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**RESEARCH**

# Articulating fertilizer subsidy effects on women's diet quality by food supply source in Mali

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## Abstract

**Background:** Mali's fertilizer subsidy program aims to reduce food insecurity among the nation's predominantly rural people by jump-starting productivity gains of major crops. This paper contributes to sparse evidence regarding its effects.

**Methods:** Theory predicts that agricultural productivity can affect diet quality directly through two channels. The production channel influences the availability of food for household consumption or sale. The income pathway, resulting from sales, leads to household food expenditure. We test this hypothesis by applying propensity score matching methods to farm household survey data collected from 2400 households in Mali in 2018.

**Results:** We find that the overall effect of the fertilizer subsidy on women's dietary diversity is positive in the Niger Delta and negative on the Koutiala Plateau. Further examination by food supply source reveals no subsidy effects on the dietary diversity provided by on-farm production in either zone. The subsidy negatively influences dietary diversity of foods sourced as gifts in the Niger Delta. Subsidy effects on dietary diversity accessed through food purchases are strong and positive in the Niger Delta, but negative on the Koutiala Plateau. The Koutiala Plateau is found in the region of Sikasso, where rising incomes from cotton production, which is the major export crop of the region and of the nation, have been shown not to alleviate poverty and malnutrition (a dilemma known as the "Sikasso Paradox").

**Conclusions:** Our approach reveals that additional income from increased yields stimulated by subsidized fertilizer can enable off-farm purchases of more nutritious food and thereby improve nutritional outcomes for women.

## Introduction

Inadequate dietary intake is the most important cause of malnutrition in low-income countries, such as sub-Saharan African countries where diets are poorly diversified and based on starchy staples. Inadequate intake and the risk of micronutrient deficiency are strongly and positively correlated with low dietary diversity that reflects a dominance of staple foods (Arimond et al. 2010). Women of reproductive age are potentially at high risk of micronutrient deficiencies such as vitamin A deficiency, iron deficiency anemia due to their high nutritional requirements during pregnancy and breastfeeding (FAO, Who 2004).

Mali is a food deficient country with a population of 19 million people, the majority of whom live in rural areas (FAO 2018). Food security analysis by the World Food Program in Mali indicates that slightly more than 25% of households suffer from moderate to severe food insecurity with an acute malnutrition rate of nearly eleven percent (WFP 2018). Further, inadequate intake and micronutrient deficiencies are commonplace in Mali. For example, a study conducted among a population aged between 15 and 49 years in the Kayes region by Torheim

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et al. (2004) revealed that the calcium intake of 80% of respondents was lower than the recommended daily intake, 70% fell under recommended amounts of vitamin A, and only about half consumed recommended quantities of iron. The WFP (2018) estimated that vitamin and mineral deficiencies affect 82% of children under five, and iron deficiency affects 52% of women of reproductive age. In a study of over 5000 women in the region of Kayes, Adubra et al. (2019) found that only 27% reached the minimum adequate threshold for dietary diversity.

A potential pathway to reducing food insecurity and malnutrition consists of improving the nutrition sensitivity of agricultural investments (Fan and Pandya-Lorch 2012). For decades, across numerous countries in sub-Saharan Africa, input subsidies have been pursued as a policy strategy to raise crop productivity by enhancing the access to and use of mineral fertilizer among smallholder farmers (Holden 2019; Jayne et al. 2018). Despite the widespread promotion of fertilizer subsidies with the aim of reducing food insecurity in sub-Saharan Africa, remarkably little is known about their actual effects on nutritional outcomes. The few studies on nutritional outcomes related to the agricultural input subsidy have often focused on the consumption of the target staple, measured in terms of calorie intake. In Mali, Smale et al. (2020) found that receiving subsidized fertilizer increases the likelihood that farm women consume the minimum number of food groups needed for an adequate diet. Their analysis also shows that positive effects may be offset by the negative association of diet quality with all subsidized fertilizer received by other plot managers in the same household—perhaps because it leads to greater farm orientation toward targeted crops.

Snapp and Fisher (2014) found positive effects of input subsidies on the quality of food consumed by smallholder farmers in Malawi through the dual pathways of additional income generated from maize sales and crop diversification. Also based on data collected in Malawi, Harou (2018) found more favourable anthropometric indicators of nutrition and more frequent consumption of cereals, meats, nuts, vegetables and fruits among fertilizer subsidy voucher recipients compared to non-recipients. Unlike Snapp and Fisher (2014); Gine et al. (2015) in Tanzania did not detect effects of the fertilizer subsidy on household nutritional outcomes. A study conducted in Ghana by Wiredu et al. (2015) revealed a positive impact of fertilizer subsidies on food security. In addition, the authors found that, combined with other factors such as nutritional education, adequate crop mix farming, and income-generating activities, fertilizer subsidies can improve and ensure food stability.

Here, we add to a sparse literature that provides rigorous analysis of the impact of fertilizer subsidies on women's diet quality. Aspects of this work were previously presented in a thesis and a research report (Assima, 2019; Assima et al., 2019). One noteworthy gap in the literature that we address is that the sources of food consumed by the household can be a very useful indicator of their vulnerability to food insecurity. Our specific contribution is to differentiate the effects of the subsidy on dietary diversity score and food accessibility by examining the food supply source: own farm, market purchase, or gifts from others. We are not aware of other studies that have articulated these effects, which have implications for the vulnerability of farm households to food insecurity. From a policy perspective, understanding the impact of fertilizer subsidies on nutrition could contribute to more nutrition-sensitive agricultural investments in Mali and elsewhere. We believe that our approach is an original one that provide insights into the linkages between farm input policy and food insecurity.

## Linking agriculture to nutrition

This section presents the conceptual framework of pathways linking agricultural interventions to nutrition outcomes, from which to test the potential channel linking fertilizer subsidies to women's dietary diversity in Mali. Various papers on the interactions have identified several pathways through which agricultural interventions may affect the nutritional outcomes (Herforth and Harris 2013; World Bank 2007). In essence, agricultural interventions can affect the nutrition outcomes of farm households through four main pathways: (1) production for own consumption, (2) farm income, (3) market prices, and (4) women's empowerment. In fact, such pathways work through synergistic interactions and interact with a number of contextual factors, which may include other interventions. Thus, there is no universal pathway through which agricultural interventions can affect nutrition outcomes. Depending on the context and the nature of policy intervention, a combination of these linkages is often useful for impact analysis. Below, we highlight the main pathways.

Pathway 1 is the primary direct pathway through which agriculture interventions are thought to affect nutrition outcomes. A policy such as fertilizer subsidies may increase staple food production and encourage diversity of food production through improved productivity. Through this pathway, if successful, a fertilizer subsidy directly can affect smallholder nutrition and diet quality if it results in consumption of a more diverse bundle of food items produced on the farm (World Bank 2007). This is especially true in low-income countries where most of smallholder households consume a substantial part of their own production.

Some empirical studies support this hypothesis. A case study examined dietary diversity in relation to crop diversity among 169 households in Kiambu, Kenya, and 207 households in Arusha, Tanzania (Herforth 2010). Using mixed models with cross-sectional household data, the study demonstrated that crop diversity positively affects household dietary diversity. Furthermore, the study showed that crop diversity was positively associated with child dietary diversity in Arusha, Tanzania. Similarly, using multiple regression analyses and national representative farm household survey data from Malawi, Jones et al. (2019) showed that the diversity of agricultural production has a positive impact on the dietary diversity of farm households. Other studies demonstrate the link between agriculture and the diet quality of households. For example, enhancing homestead production has improved household micronutrient intake in Cambodia (Olney et al. 2009). One of the most recent systematic reviews of agricultural inputs and nutrition in South Asia by Shankar et al. (2019) has shown that raising land productivity through policies promoting the use of irrigation, fertilizer and improved seed varieties has positive impacts on nutrition outcomes of farm households.

