



Too much of a good thing? Evidence that fertilizer subsidies lead to overapplication in Egypt

Sikandra Kurdi, Mai Mahmoud, Kibrom A. Abay, and Clemens Breisinger

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ABSTRACT

As part of a national policy to ensure a certain level of food self-sufficiency in strategic crops, the government of Egypt subsidizes nitrogen fertilizer directly by distributing quotas of subsidized fertilizers to farmers and indirectly by subsidizing natural gas used by local fertilizer factories. The implication of this subsidy on farmers' fertilizer demand and productivity remains unknown. Using a detailed agricultural survey collected from smallholder farmers in Upper Egypt, we show that nitrogen fertilizer application rates are substantially in excess of crop-specific agronomic recommendations. We exploit eligibility criteria and other sources of variation to show that farm plots with easier access to the subsidy tend to use more subsidized nitrogen fertilizer and less phosphate fertilizer. Easier access to the subsidy increases use of total nitrogen fertilizer per unit of land, mainly because of the increase in subsidized nitrogen fertilizer. In particular, the fertilizer subsidy program in Egypt is associated with significant overapplication of nitrogen fertilizer. Such overapplication of fertilizer is expected to adversely affect soil, water, and environmental health. Our findings have important policy implications for Egypt and other African countries known for input subsidy programs. As Egypt is currently moving on from the successful implementation of a comprehensive macroeconomic reform program towards sector-level reforms, our results suggest that eliminating fertilizer subsidies is a good place to start.

Keywords: agricultural policies; Egypt; fertilizer; input subsidies; overapplication

1 INTRODUCTION

Fertilizer subsidies in Africa have been a source of long political, academic, and public policy debates. Input subsidy programs (ISP) represent the most important agricultural development strategies in many African countries, with substantial implications on national budgets and agricultural investments. For instance, ten African countries invested about US\$ 1 billion on input subsidies in 2011, which represent about 29 percent of their national budget allocated for agriculture (Jayne and Rashid 2013). Malawi's Agricultural Input Subsidy Program is commonly cited as an important success story which sparked resurgence of input subsidies in many other African countries (Jayne and Rashid 2013). It also sparked renewed debate with both strong proponents and critics (e.g., Morris et al. 2007; Dugger 2007; Denning et al. 2009; Dorward and Chirwa 2011; Sachs 2012; Jayne and Rashid 2013; Lunduka, Ricker-Gilbert, and Fisher 2013). As decisions around input subsidies have technical, political, ideological, and economic dimensions, these debates are justifiable. As ISPs are perceived to be politically popular among voters, it has been suggested that some governments in Africa have promoted them for this reason (Jayne and Rashid 2013; Ricker-Gilbert et al. 2013; Mason, Jayne, and van de Walle 2017).

The economic case for fertilizer subsidies in developing countries rests on perceived market failures that lead to farmers using inefficiently low levels of fertilizer. It has been argued that fertilizer and input markets are prone to market failures due to the high sunk costs of fertilizer producers, high transaction costs associated with poor market infrastructure, and low demand by farmers because of liquidity constraints (Duflo, Kremer, and Robinson 2011) or due to imperfect information and uncertainty about the returns to fertilizers (Carter et al. 2014; Abay et al. 2017).¹ In these contexts, subsidies on fertilizer and other productivity-enhancing inputs can be perceived as a way of "kick-starting" diffusion and application of modern agricultural inputs in countries with low acquisition rates. That is, providing fertilizer subsidies to relax farmers' binding constraints on agricultural input use may enable farmers to increase their fertilizer application rates to optimal levels.

On the other hand, traditional neoclassical literature argues against fertilizer subsidies. The foundation of these studies lies in Schultz's (1964) work and the presumption that farmers are rational profit maximizers. Hence, farmers will use privately optimal fertilizer levels even without subsidies. This implies that fertilizer subsidies may encourage farmers to deviate from their privately optimal use levels and distort fertilizer markets. There are some empirical studies showing that farmers already apply an optimal level of fertilizer given their constraints (e.g., transport and transaction costs) and the characteristics of their farming system. For instance, Suri (2011) shows that farmers' fertilizer application rates are consistent with their comparative advantages and, hence, expected returns to fertilizers. Other studies show that farmers' fertilizer application rates are consistent with expected profit maximization (e.g., Conley and Udry 2010; Liverpool-Tasie 2017; Liverpool-Tasie et al. 2017; Jayne et al. 2018).

Empirical evaluations of the impact of fertilizer subsidies on fertilizer application and associated inputs remain inconclusive, and the impacts may differ by context. Several studies show that fertilizer subsidy programs have increased fertilizer use intensity (Chibwana et al. 2014; Jayne et al. 2013; Mason and Jayne 2013) and productivity (Dorward and Chirwa 2011; Liverpool-Tasie and Takeshima 2013; Lunduka, Ricker-Gilbert, and Fisher 2013; Mason and Jayne 2013; Wossen et al. 2017). On the other hand, other studies show that fertilizer subsidies crowd-out commercial

¹ Carter et al. (2014) argue uninformed farmers may have systematically (downward) biased beliefs about the returns that they can expect from using fertilizers on their crops. They further argue that, consequently, a one-time fertilizer subsidy can have enduring impacts on rates of adoption of fertilizers by such farmers.

fertilizer use and hamper the development of the commercial fertilizer sector (Mason and Jayne 2013; Ricker-Gilbert, Jayne, and Chirwa 2011; Xu et al. 2009; Takeshima and Nkonya 2014; Ricker-Gilbert and Jayne 2017).² For instance, Ricker-Gilbert et al. (2011) show that fertilizer subsidies reduce demand for commercial fertilizer in Malawi, while Takeshima and Nkonya (2014) and Xu et al. (2009) confirm this finding in Nigeria and Zambia, respectively. Fertilizer subsidies in Europe and Central Asia are also associated with inefficient use of fertilizer and land (Swinnen et al. 2017).

Furthermore, input and fertilizer subsidy programs in Africa are saddled with several operational limitations and targeting problems, and they may have important unintended impacts, suggesting that the overall cost of these programs may outweigh their benefits. Jayne et al. (2013) show that about 33 percent of subsidized fertilizer is diverted before reaching actual beneficiaries in some African countries. Such diversions render overall fertilizer subsidies to not be profitable, with costs being higher than benefits for most years. Other studies show that input subsidy programs in Africa suffer from targeting problems – vulnerable and poor farmers often are not well-targeted (Lunduka, Ricker-Gilbert, and Fisher 2013; Chibwana et al. 2014; Holden and Lunduka 2012; Ricker-Gilbert, Jayne, and Chirwa 2011). For instance, Pan and Christiaensen (2012) provide evidence of elite capture of fertilizer subsidy in Tanzania, especially in communities with relatively wide income gaps. Lastly, an analysis of the maize-fertilizer subsidy in Zambia shows that the subsidy is associated with a decrease in the utilization of soil fertility management practices with potential impacts that exacerbate land degradation (Morgan et al. 2019).

