories (D_0M_0, D_1M_0, D_0M_1 and D_1M_1) using a multinomial logit model and find access to credit significantly influenced the adoption of all joint and individual packages. This is consistent with the literature, such as Farrin and Miranda (2015), that found access to credit plays an important role in influencing the adoption of combinatory packages of sustainable practices. Similarly, Ng'ombe et al. (2017) found that access to credit influenced only one combinatory package of conservation agriculture in Zambia. However, contrary to this finding, results from Khonje et al. (2018) show that access to credit had no impact on the adoption of combinatory and individual packages of improved maize varieties and conservation agriculture in eastern Zambia.

We also find that the access to extension services for improved production practices has a significant impact. This suggests the importance of promoting CSAPs through approaches that can effectively reach every farming household. The findings of Manda et al. (2016) indicate that extension services play a crucial role in promoting each CSAPs in isolation, but not necessarily for joint applications. Findings from Kassie, Teklewold, Jaleta, et al. (2015), Kassie, Teklewold, Marenya, et al. (2015) indicate that the impact of adoption of fertiliser in Ethiopia and Tanzania has a positive impact. However, the study also finds that confidence in extension services skills affects more than one sustainable practice in Kenya, Malawi, Ethiopia and Tanzania, suggesting that adoption of multiple practices depends not only on access but also on farmers' trust and confidence in the skills of extension officers.

We also find variations in the adoption of DTMVs and manure application across regions in Nigeria, suggesting the need for regional target-driven promotions. This is in line with Ng'ombe et al. (2017) who find similar disparities in the adoption of conservation farm practices packages across regions in Zambia. Kassie, Teklewold, Jaleta, et al. (2015), Kassie, Teklewold, Marenya, et al. (2015) also find cross-country disparities in the adoption of joint and individual sustainable practices in eastern and southern Africa. Differences in varying agroecological factors, for example, may play a role in influencing varying adoption choices.

Our impact assessment approach first uses MIPWRA and entropy balancing estimates to account for the impact of adopting each package of DTMVs and manure. We find that the highest gain in productivity and welfare outcomes is reflected in single adoption categories. This is not the case when we further adapt the MESR to account for the endogeneity of farm households. The result reveals that the adoption of DTMVs and manure application, both jointly and in isolation, significantly increases the yield and welfare of maize farm households; however, the returns are highest for joint adopters of DTMVs and manure application (D_1M_1). For example, the results show a significant case where the per capita total expenditure of maize farming households who jointly adopted DTMVs and manure application (D_1M_1) is almost twice more than adopters of manure only (D_0M_1) and 6% more than those adopting DTMVs only (D_1M_0). Similarly, for productivity outcomes, joint adopters gained 2% more yield than adopters of DTMVs only and 11% more than adopters of manure only (D_0M_1). Similarly, for the outcome of per capita food expenditure, joint adopters significantly gained 4% more than adopters of manure only (D_0M_1). This is in agreement with Teklewold, Kassie, and Shiferaw (2013), Teklewold, Kassie, Shiferaw, and Köhlin (2013) who show that adoption of sustainable agricultural practices increased maize income in Ethiopia, and the highest pay-off is achieved when sustainable agricultural practices are adopted jointly rather than as individual packages. Also, findings from Khonje et al. (2018) indicate that the joint adoption of multiple agricultural technologies had greater impacts on crop yields, household incomes and poverty than the adoption of individual components of the technology package. On the contrary, findings in Ng'ombe et al. (2017) in assessing the impact of the adoption of conservation farm practices on crop net revenue in Zambia indicate that the highest pay-off is not found in the adoption packages showing all combination of conservation farm practices, suggesting that welfare impact may be dependent on the combination of sustainable farm practices under consideration. Similarly, Manda et al. (2016) reveal that the adoption of comprehensive combinations of sustainable agricultural practices may not usually translate to the improved productivity.

Our research shares a common finding in the literature that joint adoption of CSAPs has important implications for improving maize productivity and the welfare of farm households.

Policy should encourage the joint adoption of DTMVs and manure application. While this concurrently addresses increasing the adoption of DTMVs, which is yet to be widespread (Wossen, Abdoulaye, Alene, Feleke, Ricker-Gilbert, et al., 2017), promoting manure application is also an important option in the face of increasing inorganic fertiliser prices. It is important to address barriers to joint adoption of DTMVs and manure application. The strategy should include strengthening extension service programmes and establishing pathways for improved access to credit for farming households.

While this study provides useful insights into the adoption and impact of DTMVs and manure application, findings are limited to the household attributes available in the survey dataset. The secondary data utilised in this study do not have variables relating to remittances or income from other sources. We understand this is a limitation of this study. Also, this study considers only a year of nationally representative data of maize households in Nigeria, which may not fully capture heterogeneity effects. In addition, the analysed data considered outcome and explanatory variables at the household level only, suggesting a limitation in accounting for plot-level heterogeneities. Further studies may consider analysis using panel data to examine the interrelation of improved seeds and manure application to control for time-based unobserved heterogeneity and plot characteristics.

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Data are available upon request.

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SUPPORTING INFORMATION

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

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