Pathway 2 involves increasing the income of farm households through related activities and the sale of surplus crops. Fertilizer subsidies can generate higher revenues through market participation and improve the diversity of diets purchased on markets. A number of studies show that market participation offers more opportunities for improving nutrition outcomes (Sibhatu et al. 2015). Examining the share of households' own production in their diets and the seasonal sensitivity of this share among smallholder farmers in rural areas in Ethiopia, Sibhatu and Qaim (2017) found that markets play a vital role in diet quality. Their estimates show that 80% of dietary diversity comes from purchased foods regardless of the season and household type, suggesting the importance of income as a key mediator linking agriculture to nutrition. Based on their analysis of food consumption among pre-school children on farms in Ethiopia, Hirvonen and Hoddinott (2017) concluded that the positive effects of production diversity on dietary diversity do not hold for households that have access to food markets. In Malawi, Jones et al. (2014) found that households allocating a larger share of their cultivated land to market crops had both more diverse diets and more diverse farm production. In that land-scarce context, they explain that the option to earn income from a new crop may motivate production diversification with positive effects on diet diversity if the crop is also consumed in part. Also in Malawi, Koppmair et al. (2016) concluded that reducing the walking time to the district market by one hour

would have a larger positive effect on dietary diversity than producing one additional food group on the farm.

Pathway 3 is an important link between agriculture and nutrition outcomes. In examining the relationship between agriculture and nutrition, Johnson-Welch et al. (2005) proposed a framework that suggests that the promotion of smallholder agricultural production will lead to more food products entering the market, leading to lower food prices. This is especially true for poor people who spend a large part of their income on food expenses. By increasing food availability, agriculture can contribute with other policy measures to reducing food prices in the market, enabling greater access to food and micronutrients. By lowering commodity prices, subsidies help to increase the purchasing power of large numbers of small farmers, which should lead to increased demand for non-staples food and off-farm goods and services, boosting local labor demand and wages and improve people's nutrition (Chirwa and Dorward 2013). At the level of the individual farm household, the food price effect would occur as a feedback from changes generated by an input subsidy at an aggregated scale of production and market supply.

Pathway 4 has positive effects on dietary quality for both children and adults in the household. More interesting, the effects of women's empowerment on dietary diversity and dietary intakes of adults are becoming increasingly significant (Sraboni and Quisumbing 2018). A paper by Ruel et al. (2013) suggests that women's participation in agriculture improves their empowerment, thereby affecting their control over household assets, their decision-making power regarding household resource allocation, and their social status in the community, which ultimately leads to improved nutritional outcomes. Another paper by Jones et al. (2012) shows that changes in household income can affect women's workload, nutrition, and the time they allocate to childcare, which, in turn, can affect children's nutrition through child-care practices. An impact assessment in Nepal by Malapit et al. (2013) indicates that improving the decision-making power of women in production significantly improves the nutritional status of mothers and children.

Changes in farm assets and fertilizer use can also affect the quality of women's diets, with implications for child nutrition through women's empowerment. As noted by Ruel et al. (2013), the links between changes in agricultural productivity and nutritional outcomes are often influenced by women's decision-making power within the household.

Not all of the research consulted above demonstrated a positive relationship between agriculture and nutrition. Some research has found a few or adverse linkages between nutritional outcomes and agriculture. Headey

et al. (2011) examined the link between agricultural growth and nutrition during the period 1992–2005 in India. They found that despite the positive correlation in some states between agriculture and nutrition, overall nutritional improvements could not be explained by agricultural growth. Masset et al. (2012) reviewed 23 studies from developing countries and found positive effects on agricultural production, unclear effects on overall dietary intake, and little evidence of improved nutritional outcomes for children under five years old. However, the authors argue that the inadequate analytical approaches of many studies limit the conclusiveness of these findings.

Although Ruel et al. (2013) emphasize the importance of promoting agricultural production, keeping prices low and increasing incomes, they recognize the weak evidence supporting the link between nutritional outcomes and agricultural programs. They attribute this weakness to the quality of the evaluations. Some authors have noted the perverse effects of women's empowerment in agriculture. The workload is associated with low birth weight and size in children born to mothers engaged in agricultural work during pregnancy (Herforth 2012).

Our comprehension of this literature leads us to summarize the main linkages between fertilizer subsidies and
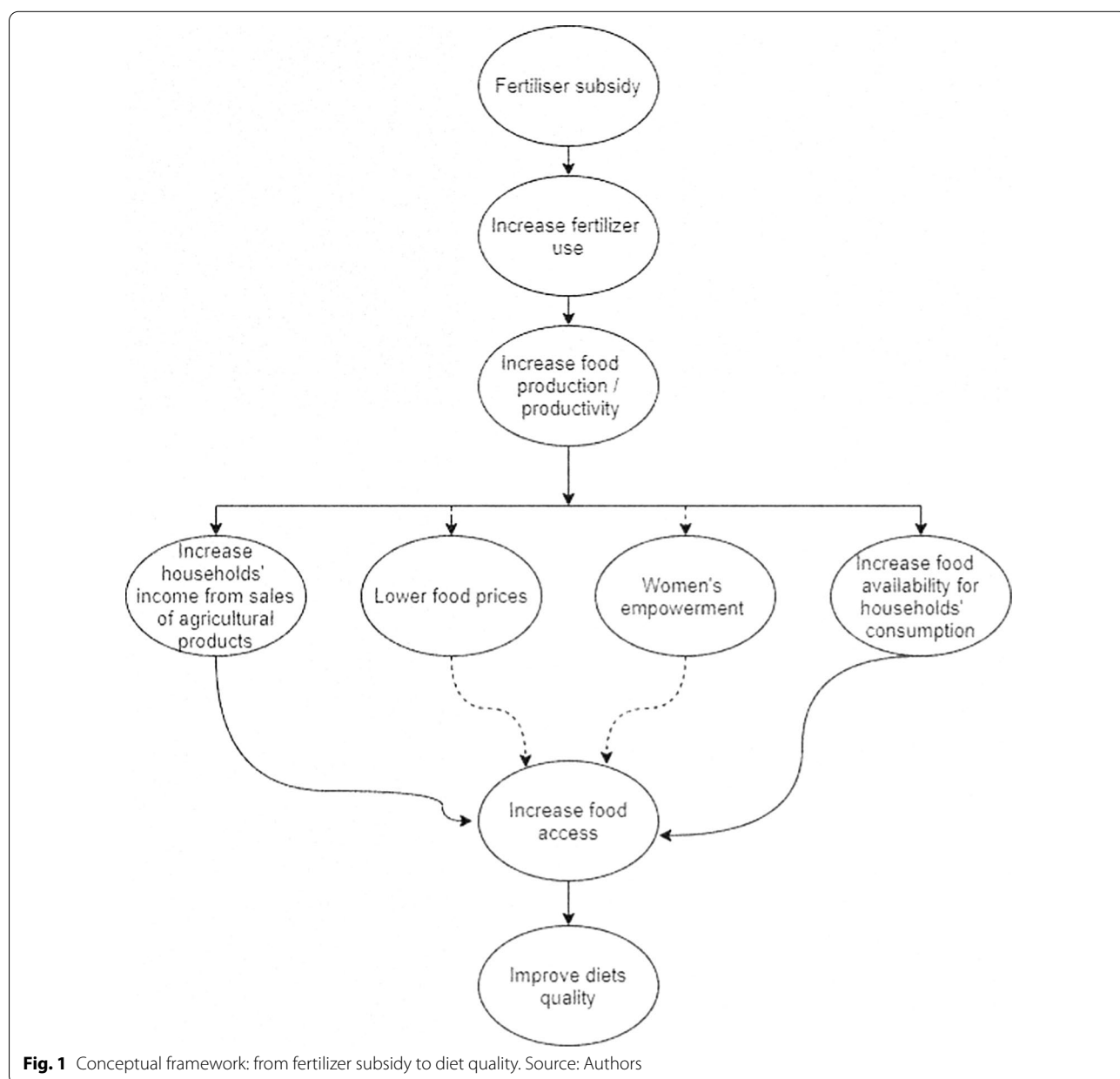