All the above studies on fertilizer subsidies come from a few sub-Saharan African countries, mainly Kenya, Malawi and Zambia, where (i) fertilizer markets are not well-developed, (ii) fertilizer application rates and associated yield are reasonably low, and (iii) agricultural production mostly relies on rainfall. In regions with more integrated markets and more intensive forms of agricultural production, the theoretical case for fertilizer subsidies as well as the empirical impacts of these subsidies remain more questionable and unexplored.

In this paper, we investigate the implication of a nitrogen fertilizer subsidy in Egypt where fertilizer markets are fairly well-developed, yields and application rates are high on a global scale, and agricultural production relies on irrigation. We use data from a detailed agricultural survey collected from smallholder farmers in Upper Egypt. We show that nitrogen fertilizer application rates are substantially in excess of the agronomic recommendations by the Egyptian Ministry of Agriculture and Land Reclamation (MALR). We rely on alternative indicators and measures that generate variations in households' access to subsidized fertilizer. Our analysis of the subsidy impact on fertilizer usage exploits the fact that landownership status can influence the ease with which farmers obtain access to quotas of subsidized nitrogen fertilizer. We also exploit households' intensive margin of variation in access to subsidized nitrogen fertilizer. We find evidence that farm plots managed by farmers with easier access to the subsidy tend to use more nitrogen fertilizer and less phosphate fertilizer. Given that the average fertilizer application rate substantially exceeds recommended rates, this implies that fertilizer subsidies in Egypt are inducing over-application of inorganic fertilizers. This has important implications on overall yields as well as on soil health and the environment (IFPRI 2019; Abdelhafez et al. 2012; Schroder et al. 2011).

Our findings have important implications for informing appropriate input use and farm management practices in Egypt and beyond. Biophysical studies show that overuse of fertilizer can cause adverse environmental impacts while also reducing the overall impact and marginal returns to fertilizers (World Bank 2007). For instance, several studies document significant environmental damage costs associated with nitrogen fertilizer application in European (Sutton et al. 2011; Von

² Other studies did not find evidence of such crowding-out effects associated with fertilizer subsidies (e.g., Holden and Lunduka 2012).

Blottnitz et al. 2006; van Grinsven et al. 2013; Sterner et al. 2019) and Asian countries (Zhang et al. 2013). Indeed, many argue that curbing nitrogen emissions and associated environmental impacts is a major challenge of the twenty-first century (Sutton et al. 2011). For instance, the annual environmental cost of nitrogen fertilizer application in the European Union is estimated to be between €70 billion and €320 billion.

Our findings have timely policy implications for Egypt, since the Egyptian government is in the midst of a period of economic reforms, which include reducing subsidies on food and fuel. Our results suggest that reforming the fertilizer subsidy system also deserves due attention. The finding that farmers are overapplying subsidized fertilizer with potentially little gain in productivity suggests substantial misallocation of factors of production (Gollin and Udry 2018; Restuccia and Santaella-Llopis 2017). Given the environmental impacts of inorganic fertilizers, our results suggest that Egypt's input subsidy may generate significant negative environmental impacts caused by the excessive application of such fertilizers.

The rest of the paper is organized as follows. Section 2 provides a background on the context of agriculture in Egypt and the fertilizer subsidy system. Section 3 describes the sample and provides descriptive statistics associated with important features of agricultural production and fertilizer use patterns across different crops. Section 4 outlines the methodology of our analysis. Section 5 presents our empirical results. Section 6 provides a discussion of our main findings and associated concluding remarks.

2 CONTEXT

2.1 Agriculture in Egypt

Agriculture remains an important sector in the Egyptian economy, both as a source of livelihood and food security. Although the overall contribution of agriculture to national GDP declined from about 58 percent in the 1960s (Owen and Pamuk 1998) to about 13 percent between 2000 and 2017, the sector employed about 29 percent of workers over the period 2000 to 2019 (World Bank 2019). Importantly, employment in agriculture represents the main source of income for the poorer population – those in the bottom 40th percentile based on value of per capita consumption – who are mostly located in rural areas of the country, particularly in Upper Egypt (World Bank 2015).

Agricultural land in Egypt is usually categorized as old and new land. Most old lands are located in the Nile valley and delta, which have been cultivated for thousands of years. New lands refer to newly reclaimed lands – particularly since early 1950s until now – which are mostly located in the desert away from the valley. Old lands are characterized by clay and loamy soils, while new lands' soils are mostly sandy, calcareous, and are relatively deficient in micronutrients and organic matter (FAO 2005).

Almost all Egyptian agriculture relies on irrigation – rainfed agriculture represents less than one percent of cultivated area and is only prevalent along the northwest coast and in north Sinai. While drip irrigation is used for some crops in the new lands, flood irrigation remains the main irrigation method in old lands. Water from the Nile is transported to irrigated lands through complex canal networks. Irregularity of water supply in secondary and tertiary canals remains one major challenge for improving irrigation efficiency and increasing agriculture productivity (IFAD 2012).

Agricultural policy in Egypt has traditionally been oriented towards food self-sufficiency as a national security goal. Thus, the Egyptian government had historically played a major role in guiding and defining the direction of the agricultural sector. Agricultural policy reforms introduced in the 1980s aimed at increasing efficiency of the sector by reducing the government role, which previously had policies regulating crop prices and crop rotation. However, the government

continues to play a critical role in agriculture and still has some policies and instruments encouraging the production of strategic crops, such as wheat and maize. For instance, a government-sponsored procurement price for wheat above the market price is a default policy instrument in every cultivation season. This is done so that the government can ensure sufficient wheat supply for the country. Such policies are further justified to maintain major flour and bread subsidy programs, which benefit most of the Egyptian population. Furthermore, while government intervention has declined for other inputs, such as seeds and pesticides, the government remains active in regulating fertilizer markets (Kassim et al. 2018)

2.2 Fertilizer subsidy system

The Egyptian government intervenes in the fertilizer market in two important ways. First, the government indirectly subsidizes nitrogen fertilizer production by subsidizing natural gas used by local factories. Second, the majority of nitrogen fertilizer production factories are partially owned by the government (Elgerzawy 2014; Sweed 2019). The government requires these fertilizer factories to sell a quota of their nitrogen fertilizer production to agricultural cooperatives at a fixed price, which is below market price. The rest of the factories' production can be sold in the free market, either locally or internationally. Based on 2018 prices, the cost for the government of each ton of subsidized nitrogen fertilizer is around 1,500 EGP (85 USD), with an estimated total cost of more than 2 billion EGP (114 million USD) (Sweed 2019). Egypt is a net exporter of both nitrogen and phosphate fertilizers. In 2017, local annual production of nitrogen and phosphate by local fertilizer factories reached 2.8 million tons and 1.4 million tons, respectively (FAO 2019).