**Fig. 1** Conceptual framework: from fertilizer subsidy to diet quality. Source: Authors

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diet quality as in Fig. 1. A fertilizer subsidy may directly increase access to and use of fertilizer, raising agricultural productivity (production per ha) and overall food production on the farm. If the increased production or productivity is generated among food staples, it may lead to greater availability of food (and especially calories) for the household and household members. Higher caloric consumption on farms from larger harvests of food staples improves energy intake but not necessarily diet quality. Increased cereal harvests may also be commercialized, contributing to a broader range of products or more nutritious foods accessed through market purchases.

Though the history of the program in Mali is long (Koné et al. 2019; Theriault et al. 2018), the current policy was established in the aftermath of the global food and financial crises of 2008 (Smale et al. 2011). The new program began with a focus on rice as the target cereal crop. Today, in addition to the main cereal crops or rice and maize, the program includes sorghum and millet at a lower rate of subsidization. Cotton was subsidized at the time of this research. All Malian producers are eligible for the subsidy program if they cultivate at least one of the target crops.

Indirectly, they may provide incentives to farmers to produce a diversity of food crops, including vegetables, fruits, or even livestock that households can consume. In this pathway, subsidy effects on production for own consumption can reinforce linkages between cropping patterns on farms and diet quality.

## Methods
### Data
In 2018, a team of researchers from the Institute d'Economie Rurale and Michigan State University conducted a farm household survey to assess the impacts of the fertilizer subsidy program. We use data from this survey.

The sample was drawn from a baseline census of households in 120 villages located in two agro-ecological zones: (i) Koutiala Plateau mainly based on cotton, maize, and sorghum production system; and (ii) Niger Delta mostly oriented toward irrigated rice production system. Twenty farm families were randomly selected for interview in each sampled village. The total sample included 2400 households. The data were weighted by the inverse of the probability of selection to ensure the statistical representativeness of the sample. Village level surveys were also undertaken in all the communities. Data details are provided in Haggblade et al. (2017).

The household surveys included demographic characteristics, household and farm assets, economic activities, farming, and non-farming income. In addition, the survey questionnaires covered several other modules

including a section on dietary diversity, a section on the use of fertilizer (subsidized or not subsidized), and a section on production as well as plot size measurement with GPS. All women of reproductive age in each household responded to the questionnaire on dietary diversity, constituting a total sample of 5930 women, including 2486 women in the Niger Delta and 3444 in the Koutiala plateau. The team used a multi-visit survey to collect data in four field visits using computer-assisted personal interview (CAPI) methods. The first visit took place from September 26 to October 21, 2017. This round collected data on households' characteristics and sown plots. The second phase took place from December 11, 2017, to February 1, 2018, and covered data collection on planting and weeding. During the third visit, which took place from March 15 to May 25, 2018, the survey team collected data on production. The fourth visit, from July 7 to August 22, 2018, collected commercialization and diet diversity data. The team also collected data on diet diversity, during the harvest season, from February to March 2019, from a sub-sample of 1087 women. The survey questionnaires were programmed on tablets using CSPro software. Data were converted into STATA format for cleaning and analysis.

### Econometric strategy
Although randomized controlled trials (RCTs) are the most robust impact assessment method because they eliminate selection bias (Imbens and Wooldridge 2009), their application was impossible in the subsidized fertilizer program for ethical and logistical reasons. In the absence of such an approach, differences in the intrinsic characteristics of participants may lead to self-selection. Because of this endogeneity, simple comparisons across program beneficiaries and non-beneficiaries are not able to distinguish effects produced by the subsidy program and changes due to initial differences.

Various methods have been used to address the question of endogeneity with cross-sectional data (Imbens and Wooldridge 2009). These include the class of treatment effect models known as propensity matching score (PSM). Propensity score matching is one of the most used econometric methods for constructing an appropriate counterfactual group to assess program impacts with non-experimental data. This technique has been applied in numerous contexts, including agriculture, to determine the effects of agricultural interventions. We use matching models to test the empirical link between the subsidy and nutrition outcome variables. Rosenbaum sensitivity analysis was applied to test the robustness of results.

## Average treatment effects

The main objective of the analysis is to estimate the average treatment effects of fertilizer subsidies on women's dietary diversity scores.

Let $Y_i$ (1) represents the potential outcome of individual i with participation in the fertilizer subsidy program and $Y_i$ (0) without participation. The dummy variable, $D_i \in \{0,1\}$ equal to 1 if individual *i* is treated, that is to say, one with participation in fertilizer subsidy program and 0 otherwise, and $X_i$ denotes a vector of covariates that denotes household, individual and farm characteristics. Assuming that women's diets quality is a linear function of the vector of covariates $X_i$, and the treatment dummy variable $D_i$, the impact model, can be specified as:

$$Y_i = \alpha D_i + \beta X_i + \varepsilon \tag{1}$$

$\alpha$ represents a change in outcome $Y_i$ due to participation in the subsidy program and $\varepsilon$ is the error term.

Estimating the effect ($\alpha$), in Eq. (1) using ordinary least squares assumes that participation in the subsidy program is random while it is not. Hence, we are confronted with the problems of counterfactual or potential selection bias. As a solution, we employ a propensity score model developed by Rosenbaum and Rubin (1983) to find comparable participating and nonparticipating farmers based on the set of covariates such as women, and household characteristics. The propensity score is estimated with logistic regression.

For each individual *i*, we observe {$X_i$, Di, $Y_i$}, where $Y_i = Y_i$ (0) if $D_i = 0$ and $Y_i = Y_i$ (1) if $D_i = 1$. We observe the outcome from participating $Y_i$ (1) or not participating $Y_i$ (0), but cannot observe the outcome from both participation regimes. What we can observe is given by the following equation:

$$Y_i = D_i Y_i(1) + (1 - D_i) Y_i(0) \tag{2}$$

One of the key assumptions of the propensity score method is the conditional independence assumption (Rosenbaum and Rubin 1983). This assumption implies that selection bias can be controlled if there is a set of observable variables conditionally to which treatment assignment independence can be verified. The common support or overlap assumption is the second key assumption. This assumption ensures that individuals in the treatment and control groups are sufficiently alike to allow meaningful comparisons. Assuming the conditional-independence assumption holds, and the overlap condition satisfied, the average treatment effect (ATE) is identified as:

$$ATE = E[Y_i(1) - Y_i(0)]. \tag{3}$$

Different matching approaches can be used to match the units of the control group with the units of the treatment group. These approaches include nearest-neighbour matching, radius matching, and kernel-based matching. Nearest-neighbour matching is a matching procedure in which units of the control group are matched to units in the treatment group based on the nearest propensity score distance. The nearest-neighbour matching has the advantage of producing more accurate estimates; however, it has the challenge of good matching. Radius matching provides a tolerance level by specifying a maximum propensity score distance or caliper for matching. In kernel-based matching, matching is achieved with an inversely proportional weighting of the propensity scores that gives the highest weightings to the control group units with a lower propensity score distance (Heckman 1998). The Gaussian kernel matching uses all the available information of the control group units, which reduces the variability of the estimators. When the common support condition is satisfied, the kernel match provides more robust estimates because of the lower variance resulting from the use of more information. Given the problem of poor matching with the nearest-neighbour matching and the difficulty in determining a proper radius for radius matching, this study adopts the Gaussian kernel matching approach.

## Sensitivity analysis

Since the matching methods are based on observable characteristics, the analysis of the sensitivity of the matching estimates to determine how robust they are to the unobserved factors has become important in the literature (Becker and Caliendo 2007). The Rosenbaum Boundary Method (Rosenbaum 2002) was performed here. Following Rosenbaum (2002), the ratio of the odds that a treated case *i* has the unobserved factors to the odd that the control case *j* has same factors is defined by

$$\frac{P_i}{P_j} * \frac{1 - P_j}{1 - P_i} = exp[\gamma(u_i - u_j)] \tag{4}$$

where $P_i$ and $P_j$ are treatment probabilities, and $u_i$ and $u_j$ are an unobserved covariate for the two individuals. $\gamma$ is the effect of unobserved covariate on the treatment selection.

If $u_i - u_j = 0$, or $\gamma = 0$, the unobserved variable is the same for the treatment and the control. That is to say, the unobserved variable has no influence on the probability of treatment then $exp[\gamma(u_i - u_j) = 1$, suggesting that there is no hidden bias due to unobservable variables.

Let us set $\Gamma = exp(\gamma)$. The Rosenbaum (2002) bounds on the odds ratio are then defined as:

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$$\frac{1}{\Gamma} < \frac{P_i}{P_j} * \frac{1-P_j}{1-P_i} < \Gamma$$

The Rosenbaum bounds method computes the confidence intervals of the outcome variable for different values of Γ using the matching estimates. If the smallest value of Γ for which the confidence interval contains zero is less than two, the effect of the estimated treatment is sensitive to unobservable (Becker and Caliendo 2007).

### Outcome variables

The outcome of interest in this analysis is the Women's Dietary Diversity Score (WDDS). The WDDS assesses the variety of foods consumed by women within households. The WDDS allows us to focus on the individual level of access to food, especially women, whose nutrient needs are greater during pregnancy and breastfeeding (FAO, Who 2004), and whose role in the preparation of meals and feeding children is crucial, indicating that their nutritional status is important for the well-being of the entire household. WDDS is a quantitative variable that counts the number of food groups out of a total of nine that each woman of reproductive age reported consuming in the last seven days prior to the survey (Martin-Prevel et al. 2015). Food items consumed over the seven-day recall period are grouped into the following nine food groups: (1) starchy staples; (2) dark green leafy vegetables; (3) other vitamin A-rich fruits and vegetables; (4) meat, poultry, and fish; (5) other fruits and vegetables; (6) dairy; (7) eggs; (8) organ and (9) pulses, nuts and seeds.

Using data on the source of each food consumed, we calculated the WDDS by source: ownWDDS for own production, purchaseWDDS for purchases and gift-WDDS for gifts or food aid. This decomposition of WDDS by food source enables us not only to assess the pathway through which fertilizer subsidies affect the quality of women's diets but also to assess the impact of fertilizer subsidies on the vulnerability of households to food insecurity. The approach also provides insight into food access as measured by purchased food relative to the consumption of food gifts. Given that the statistical unit in this study is the household, we have transformed the original dietary diversity scores of women at the individual level by computing the average across women's scores within each household.

### Independent variables

There is no rule in the selection of independent variables to include in propensity score matching. However, we can find some recommendations in the literature. The recommendations suggest that the variables that simultaneously influence the treatment and the outcome variable should be included in the model to satisfy the conditional

**Table 1** Independent variables (mean for treated and control)

| Variable | Description | Treated | Control | p-value |
|---|---|---|---|---|
| Age | Woman age (years) | 32.91 | 32.17 | 0.03 |
| Distbitumee | Distance to paved road (m) | 15.43 | 18.28 | 0.00 |
| Distmarket | Distance to market (km) | 8.39 | 10.60 | 0.00 |
| Areaeaf | Land cultivated (ha) | 11.53 | 13.40 | 0.00 |
| Children | Number of children | 8.54 | 9.07 | 0.00 |
| Localmarket | Weekly market (dummy) | 0.30 | 0.27 | 0.00 |
| Plotage | Plot age (years) | 19.57 | 17.81 | 0.00 |
| Familysize | Family size | 18.39 | 19.22 | 0.00 |
| Edugerant | Education of plot manager | 1.82 | 1.13 | 0.00 |
| Agegerant | Age of plot manager (years) | 44.76 | 42.70 | 0.00 |
| Ltransfert | Transfer income (FCFA) | 3.41 | 3.59 | 0.21 |
| Nonfarminc | Non-farm income (FCFA) | 6.90 | 7.55 | 0.00 |
| Headeaf | Plot manager is head's household (dummy) | 0.61 | 0.50 | 0.00 |
| Farminc | Farm income (targeted crops) (FCFA) | 12.81 | 11.46 | 0.00 |
| Allcropsaleskg | Total crops soled (kg) | 22.41 | 19.39 | 0.03 |
| Disthealthcter | Distance to health center (km) | 2.03 | 2.36 | 0.02 |
| Memberop | Cooperative membership (dummy) | 0.88 | 0.82 | 0.00 |
| Bicycle | Number of bicycles | 3.09 | 2.78 | 0.00 |
| Motobike | Number of motorbikes | 1.80 | 1.73 | 0.05 |
| Depratio | Dependency ratio | 0.50 | 0.51 | 0.02 |

Source: Authors, from data collected by IER/MSU in 2017–18

**Table 2** Summary statistics for woman's diets quality

| Variable | Obs | July 2018 | | February 2019 | | p-value |
|---|---|---|---|---|---|---|
| | | Mean | Std. dev | Mean | Std. dev | |
| WDDS | 1087 | 4.32 | 1.51 | 5.61 | 1.44 | 0.000 |
| ownWDDS | 1087 | 2.99 | 1.41 | 2.70 | 1.66 | 0.000 |
| purchaseWDDS | 1087 | 1.99 | 1.66 | 2.73 | 1.76 | 0.000 |
| giftWDDS | 1087 | 0.32 | 0.68 | 0.27 | 0.70 | 0.1000 |

Source: Authors, from data collected by IER/MSU in 2017–18

independence assumption. In addition, the model should always include variables that are not correlated to treatment but correlated with the outcome. The addition of these variables in the model allows a gain of precision in the estimated treatment effects (Caliendo and Kopeinig 2008).