Farmers obtain access to a pre-specified quota of subsidized nitrogen fertilizers through a government controlled and mandated system of agricultural cooperatives. Each farmer's nitrogen fertilizer quota is a function of the size of their landholding and the crop(s) they cultivate during the season. The required documents for obtaining this subsidy quota include proofs of ownership or tenancy of farmland. In case of ownership, a certificate of ownership by the landholder is sufficient. However, in the case of tenancy, the required documents include a rent contract between the farmer and the landlord, a certificate of ownership by the landlord, and proof that there are no conflicts between the farmer and the landlord. Hence, it is relatively easier for landholders to obtain access to subsidized nitrogen fertilizers from the cooperatives. Furthermore, informal renting of plots, without official rental contract, is common in rural areas of Egypt, which further impedes tenants' access to subsidized fertilizers.

Government subsidization of nitrogen fertilizers is perceived as part of the government's strategy for promoting wheat cultivation. Wheat requires relatively more nitrogen than phosphate fertilizers, compared to horticultural crops (Kassam and Dhehibi 2016). Our own interviews with farmers and experts at MALR confirmed that cooperatives, in the distribution of subsidized nitrogen fertilizers, tend to give priority to farmers cultivating wheat.

There are few studies on the overall implication of fertilizer subsidies in Egypt. Studies on the impact and potential of fertilizer subsidy programs in other African and Asian countries are probably less informative for the specific context of Egypt, where farming systems and fertilizer markets are distinct. For instance, in most cases fertilizer subsidies in other African countries are justified to boost the low level of fertilizer application rates. In contrast, fertilizer application rates in the context of Egypt are much higher than the rates in those countries. Fertilizer application rates in Egypt have particularly increased in the past 50 years. In recent years, application rates have been above those recommended by MALR. Although we lack rigorous empirical evidence to attribute such increase in application rates to them, these generous fertilizer subsidies may have contributed to the remarkable increase in the application levels of nitrogen fertilizers. However, other possible reasons for the increase in demand for nitrogen fertilizer may include an increase in cropped areas and in crop intensification; the introduction of high yielding crop varieties requiring

high recommended rates of fertilizers; and the depletion of some nutrients in irrigation water from the Nile after the construction of Aswan High Dam (FAO 2005).

Similar to input subsidy programs elsewhere in Africa, the fertilizer subsidy program in Egypt suffers from some operational limitations and targeting problems, which lead to the rise of parallel markets. Leakages in the subsidy system result in a black market in which subsidized fertilizers are illegally sold at a price similar to the free market price. Correspondingly, there is often a shortage of subsidized fertilizers at the cooperatives, which means that the cooperative may not be able to provide some farmers with their full subsidy quota entitlement. This implies that the same quality of nitrogen fertilizer is being sold at different prices, subsidized versus non-subsidized prices, which can have important implications on farmers' input use and intensity decisions.

3 DATA AND DESCRIPTIVE STATISTICS

3.1 Data and sample

The data used in the analysis are from a sample of 2,246 smallholder farm households in five governorates in Upper Egypt – Assiut, Beni Suef, Luxor, Menya, Qena, and Sohag. The data were originally collected for a baseline survey for evaluating the impact of a project of the United States Agency for International Development (USAID), the Food-Security and Agribusiness Support (FAS) project, which started in 2015. FAS aims to increase the income of smallholder farmers through developing horticulture value chains by encouraging production and marketing of horticultural crops, both for domestic and for export markets. The FAS project provides marketing support to smallholders by facilitating contractual agreements between smallholders and potential buyers. Hence, the evaluation sample, which was collected in 2018, consists of two groups of smallholder farmers with less than 10 feddans³ of land that are producing horticultural crops – vegetables, fruits, herbs, and spices. Those farmers who signed (or were listed for inclusion by their local farmers group) a FAS-facilitated forward contract are the treatment group, while control group farmers were randomly selected potentially eligible farmers within the same villages, identified using a random walk method.⁴

This sample, while not nationally representative of farmers in Egypt, is an appropriate one for examining the impacts of the fertilizer subsidy. Nationally, small scale farmers cultivating less than 10 feddans represent more than 60 percent of landholdings in Egypt (ARC 2010). Furthermore, the nitrogen fertilizer subsidy program in Egypt targets small scale farmers such that the subsidy quota has a cap of 25 feddans per farmer. Thus, while our data excludes larger farms, the focus on small farms is appropriate in this context for studying the implication of fertilizer subsidy on fertilizer demand and crop productivity. Our sample also has a higher than average share of farmers cultivating wheat, a relevant crop given that the nitrogen fertilizer quota distribution tends to prioritize farmers cultivating wheat. 67 percent of farmers in our sample cultivate wheat in the winter season, while only 50 percent of all cultivated area in Egypt is used for wheat (MALR 2016).

Table 3.1 provides summary statistics for key household and field (plot) characteristics of the sample. The sample consists of 3,678 plots that were cultivated during winter season 2017/18. In 24 percent of the plots, farmer reported planting more than one primary crop on the same field – either due to intercropping, reporting multiple plots as a single plot, or growing an additional crop in-between the main summer and winter seasons. Since our analysis focuses on fertilizer usage per crop, we exclude these plots from the analysis and focus on the 2,787 plots with a single primary crop. An average household in the sample cultivated 1.7 plots. The average plot size is 1.1

³ 1 feddan=0.42 hectares.

⁴ See El-Enbavy et al. (2019) for more details on the sampling design.

feddan. About 67 percent of the fields in the sample are owned by the farmer. More than 80 percent of the plots are located in old lands. Irrigation water was available in the nearest water source at least every five days for 42 percent of the plots in the sample.

Table 3.1: Household and field characteristics, summary statistics

Variables	Mean	Standard deviation	Observations
Household characteristics			
Male household head, 0/1	0.98	0.14	2,182
Age of household head, years	46.58	12.85	2,182
Education of household head – has prep education or more, 0/1	0.52	0.50	2,182
Household size, members	5.14	2.04	2,182
Household head participates in non-agricultural occupations, 0/1	0.22	0.41	2,182
Farm size, feddan	2.16	2.60	2,182
Livestock assets (TLU) ⁵	1.83	1.73	2,182
Plots cultivated	1.69	0.94	2,182
Plots owned, number	1.14	1.04	2,182
Household planted wheat, 0/1	0.67	0.47	2,182
Total consumption, EGP per capita per month	680.09	340.90	2,182
Field characteristics			
Field owned	0.67	0.47	2,787
Size of the field (feddan)	1.09	1.39	2,787
New Lands (desert)	0.17	0.37	2,787
Irrigation water available at least every five days	0.42	0.49	2,787
Field owned	0.67	0.47	2,787

Source: Analysis of 2018 baseline survey of smallholder farmers in Upper Egypt.

3.2 Fertilizer use patterns

Table 3.2 shows the average usage of the three major nutrients in inorganic fertilizers – nitrogen, phosphate, and potassium – based on the reported application of inorganic fertilizers recorded in the survey.⁶ The major types of inorganic fertilizers in our sample are urea (46.5 percent N), ammonium nitrate (33.5 percent N), single superphosphate (15 percent P₂O₅), potassium sulphate and potassium chloride (both approximately 50 percent K₂O). Less than one percent of farmers reported using other types of inorganic fertilizers, such as ammonium sulphate, triple superphosphate, and mixed NPK fertilizers. Importantly, the data distinguishes between subsidized and non-subsidized inorganic nitrogen fertilizers. We convert and compute the nitrogen contents in both subsidized and non-subsidized urea and ammonium nitrate fertilizers.

Table 3.2: Fertilizer use, summary statistics

Variables	Mean	Standard deviation	Observations
Total nitrogen fertilizers, kg/feddan	149.1	88.86	2,493
Subsidized nitrogen fertilizers, kg/feddan	97.8	57.53	1,046
Non-subsidized nitrogen fertilizers, kg/feddan	133.8	83.49	2,014
Phosphate, kg/feddan	58.9	37.15	1,176
Potassium, kg/feddan	49.4	61.28	132

Source: Analysis of 2018 baseline survey of smallholder farmers in Upper Egypt.

Note: Summary statistics are for farm plots for which the farmer reported using any amount of the fertilizer in question.

⁵ Tropical Livestock Unit (TLU) values are computed using the following arithmetic formula: TLU = camels + (0.7*cattle) + (0.8*horses) + (0.5*donkeys) + (0.5*mules) + (0.1*sheep) + (0.1*goats) + (0.01*chicken).

⁶ Data cleaning involved winsorizing of outliers by top-coding the top 2 percent of observations in the case of nitrogen and phosphate, and the top 0.1 percent in the case of potassium. We run robustness checks with different thresholds for top-coding outliers, and the analysis results were found robust when top-coding the top 0.5, 1.5, and 2.5 percent.

We find, overall, that total nitrogen application rates are much higher than the acquisition rates in many African countries (e.g., Sheahan and Barrett 2017; Abay et al. 2018), but comparable to some Asian countries (e.g., Zhang et al. 2013). However, these fertilizer application rates are averaged across different crops with varying nutrient requirement.

Table 3.3 shows by crop the average amount of nitrogen, phosphate, and potassium applied per feddan, compared to average fertilizer requirements, and the amount of nitrogen fertilizer quota for each crop.⁷ Our benchmark for fertilizer requirements are the MALR recommendations for old lands based on soil structure studies by MALR’s Soil, Water and Environment Research Institute. Idiosyncratic factors, such as crop rotation, irrigation frequency, and residual effect of fertilizers and organic matter, can affect fertilizer requirements of each plot. Despite some variations across crops, our summary statistics show a general trend of nitrogen use that is higher than recommendations. For instance, wheat farmers are applying nitrogen fertilizer at almost twice the recommended rate. In contrast, phosphate and potassium usage is generally lower than recommendations, even for crops such as tomatoes for which recommended levels are quite high.

Table 3.3: Crop-specific fertilizer use and recommendations in the old lands, kg/feddan

Crop	Nitrogen fertilizer subsidy quota*	Nitrogen fertilizer requirement	Nitrogen fertilizer applied	Phosphate (P ₂ O ₅) fertilizer requirement	Phosphate (P ₂ O ₅) fertilizer applied	Potassium (K ₂ O) fertilizer requirement	Potassium (K ₂ O) fertilizer applied
Wheat	69	75	139.2	15	14.5	24	0.4
Sugar beets	69	90	140.5	22.5	40.2	24	0.9
Green beans	69	70	155.2	30	43.9	24	17.4
Onions	92	120	205.2	45	23.8	0	4.7
Garlic	46	120	194.2	60	21.9	72	2.6
Potatoes	115	180	205.0	75	19.3	96	8.8
Tomatoes	138	250	154.7	60	60.1	144	10.0
Basil	0	100	176.9	45	11.4	48	0.0
Fennel	0	100	107.3	45	3.0	48	0.0
Clover	0	15	64.6	22.5	44.2	0	0.1

Source: Analysis of 2018 baseline survey of smallholder farmers in Upper Egypt. Fertilizer requirements are based on Ministry of Agriculture and Land Reclamation recommendations for the old lands (MALR 2015).

Note: * Nitrogen fertilizer quota is in kg of urea or ammonium nitrate per feddan for selected crops. The quota amounts reported in this table are the nitrogen equivalent of the subsidy quota.

“Old lands” refers to the irrigated lands in the Nile valley and delta.

4 METHODOLOGY

Our identification strategy in analyzing farmers' response to the nitrogen fertilizer subsidy exploits the fact that landowners can access the subsidy by showing their ownership certificate, while renters need to obtain the subsidy through their landlords or by showing the ownership certificate of the landholder, the rent contract, and a proof of no conflicts between the farmer and the landholder. This creates variation in households' access to subsidized nitrogen fertilizer for owned and rented land. Because of this, rented plots have more limited access to subsidized nitrogen fertilizer than do owned plots.