The independent variables that were selected based on these recommendations are summarized in Table 1, along with their summary statistics. Drawing from previous literature, control variables included three levels of analysis. At the individual level, we included women's age, education and membership in a cooperative. These variables play an important role in access to information, meaning that they strongly affect participation in the subsidy program and dietary diversity of food consumption. At the household level, variables include: the status of plot manager, family size, number of children, dependency ratio, non-farm income, transfer income, farm income from sales of targeted crops, quantity of sales of all crops, total farm size, plot age and transport equipment owned (bicycle and motorbike). These factors have direct effects on households' decisions to participate in the subsidized fertilizer program, treatment, and on their food consumption patterns. Based on the conditional independence assumption, we included these variables in the model because they simultaneously affect participation decision and the outcomes. Community level variables include distance to the nearest market, distance to paved road, distance to the nearest health center, and whether a weekly market is available within the community. These variables capture the role of the village level infrastructure in enhancing households' diets quality (Table 1).

## Results
### Descriptive statistics
Table 2 summarizes the results from bivariate analysis for key variables during lean and post-harvest seasons. The results show that the difference between the postharvest and the lean seasons is statistically significant for all variables except for gifts. In Mali, in a typical year, the lean season runs from June to August and the post-harvest period extends from September to May. The mean WDDS was slightly more than four while during the lean season while it was more than five during the post-harvest season. The average of ownWDDS is 2.99 during the lean season and 2.70 during the harvest period, which means that during the lean period, households consume more food from their own production. The same goes for gifts with average values of 0.32 during the lean season and 0.27 during the post-harvest season. In contrast, consumption of purchased food increases during the post-harvest season, rising from 1.99 during the lean period to 2.73 on average after harvest.

With regard to WDDS components, purchased food constitutes the most important source of women's diets in the harvest season while own production is the most important source during the lean season. We observe significant differences between the two seasons, with the average scores for WDDS being lower during the lean season. By breaking down the dietary diversity score of women according to the food source, we note that, unlike on-farm production that is important in women's diets during the lean season, women obtain most of their diets from food purchased on markets during the harvest season. This was expected as farm incomes are more likely to increase during harvests allowing farmers to have more money to spend on non-staple foods. It also suggests that market purchases literally expand the food basket, as suggested by seasonal pattern in the WDDS.

The results contrasted between the agroecological zones concerning the WDDS (Table 3). The difference between seasons in the two zones is statistically significant a 1% level. The women of the Koutiala plateau appear to have lower dietary diversity score as compared to their counterparts in the Niger Delta, regardless of the season considered. The difference between the harvest and lean seasons is more marked for the women of the Koutiala plateau, who lose an average of 1.55 dietary diversity score while those of the Niger delta lose only 0.91 during the lean season.

**Table 3** Summary statistics for woman's diets quality by zone

| Zone | Obs | July 2018 | | February 2019 | | p value |
|---|---|---|---|---|---|---|
| | | Mean1 | Std. dev | Mean2 | Std. dev | |
| All zones | 1087 | 4.32 | 1.51 | 5.61 | 1.44 | 0.000 |
| Koutiala Plateau | 632 | 3.95 | 1.42 | 5.50 | 1.45 | 0.000 |
| Niger Delta | 455 | 4.84 | 1.49 | 5.75 | 1.42 | 0.000 |

### Econometrics results: average treatment effects

Table 4 presents the results of the average treatment effects of the fertilizer subsidy on the WDDS, own-WDDS, purchaseWDDS, and giftWDDS.

Effects of subsidized fertilizer on Woman's Dietary Diversity Score (WDDS) differed by agro-ecological zone. In the Niger Delta, the average treatment effect of subsidized fertilizer on WDDS is positive and statistically significant at 5% level, meaning that participating in the subsidized fertilizer program improves overall dietary diversity score. At the same time, subsidized fertilizer is negatively associated with WDDS in the agro-ecological zone of the Koutiala Plateau, suggesting that subsidized fertilizer may negatively affect women's diet quality outcomes in this area (Table 4).

On average, women's dietary diversity scores from food gifts are negatively associated with participation in the subsidy program in Niger Delta. Thus, participants in the program rely less on food gifts for a diverse diet. This result suggests that the subsidy program improves household resilience to food insecurity in that zone, as indicated by the diet of women of reproductive age in the household. Conversely, we fail to detect a linkage between subsidized fertilizer effect and women's dietary diversity from food gifts in the Koutiala Plateau.

The average treatment effect, ATE, of women's dietary diversity from food sources on the farm is negative but not statistically significant in either of the two agro-ecological zones, leading to some uncertainty about the own production pathway from subsidized fertilizer to diet quality.

In the agro-ecological zone of Niger Delta, the ATE of subsidized fertilizer on Women's Dietary Diversity Score from purchased food is positive; on the Koutiala Plateau, it is negative. Both effects are statistically significant. This result tells us that different pathways are at work with respect to market participation and food security in the two agro-ecological zones.

### Robustness checks and sensitivity analysis
#### Balancing quality

The key concept of the matching methods is that of conditional independence assumption, which states that there are no differences between the treatment and

**Table 4** Average treatment effects

| Outcomes | Niger Delta | Koutiala Plateau |
|---|---|---|
| WDDS | 0.228** | −0.143** |
| ownWDDS | −0.044 | −0.014 |
| purchaseWDDS | 0.410** | −0.145** |
| giftWDDS | −0.204** | 0.036 |
| N (Treated) | 708 | 1122 |
| N (Untreated) | 346 | 504 |
| N (total) | 1054 | 1626 |