We compare fertilizer application rates across owned and rented plots while controlling for plot and household characteristics and household fixed-effects. To identify additional potential effects of land ownership, besides that of facilitating access to subsidized nitrogen fertilizer, we also estimate separate impacts on subsidized and non-subsidized nitrogen fertilizer, which are believed

⁷ Since more than 80 percent of the plots on our sample are located in the old lands, this table focuses on observations for fertilizer use in those areas, comparing it to recommendations for fertilization on crops grown in the old lands. Fertilizer requirements for the new lands are quite different due to quite different soil types in these reclaimed areas. Our observations for fertilizer use patterns in the new lands suggest a similar trend of over-usage of N fertilizer and under-usage of P and K fertilizers.

to be of comparable quality, differing only in their prices. Equation (1) is the empirical specification for estimating such comparisons:

$$N_{hp} = \beta_1 \text{ownplot}_{hp} + \beta_3 X_{hp} + \eta_c + \eta_h + \epsilon_{hp} \quad (1)$$

Where N_{hp} stands for fertilizer application rate per feddan for each type of nitrogen fertilizer: total, subsidized, and non-subsidized. ownplot_{hp} represents a dummy variable taking a value of 1 for owned plots and 0 for rented plots. X_{hp} stands for other observable characteristics of farmers and plots. These observable characteristics include age and education of household head and plot size and higher order effects of plot size. Some of the observable covariates in X_{hp} include non-linear terms to capture potential non-linearities in the relationship between the intensity of fertilizer use and these observables. η_c absorbs crop fixed-effects, while η_h captures household (farmer) fixed-effects that can control for plot-invariant unobserved heterogeneity. ϵ_{hp} stands for other unobservable factors that may affect the application of inorganic fertilizers.

A potential concern with this identification strategy is that, in addition to enabling easier access to subsidized fertilizer through the cooperative, land ownership also directly affects farmers' investment decisions. Landowners theoretically have greater incentives than renters to invest in the long-term soil quality of their plots and an association between land tenure and fertilizer application rates has been observed empirically in other contexts (e.g., Jacoby and Rozelle 2002). To address this concern, we also estimate the empirical specification in equation (1) for non-subsidized fertilizers, including phosphate fertilizers. If the land tenure story is important in this context, we would expect to find that plot ownership is positively correlated with phosphate application as well.

Estimating β_1 and comparing it across subsidized and non-subsidized fertilizers can inform the effect of land ownership and associated easier access to subsidized nitrogen fertilizers. Along this comparison, a positive and significant value of β_1 for subsidized nitrogen fertilizer and a smaller or statistically insignificant β_1 for non-subsidized nitrogen fertilizer suggest that land ownership is facilitating easy access and higher application of subsidized nitrogen fertilizer.

The above specifications provide aggregate and average impacts of the subsidy across crops. However, as seen in Table 3.3, nutrient requirements and application rates vary across crops as does the subsidized quota allowance. Furthermore, in the distribution of subsidized fertilizers, agricultural cooperatives tend to favor farmers cultivating wheat, especially when there is any shortage of fertilizer. Thus, we also estimate crop-specific fertilizer application rates for the major crops in our sample. One main difference in implementing these crop-specific estimations is that we cannot control for household fixed-effects, as only a few farmers have multiple plots (with different ownership status) cultivating the same crop. Instead, we control for a long-list of observable household and plot-level characteristics. Despite this limitation, such estimations enable estimating heterogeneous responses in fertilizer application rates across various crops.

Finally, we look at not just the total increase in application induced by the subsidies, but at whether subsidies are particularly associated with fertilizer application in excess of MALR recommendations. We first establish that subsidy access, as expected, increases the share of subsidized fertilizer compared to total fertilizer using the following specification:

$$\text{sharesub}_{hp} = \beta_1 \text{ownplot}_{hp} + \beta_3 X_{hp} + \eta_c + \eta_h + \epsilon_{hp} \quad (2)$$

Where sharesub_{hp} now stands for the proportion of subsidized nitrogen (relative to the total nitrogen fertilizer applied) in each plot. Remaining notations are as described in equation (1).

Finally, the above empirical specifications cannot adequately address the question of whether nitrogen fertilizer subsidies are inducing overapplication of nitrogen fertilizers. To examine this, we

generate indicator variables for those plots where nitrogen fertilizer application rates are higher than agronomic recommendation rates of MALR. That is, for each plot we create a dummy variable that takes a value of 1 for those plots where nitrogen application rates are higher than the crop-specific nutrient requirements. In this estimation, we rely on variations in intensive margin of access to nitrogen subsidy. We then examine whether higher access to nitrogen subsidies induces overapplication of nitrogen fertilizer. We then re-estimate equation (1) for each fertilizer type using the overapplication dummy as the dependent variable – hence, using the following specification:

$$ON_{hp} = \alpha_1 sharesub_{hp} + \alpha_2 X_{hp} + \eta_c + \eta_h + \epsilon_{hp} \quad (3)$$

Where ON_{hp} now stands for the indicator variable that takes a value of 1 for those plots where nitrogen fertilizer is overapplied and 0 otherwise. Remaining notations are as described in equation (1). We expect that a higher share of subsidized (and, hence, relatively cheaper) nitrogen fertilizer would induce overapplication of total nitrogen fertilizer in a plot.

We might be concerned that farmers would take subsidized fertilizer for the plots they own, then make a separate decision about how to distribute the fertilizer across the plots. In this sense, our estimates with farmer fixed-effects may represent a lower bound for the true impact. Our results suggest that this reallocation across plots is not sufficient to obscure the relationship between ownership and fertilizer application, which is likely due to differences in timing of fertilizer application by crop or due to an implicit "flypaper" effect such that the subsidy quota acts as a labelling for the expected impact of the fertilizer.

Farmers living in the same village are usually exposed to the same agricultural cooperative, implying potential correlation in error terms because of common supply or demand related shocks to fertilizer markets. Thus, in all our estimations we cluster standard errors at village level.⁸ We also estimate our empirical specifications using levels of fertilizer application rates as well as using inverse hyperbolic sine (IHS) transformations.

5 RESULTS

5.1 Access to fertilizer subsidy and application of nitrogen and other fertilizers

In this section, we report the estimation results associated with equation (1) and its variants. Table 5.1 provides estimation results for each type of fertilizer: total nitrogen, subsidized nitrogen, non-subsidized nitrogen, and phosphate. All these specifications control for household fixed-effects, and, hence, can capture farmer-specific unobserved managerial and farming skills that could affect all plots cultivated by the same farmer.

⁸ We also experiment by clustering standard errors at household level, but our main inferences remain robust to the level of clustering.

Table 5.1: Fertilizer demand by fertilizer type

Explanatory variable	(1)	(2)	(3)	(4)
	Total nitrogen (kg/ feddan)	Subsidized nitrogen (kg/ feddan)	Non-subsidized nitrogen (kg/ feddan)	Phosphate (kg/ feddan)
Field owned, 0/1	11.67** (5.45)	15.53*** (5.26)	-3.77 (5.94)	-5.08* (2.67)
New lands (desert), 0/1	-0.75 (15.40)	-14.00* (8.05)	13.28 (17.64)	-6.41 (6.00)
Field size, feddan	-32.34*** (7.57)	-7.28** (2.72)	-25.08*** (7.23)	-1.50 (1.85)
Field size-squared	1.43*** (0.51)	0.31* (0.16)	1.13** (0.45)	0.11 (0.10)
Irrigation water available at least every five days, 0/1	3.45 (16.98)	9.61 (6.64)	-6.15 (15.01)	1.89 (6.89)
Household fixed-effects?	Yes	Yes	Yes	Yes
Crop fixed-effects?	Yes	Yes	Yes	Yes
R-squared	0.348	0.150	0.234	0.239
Observations	2,767	2,768	2,767	2,766

Source: Analysis of 2018 baseline survey of smallholder farmers in Upper Egypt.

Note: The outcome variables in this table represent total, subsidized and non-subsidized nitrogen fertilizer and phosphate fertilizer application rates (kg/feddan) in each plot.

Standard errors clustered at village level are given in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

The estimate in the first column of Table 5.1 shows that owned plots, those with easier access to subsidized nitrogen fertilizer, on average receive 12 kg additional nitrogen fertilizer per feddan. However, this does not inform whether this additional application is driven by their access to subsidized nitrogen or because of differential investment and farming practices across owned and rented plots. In the second and third columns, we separately estimate such effects for subsidized and non-subsidized nitrogen fertilizer, which are of the same quality but sold at different prices.⁹ The results in the second column show that field ownership and, hence, access to subsidized nitrogen fertilizer is associated particularly with higher application of subsidized nitrogen. On average, owned plots receive an additional 16 kg subsidized nitrogen fertilizer per feddan, relative to rented plots. This increase in subsidized nitrogen application is not accompanied by a large or statistically significant decrease in use of non-subsidized nitrogen fertilizer (coefficient of -3.8), implying that nitrogen fertilizer subsidies are mostly extra-marginal. These results are consistent with findings from other African countries, which generally show that fertilizer subsidies increase fertilizer application rates (e.g. Chibwana et al. 2014; T. S. Jayne et al. 2013; Mason and Jayne 2013).

The fourth column of Table 5.1 shows that farmers apply 5 kg per feddan less phosphate on owned plots (significant at the 10 percent level). This is in contrast to the positive coefficient that would be expected if our results on fertilizer application were being driven by land tenure affecting investment in long-term soil fertility. Instead, this is likely the result of increased spending on nitrogen fertilizer displacing spending on phosphate. Anecdotal evidence from conversations with cooperative managers suggests that farmers do not distinguish between the agronomic benefits of phosphate and nitrogen fertilizer due to the poor quality of agricultural extension services in Egypt.

Besides influencing demand for a specific type of fertilizer, nitrogen subsidies can affect demand for other type of fertilizers, e.g., Holden and Lunduka 2012. The evidence base for potential crowding-in or crowding-out effects associated with fertilizer subsidy programs in Africa remain mixed. For instance, some studies show that fertilizer subsidies crowd-out commercial

⁹ Estimation results using inverse hyperbolic sine (IHS) transformation of fertilizer application rates are given in Table A1 (in the appendix).

fertilizer or other types of fertilizers (e.g., (Mason and Jayne 2013; Ricker-Gilbert, Jayne, and Chirwa 2011; Xu et al. 2009; Takeshima and Nkonya 2014; Ricker-Gilbert and Jayne 2017), while others show some crowding-in effects, particularly for organic manure usage (Holden and Lunduka 2012). The overall welfare and productivity impacts (costs) of such crowding-in or crowding-out can be substantial. For instance, crowding-in or crowding-out of modern agricultural inputs can only be productivity-enhancing if they conform with soil nutrient content and agronomic conditions.

We also examine the implication of land ownership and easier access to subsidized fertilizer on the share of subsidized nitrogen fertilizer. We hypothesize that households' access to subsidized nitrogen fertilizer can affect the composition of fertilizers they apply. The results in Table 5.2 show that land ownership and, hence, easier access to subsidized fertilizer increases the share of subsidized nitrogen fertilizer in the overall level of application of nitrogen fertilizer.

Table 5.2: Access to fertilizer and share of subsidized nitrogen fertilizer applied

Explanatory variable	(1)	(2)
	Share of subsidized nitrogen	Share of subsidized nitrogen
Field owned, 0/1	0.11** (0.05)	0.24*** (0.03)
New lands (desert), 0/1	-0.07 (0.06)	-0.14*** (0.04)
Field size, feddan	0.01 (0.02)	0.01 (0.01)
Field size-squared	0.00 (0.00)	-0.00 (0.00)
Irrigation water available at least every five days, 0/1	0.08* (0.04)	-0.04 (0.03)
Household fixed-effects?	No	Yes
Crop fixed-effects?	Yes	Yes
R-squared	0.113	0.189
Observations	2,584	2,584

Source: Analysis of 2018 baseline survey of smallholder farmers in Upper Egypt.

Note: The outcome variable in this table represents the share of subsidized urea and ammonium nitrate in total urea and ammonium nitrate applied in each plot. The first column controls for household fixed-effect, while the second controls for household characteristics and crop fixed-effects. Standard errors clustered at village level are given in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

The estimates in Table 5.1 and Table 5.2 are aggregated results across different crops. In Table 5.3 we show that owned plots receive higher amount of total nitrogen fertilizer for almost all crops grown by farmers. This table shows evidence of farmers' tendency to use more nitrogen fertilizer on owned fields when cultivating a major crop, such as wheat, clover, potatoes, tomatoes, and fennel.¹⁰ These results confirm that our results are robust to alternative definitions and measures of access to nitrogen fertilizer subsidies.

¹⁰ As explained earlier, the limited variation in field ownership status for the same crop within the household means that we cannot use the specification with farmer fixed-effects when analyzing data for each single crop.