Source: Authors, from data collected by IER/MSU in 2017–18
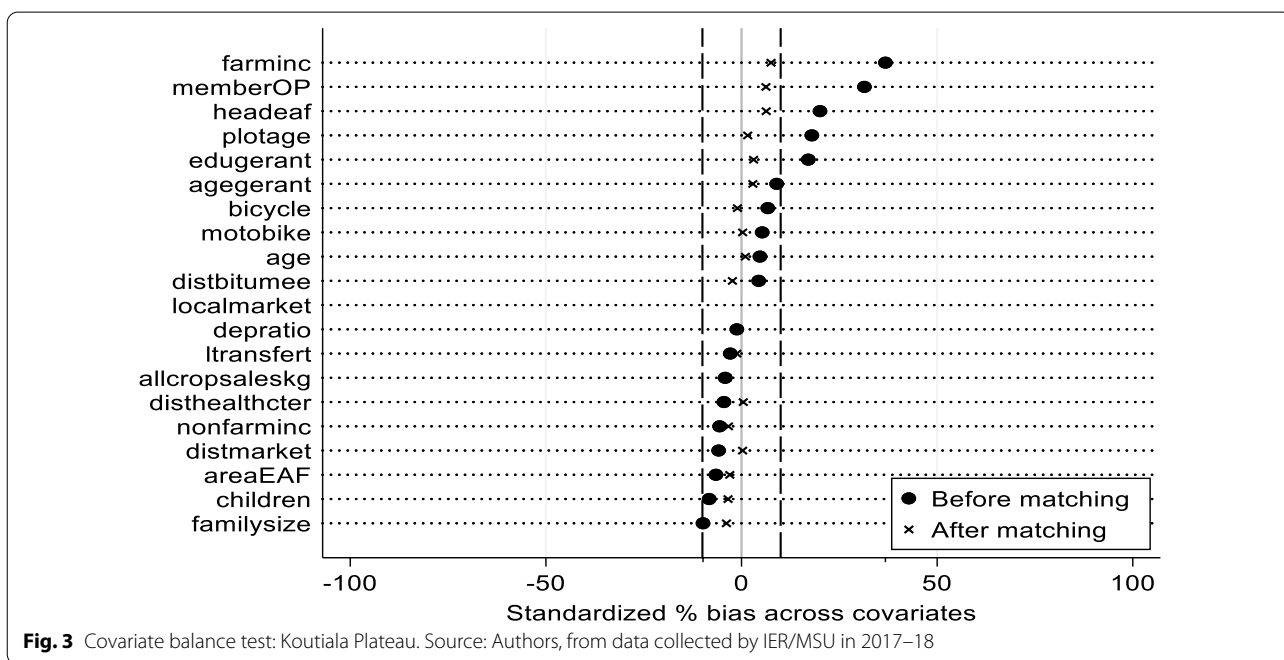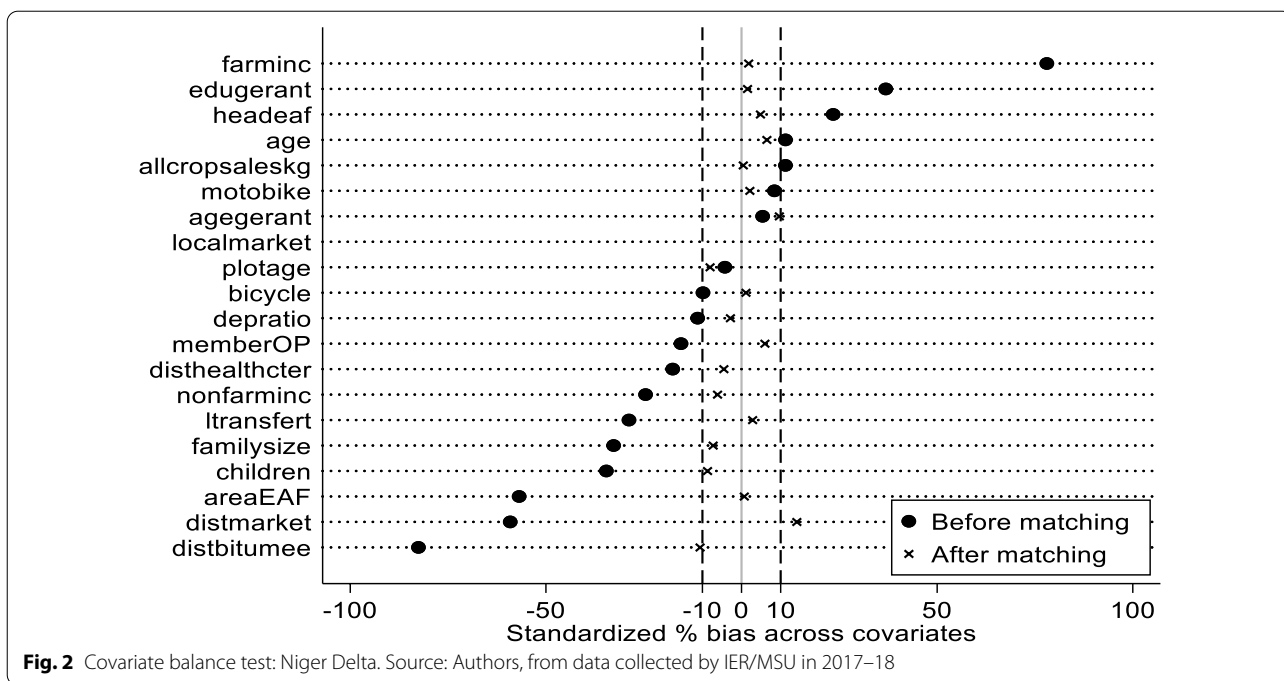
*$p < 0.10$, **$p < 0.05$, ***$p < 0.001$

control groups, conditional on the observed covariates. Therefore, the first step in using matching methods is to diagnose the quality of matching through the covariate balance in the matched groups. The graphical results of the balance test are reported in Figs. 2 & 3 (performed with pstest in STATA). Figures 2 & 3 suggest that we achieve good balance after matching by reducing the percentage of balance bias up to more than 90% overall. After matching, we found no statistically significant difference between the means of all model covariates; this is to say, propensity score matching balanced covariate variables.

#### Overlap condition

To investigate the validity of the estimated effects, we verified the common support or overlap condition. As shown in Figs. 4 & 5 (generated with psgraph in STATA), the probability of participating in subsidized fertilizer program knowing the observed covariates lies between 0 and 1. This means that participants with the same covariate values have a positive probability of being both participants and non-participants, suggesting that the common support condition is fulfilled. To ensure this, we trimmed the data by removing the observations that fell outside the common support region.

#### Propensity score

Table 5 in the appendix shows the logistic regression estimates used to compute propensity scores for matching. Overall, the model fits the data well. The McFadden
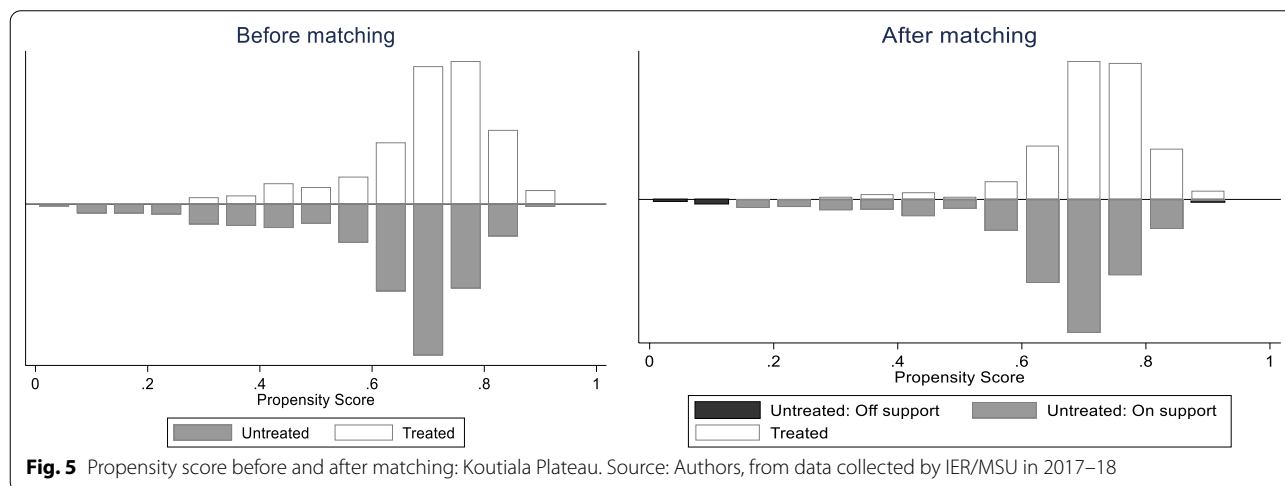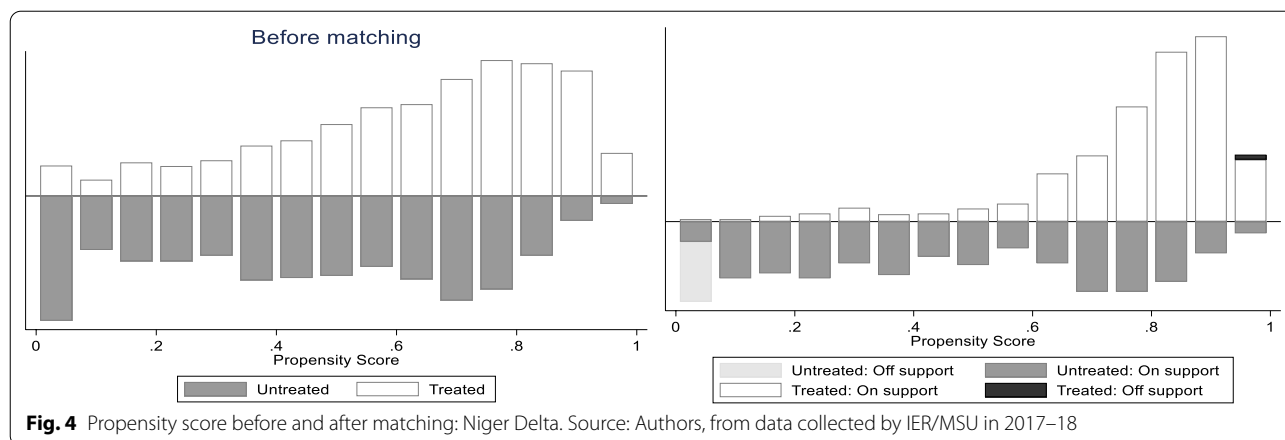
**Fig. 2** Covariate balance test: Niger Delta. Source: Authors, from data collected by IER/MSU in 2017–18



**Fig. 3** Covariate balance test: Koutiala Plateau. Source: Authors, from data collected by IER/MSU in 2017–18

pseudo $R^2$ of 27% indicates that we can reject the hypothesis that all coefficients are equal to zero at the 5% percent level of significance. Distance to infrastructure (market, paved road), number of children in the household, and value of non-farm income are negative and significant, which indicates that these decrease the likelihood of treatment (use of subsidized fertilizer). The

probability of treatment rises with the education of plot manager, dependency ratio, and farm income.

### Sensitivity analysis

Tables 6 and 7 indicate the critical values for which the gamma is the lowest with a confidence interval containing zero for each outcome. The tables show

**Fig. 4** Propensity score before and after matching: Niger Delta. Source: Authors, from data collected by IER/MSU in 2017–18



**Fig. 5** Propensity score before and after matching: Koutiala Plateau. Source: Authors, from data collected by IER/MSU in 2017–18

that the gamma for which the overall women's dietary diversity score is the lowest with zero in the 95% confidence interval is 1.4 in Niger Delta and 1.2 in Koutiala Plateau. For the dietary diversity score related to purchased food, the lowest gamma with zero in the 95% confidence interval is 1.6 in Niger Delta and 1.4 in Koutiala Plateau. For the dietary diversity score based on purchased food, we will begin questioning the estimated impact when the difference in odds of individuals with the same observed characteristics differ by 60% in Niger Delta and by 40% in Koutiala Plateau. The lowest value of gamma producing a 95% confidence interval containing zero for the dietary diversity score based on gift food is much higher, reaching 3.2 in the Niger Delta. These values suggest that the unobserved characteristic would have to increase the odds ratio by around 40% and 20% before we being to question the estimated impact on the overall dietary diversity in Niger Delta and Koutiala Plateau (respectively). The

critical value of gamma for the dietary diversity score based on food received as gifts implies that the treatment effects are more robust to hidden bias from unobserved characteristics relative to the overall dietary diversity score and the dietary diversity score based on purchased food. However, the degree of sensitivity for these two outcomes falls within the range of acceptable degree of sensitivity reported in the literature (Aakvik 2001; Becerril and Abdulai 2010) (Table 7).

## Discussion
Descriptive statistics indicate significant differences in the dietary quality of women in farm households of Mali between seasons, with lesser extent of consumption during the lean season. Regarding the components of the dietary diversity score, while the dietary diversity resulting from own production is greater during the lean season, that resulting from the purchase is greater during the post-harvest season. One reason may be that the lack of financial means during the lean season prevents

**Table 5** Logit regression for computing propensity scores results

| Variables | Niger Delta | Koutiala Plateau |
|---|---|---|
| Age | 0.010 | 0.003 |
| Distbitumee | −0.038[***] | 0.003[*] |
| Distmarket | −0.038[**] | −0.01 |
| Areaeaf | −0.047[***] | −0.019[*] |
| Children | −0.096[*] | 0.017 |
| Localmarket | 0.000 | 0.000 |
| Plotage | −0.007 | 0.012[**] |
| Familysize | 0.040 | −0.028 |
| Edugerant | 0.066[**] | 0.073[**] |
| Agegerant | 0.001 | 0.004 |
| Ltransfert | −0.014 | −0.006 |
| Nonfarminc | −0.043[***] | −0.008 |
| Headeaf | 0.236 | 0.145 |
| Farminc | 0.473[***] | 0.093[***] |
| Allcropsaleskg | −0.001 | −0.001 |
| Disthealthcter | −0.011 | −0.015 |
| Memberop | −0.212 | 1.239[***] |
| Bicycle | −0.012 | 0.050[*] |
| Motobike | 0.146 | 0.144[**] |
| Depratio | 1.630[*] | 0.267 |
| _cons | −5.074[***] | −1.895[**] |
| McFadden pseudo $R^2$ | 0.268 | 0.057 |
| N | 1333 | 1626 |

Source: Authors, from data collected by IER/MSU in 2017–18

[*] $p < 0.10$, [**] $p < 0.05$, [***] $p < 0.001$. Dependent variable is receipt of subsidized fertilizer

**Table 6** Rosenbaum bounds sensitivity analysis for the main outcomes, Niger Delta

| Outcome variables | Gamma | CI+ | CI− |
|---|---|---|---|
| WDDS | 1 | 0.217 | 0.328 |
| | 1.2 | 0.156 | 0.633 |
| | 1.4 | *−0.112* | *0.692* |
| | 1.6 | −0.210 | 0.728 |
| ownWDDS | 1 | −0.141 | 0.015 |
| | 1.2 | −0.275 | 0.088 |
| | 1.4 | −0.398 | 0.194 |
| purchaseWDDS | 1 | 0.289 | 0.526 |
| | 1.2 | 0.093 | 0.662 |
| | 1.4 | 0.002 | 0.839 |
| | 1.6 | *−0.069* | *0.970* |
| | 1.8 | −0.213 | 1.014 |
| | 2 | −0.335 | 1.072 |
| giftWDDS | 1 | −0.466 | −0.422 |
| | 3 | −0.573 | −0.007 |
| | 3.2 | *−0.578* | *0.009* |
| | 3.4 | −0.582 | 0.022 |

Source: Authors, from data collected by IER/MSU in 2017–18

In italic, the critical values for which the gamma is the lowest with a confidence interval containing zero

**Table 7** Rosenbaum bounds sensitivity analysis for the main outcomes, Koutiala Plateau

| Outcome variables | Gamma | CI+ | CI− |
|---|---|---|---|
| WDDS | 1 | −0.10815 | −0.01207 |
| | 1.2 | *−0.46485* | *0.013484* |
| | 1.4 | −0.47451 | 0.027194 |
| ownWDDS | 1 | −0.06283 | −0.05218 |
| | 1.2 | −0.06858 | −0.04416 |
| | 1.4 | *−0.07762* | *0.05127* |
| | 1.6 | −0.09938 | 0.417201 |
| purchaseWDDS | 1 | −0.27474 | −0.25001 |
| | 1.2 | −0.29599 | −0.23023 |
| | 1.4 | *−0.33232* | *0.142029* |
| | 1.6 | −0.67277 | 0.19666 |
| giftWDDS | 1 | −0.34553 | 0.1392 |
| | 1.2 | −0.34865 | 0.143183 |
| | 1.4 | −0.34973 | 0.145231 |

Source: Authors, from data collected by IER/MSU in 2017–18

In italic, the critical values for which the gamma is the lowest with a confidence interval containing zero

women from consuming certain purchased food items. These results are consistent with previous studies in the Sahel region. For example, in Burkina Faso, Savy et al. (2006) found that the lack of financial means during the lean season resulted in a decrease in the consumption of purchased food.