Table 5.3: Total nitrogen fertilizer demand, crop-level results

Explanatory variable	(1)	(2)	(3)	(4)	(5)	(6)
	Wheat	Clover	Onions	Potatoes	Tomatoes	Fennel
Field owned, 0/1	18.84**	25.85***	18.64	78.20**	57.14**	27.60**
	(7.26)	(8.26)	(15.92)	(34.13)	(19.74)	(9.83)
Field size, feddan	-22.67**	-37.82***	-57.90***	-66.16***	48.03	-0.40
	(9.94)	(13.67)	(15.55)	(14.29)	(56.52)	(6.33)
Field size-squared	1.28*	5.67**	2.63***	4.55***	-12.80	0.05
	(0.72)	(2.25)	(0.86)	(1.18)	(8.84)	(0.38)
Irrigation water available at least every five days, 0/1	10.47	15.72	-8.10	-32.25**	35.97	3.54
	(11.64)	(11.03)	(17.96)	(13.85)	(36.03)	(21.91)
Total consumption, EGP per capita per month	-0.03**	-0.04***	-0.01	-0.05*	-0.01	0.02
	(0.01)	(0.01)	(0.02)	(0.02)	(0.03)	(0.01)
Livestock assets, TLU	4.09	5.72***	-1.83	7.60	13.22	-3.31
	(2.71)	(1.78)	(2.98)	(4.51)	(12.45)	(2.98)
Household head: non-agricultural occupation, 0/1	0.96	-11.37*	36.29	-16.78	10.98	-13.61
	(9.69)	(6.59)	(25.50)	(19.19)	(14.04)	(15.66)
Age of household head, years	-0.18	0.32	0.70	0.93	-2.07***	-0.97*
	(0.28)	(0.24)	(0.60)	(1.26)	(0.66)	(0.47)
Education of household head – has prep education or more, 0/1	-3.87	7.33	8.14	17.44	-64.74**	-44.62*
	(7.38)	(5.72)	(19.10)	(31.29)	(25.38)	(19.83)
Farmer fixed-effects?	No	No	No	No	No	No
R-squared	0.071	0.113	0.184	0.282	0.366	0.260
Observations	1020	675	265	113	54	111

Source: Analysis of 2018 baseline survey of smallholder farmers in Upper Egypt.

Note: The outcome variables in this table represent total nitrogen fertilizer application rate (kg/feddan) in each plot. Standard errors clustered at village level are given in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. TLU = tropical livestock unit.

So far, the results show that nitrogen subsidies increase nitrogen fertilizer application rates while reducing the intensity of other types of fertilizers (mainly phosphate fertilizers). However, they cannot inform whether this increase in nitrogen fertilizer application rates is needed or agronomically recommended in the context of Egypt where overall use of nitrogen fertilizer is high. To address this question, we employ crop-specific agronomic recommendations from MALR to examine whether nitrogen fertilizer subsidies are inducing overapplication of nitrogen fertilizers per unit of land. For this purpose, we create indicator variables for those plots where the application of nitrogen fertilizer is higher than recommended by MALR for the crop grown on the plot. We then estimate equation (3) with the dependent variable being an overapplication dummy indicating whether the quantity (in kg per feddan) of subsidized, non-subsidized, or total nitrogen exceeds the recommended application rates of MALR.

The estimates in Table 5.4 provide estimation results associated with equation (3). The first column of Table 5.4 shows that higher access to subsidized fertilizer (and, hence, a higher share of subsidized fertilizer at farm level) increases farmers' tendency to overapply total nitrogen fertilizer. The second column confirms that much of this is driven by overapplication of subsidized nitrogen fertilizer. Finally, the third column estimate indicates that those households with better access to subsidized fertilizer (and, hence, a higher share of subsidized fertilizer at farm level) are less likely to overapply non-subsidized nitrogen fertilizer. This is intuitive as both subsidized and non-subsidized nitrogen fertilizers are of similar quality and, hence, perfect substitutes, but available at different prices. Farmers are overapplying cheaper and easily accessible subsidized fertilizers, implying that the generous nitrogen subsidy program is inducing fertilizer use intensity beyond a level that is agronomically required and that plants can utilize.

Table 5.4: Nitrogen subsidy and overapplication of nitrogen fertilizer

Explanatory variable	(1)	(2)	(3)
	Overapplication of total nitrogen fertilizer, 0/1	Overapplication of subsidized nitrogen fertilizer, 0/1	Overapplication of non-subsidized nitrogen fertilizer, 0/1
Share of subsidized nitrogen	0.51* (0.26)	1.08*** (0.18)	-0.46* (0.24)
Share of subsidized nitrogen - squared	-0.51** (0.24)	-0.39* (0.20)	-0.20 (0.23)
New lands (desert), 0/1	-0.15 (0.10)	-0.05 (0.09)	-0.12 (0.08)
Field size, feddan	-0.11*** (0.03)	-0.05** (0.02)	-0.09*** (0.03)
Field size - squared	0.01*** (0.00)	0.00*** (0.00)	0.01*** (0.00)
Irrigation water available at least every five days, 0/1	0.05 (0.09)	0.02 (0.08)	0.03 (0.07)
Crop-level fixed-effects?	Yes	Yes	Yes
Farmer fixed-effects?	Yes	Yes	Yes
R-squared	0.321	0.369	0.381
Observations	2,584	2,584	2,584

Source: Analysis of 2018 baseline survey of smallholder farmers in Upper Egypt.

Notes: All specifications control for household and crop fixed-effects. Standard errors clustered at village level are given in parentheses.

* p < 0.10, ** p < 0.05, *** p < 0.01.

5.2 Extensions and robustness checks

A potential spillover effect of the nitrogen subsidy in Egypt is that farmers can obtain their assigned quota for any of the fields they own then reallocate the use of nitrogen fertilizer across plots. In terms of overall household-level profit maximization, such reallocation could be optimal for the farmer, although variations in soil and crop type may constrain such reallocations. Hence, we use farmer's ownership of at least one plot as an indicator of having access to the fertilizer subsidy. Table A2 (in the Appendix) shows that ownership of at least one plot is significantly associated with a higher share of subsidized nitrogen fertilizer application as well as higher application of nitrogen fertilizers per unit of land.