The regression from propensity score matching reveals a positive effect of subsidized fertilizer on the nutritional outcomes of farm households in the Niger Delta, in line with other studies on of input subsidies in sub-Saharan Africa (Smale et al. 2020; Snapp and Fisher 2014; Harou 2018; Wiredu et al. 2015). In Malawi, Harou (2018) found that children under five who lived in households that benefited from the subsidy had higher weight-for-age, weight-for-length and body mass index than those in non-beneficiary households. Wiredu et al. (2015) found a positive impact of subsidized fertilizer on the food security of rice smallholders in northern Ghana and suggested additional policy actions to stabilize food security. Snapp and Fisher (2014) found a positive impact resulting from greater commercialization of maize on household dietary diversity scores in Malawi. Smale et al. (2020)

found a positive effect on the likelihood that women would attain the minimum adequate dietary diversity threshold.

The innovation of this study lies in the fact that the overall dietary diversity score is broken down according the food supply source—an approach which we have not found in previously published literature. We have differentiated the overall score according to whether the food was obtained on the farm, from market purchase, or from gifts. This allows us to better understand the effects of subsidized fertilizers as well as the influence of contextual factors such as the role of the market, farming system and social networks on changes of dietary diversity score.

In contrast to the findings for the Niger Delta, we found a negative association between subsidized fertilizer and women's dietary diversity scores in the Koutiala Plateau. This seemingly surprising result appears to be consistent with results of previous studies conducted in this region of Mali regarding the "Sikasso Paradox." The paradox is that despite long-term, substantial investments in rural development related to the cotton value chain in this region, poverty and malnutrition persist. Examining the impact of cotton cultivation on the living conditions of households in Mali and Burkina, Mesple-Somps et al. (2008) showed that households in Mali's cotton zone spent much less on food, with unfavorable nutritional outcomes, while at the same time, they seemed much better equipped in terms of durable goods. In their analysis of the linkages between child nutrition and agricultural growth, Tefft and Kelly (2004) found that women in the irrigated rice zone had better access to income and control over their incomes than their counterparts in the cotton zone, where the income is concentrated in the hands of the household head. Plot-level information in our survey data show that women are nearly as likely as men to manage rice plots, but rarely manage cotton plots. Under customary norms, managing a plot is associated with controlling revenues from the plot. Published evidence demonstrates that access to and control over household resources by women is a major contributor to improving the nutritional outcomes of women and their children. Tefft and Kelly (2004) found that the nutritional status of children under four years of age was better in the irrigated rice zone than in the cotton zone. More recently, Cooper and West (2017) studied agricultural change and malnutrition in the cotton zone of Sikasso. Although they found little evidence of association between nutritional outcomes and cotton cultivation at the household level, they did find a negative association between cotton cultivation and nutritional outcomes at the village level.

Women's dietary diversity score from own production is negative in sign in both zones but not statistically significant in either. This indicates that though fertilizer subsidies may increase staple crop production like rice, they do not provide enough incentive for farmers to produce a variety of nutritious food and improve the quality of their diet. In fact, the subsidy may reduce cultivation of crops not targeted by the subsidy—a point which merits further research attention. When policy interventions aim to increase the production of staple foods, they may affect the amount of energy available but not necessarily the diversity of food groups consumed, micronutrient consumption, or diet quality.

At the same time, women's dietary diversity score sourced from purchased food is positive in the Niger Delta but negative in the Koutiala Plateau and statistically significant in both zones. These findings underscore the important role that the market plays in changes in women's dietary diversity score and are consistent with the literature on the linkages between agriculture and nutrition outcomes. Results show the importance of income and the involvement of the market as mediators between fertilizer subsidies, production and consumption, and the nutritional outcomes. Clearly, these mediators work differently within farm households located in the two agroecological zones.

Another key result of this study is the fact that women's dietary diversity scores from gift food negatively correlates with subsidized fertilizer in Niger Delta, suggesting that fertilizer subsidy may improve the farm household's resilience to food insecurity in that region. In the Koutiala Plateau, the sign is positive on food received as a gift but the coefficient is not statistically significant.

Like all studies based on cross-sectional, observational data, this study has some limitations. The endogeneity issue or selection bias limits the causal effects inferences of the matching technique, which relies on observed covariates. To address this, a sensitivity analysis was conducted to test the stability of the results. Another limitation of this study is the fact that we constructed women's dietary diversity scores based on 7-day recall as compared to direct measurement—the main challenge being the measurement error since we do rely on the memory of respondents. Finally, our data do not enable us to test either pathway 3 (prices) or pathway 4 (women's empowerment). We have focused on pathways 1 and 2.

## Conclusion

Little evidence exists concerning the effects of fertilizer subsidies on diet quality in the households of smallholder farmers who participate in these programs. This analysis contributes to the literature by providing relevant evidence on the effects and pathways that link subsidized fertilizers to diet quality of farm households. The analysis was conducted in the specific context of irrigated rice and cotton cultivation zones of Niger Delta and Koutiala Plateau in Mali.

Taking into account the nature of the data used in this study, which are non-experimental, we applied propensity score matching methods to account for the issue of endogeneity in investigating the effects of subsidized fertilizer on the quality of the diet of farm households. For robustness checks, we also performed a sensitivity analysis to test the stability of the results. Disaggregation of the dietary diversity score was made possible by data collected on the source of each food item consumed. Examining the effects of subsidized fertilizer on household dietary diversity using the food source categories of own production, food purchases and gifts enabled a better understanding of the relative importance of the pathways linking fertilizer subsidies and household dietary diversity.

The study reveals some differences in pathways across the two study zones. We found that the average treatment effects on women's overall dietary diversity and women's dietary diversity from purchased food are significant and positive in Niger Delta, indicating that subsidized fertilizers have positive effects on the diversity of women's overall diets through the income pathway. Conversely, we found a negative association between women's overall dietary diversity and women's dietary diversity from purchased food in Koutiala Plateau. However, in neither of the two zones was pathway 1 (on-farm production) a significant source of changes in dietary diversity induced by the fertilizer subsidy.

Findings illuminate the relationships among production, consumption, and the market in the pathway of input subsidy impacts. Looking back to the conceptual framework, this means that an increase in production generates higher incomes through sales of agricultural products and related activities that households may (or may not) be used to purchase other nutritious foods. From the policy point of view, results suggest that any policy to improve nutrition by stimulating agricultural production should consider the specificities of each zone. These include the farming systems and the intrahousehold structure of decision-making that influences the control of men and women over resources and the income that results. Further, investments that encourage local market development by stimulating the low-cost supply of diverse, nutritious food sources could support better diet quality. Facilitating and supporting crop commercialization by women in local markets is an option. Products derived from cowpea are one well-known example in Mali. Educational programs to convey nutrition information such as the program undertaken by UNICEF with community mobilisers and support groups for mothers in the Sikasso region are also fundamental.

Another major finding of this study is the negative relationship between subsidized fertilizer and dietary diversity sourced from gift food in one of the two regions. The negative relationship indicates that participants in the subsidized fertilizer program are less dependent on gift foods.

This result is particularly important since it may signal an improvement in the self-sufficiency of households receiving subsidized fertilizers, demonstrating a potential improvement in resilience to food insecurity.

## Declarations

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