Some of the estimations in Table 5.2 and Table 5.3 assume that tenure (ownership) status of plots only affects access to subsidized fertilizer, with negligible implications on other major input use and investment decisions. This assumption may not hold if farmers' investment and input use on owned and rented plots vary. The possibility of differences in farmers' input investment decisions based on the ownership status of the field is analyzed by examining whether ownership status has any implication on reported field preparation costs. Table A3 in the Appendix shows that field ownership status has a negligible implication on field preparation costs, both within the same farm household (specification with farmer fixed-effects) and across farmers. These findings suggest that the increase in nitrogen fertilizer on owned fields is not driven by farmers' preferences for investing more on inputs for the fields they own, as is also shown in Table 5.1. Rather, it is a consequence of farmers' access to cheaper subsidized nitrogen fertilizer.

6 DISCUSSION AND POLICY IMPLICATIONS

This paper examines the implication on farmers' fertilizer demand and productivity of the nitrogen fertilizer subsidy in Egypt using a detailed agricultural survey collected from smallholder farmers in Upper Egypt. We first show that nitrogen fertilizer application rates are substantially in excess of

agronomic recommendations by the Egyptian Ministry of Agriculture and Land Reclamation (MALR). We then explore the role of nitrogen fertilizer subsidies in inducing overapplication of nitrogen fertilizer using alternative sources of extensive and intensive margins of variations in households' access to subsidized fertilizer. We exploit plot ownership status that generates significant variations in households' access to subsidized fertilizer as well as intensive margin of variation in households' access to subsidized fertilizers. We find that farmers with easier access to the subsidy tend to use more nitrogen fertilizer and less phosphate fertilizer per unit of land.

The evidence that nitrogen subsidies induce overapplication of nitrogen fertilizer has important implications for improving farm management practices and farm productivity as well as reducing the adverse effects of inorganic fertilizers. Over-usage of nitrogen fertilizer is not only inefficient from an economic perspective, but also unsustainable and harmful to the environment. In terms of farm management practices, it seems that the generous nitrogen subsidy is encouraging farmers to deviate from agronomically recommended fertilizer usage practices, with some important economic implications to the household and the overall economy. Given that agronomic recommendations are associated with best practices and maximum yield gains, this may imply that farmers are incurring additional costs of fertilizer with little gain in yields, e.g., Yadav, Peterson, and Easter 1997; Ju et al. 2009. Indeed, in some cases overuse of inorganic fertilizer can reduce the overall impact and marginal returns to fertilizers (World Bank 2007).

Nitrogen fertilizers are also known for their adverse effects on human, soil, water and environmental health. The adverse environmental impacts of excessive use of inorganic fertilizers is well-documented in several European and Asian countries (Sutton et al. 2011; Von Blottnitz et al. 2006; van Grinsven et al. 2013; Zhang et al. 2013). Some cost-benefit computations show that some of the adverse health and environmental impacts may outweigh the economic gains from nitrogen fertilizer application, particularly in northwestern Europe (van Grinsven et al. 2013). Sutton et al. (2011) show that the European Union incurs environmental cost worth of €70 billion to €320 billion per year due to excess nitrogen application. Other studies show that the environmental cost and impact associated with nitrogen fertilizer application is much higher for China than the European Union (Zhang et al. 2013). Excess use of nitrogen fertilizers causes contamination of drainage water and can result in acidification of soil in the long run (IFPRI 2019; Abdelhafez et al. 2012; Schroder et al. 2011).

Our results have important policy implications in support of reforming the fertilizer subsidy and extension systems in Egypt. The evidence that inorganic fertilizer application rates substantially deviate from agronomic recommendations casts doubt on the effectiveness of rural agricultural extension systems. Qualitative evidence on the limited effectiveness of the public extension sector in Egypt are found in the literature (Dhehibi, Kassam, and Shefir 2018; McDonough et al. 2017). Moreover, our interviews with farmers in the field confirm that farmers have imprecise information on optimal fertilizer usage and the substitutability between different types of fertilizers. Improving farmers' awareness about optimal fertilizer application through increasing effectiveness of the extension sector and associated R&D investments could improve farmers' input management practices.

Following existing biophysical studies which show overuse of fertilizer can reduce marginal returns to fertilizers, our findings suggest that farmers as well as the Egyptian government may re-allocate funds spent on fertilizer subsidies without affecting agricultural yields. Such a re-allocation of resources could improve farmers' investments. Finally, the potential negative environmental externalities of nitrogen fertilizer application in Egypt are worth highlighting and quantifying. In addition to reallocating funds, the government may also consider smart instruments and technologies that can encourage farmers to apply optimal levels of nitrogen fertilizers.

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APPENDIX

Table A1: Fertilizer demand by fertilizer type with inverse hyperbolic sine (IHS) transformed dependent variable

Explanatory variable	(1)	(2)	(3)	(4)
	IHS transformation of total nitrogen fertilizer (kg/feddan)	IHS transformation of subsidized nitrogen fertilizer (kg/feddan)	IHS transformation of non-subsidized nitrogen fertilizer (kg/feddan)	IHS transformation of non-subsidized nitrogen fertilizer (kg/feddan)
Field owned, 0/1	0.22** (0.10)	0.82*** (0.28)	-0.24 (0.16)	-0.37** (0.16)
New lands (desert), 0/1	0.48* (0.26)	-0.55 (0.40)	0.68* (0.39)	-0.04 (0.49)
Field size, feddan	-0.31** (0.14)	0.02 (0.07)	-0.10 (0.15)	0.19* (0.11)
Field size-squared	0.01 (0.01)	-0.00 (0.01)	-0.00 (0.01)	-0.01 (0.01)
Irrigation water available at least every five days, 0/1	-0.08 (0.42)	0.36 (0.27)	-0.27 (0.45)	0.14 (0.43)
Household fixed-effects?	Yes	Yes	Yes	Yes
Crop fixed-effects?	Yes	Yes	Yes	Yes
R-squared	0.412	0.202	0.246	0.273
Observations	2,767	2,768	2,767	2,766

Source: Analysis of 2018 baseline survey of smallholder farmers in Upper Egypt.

Notes: The outcome variable in this table represents inverse hyperbolic sine (IHS) transformation of amount of nitrogen fertilizer (kg/feddan) applied in each plot and for each type of fertilizer. Standard errors clustered at village level are given in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01.

Table A2: Fertilizer demand by farmers who owned at least one plot

Explanatory variable	(1) Share of subsidized nitrogen	(2) Total nitrogen (kg / feddan)	(3) Subsidized nitrogen (kg / feddan)	(4) Phosphate (kg P ₂ O ₅ / feddan)
Household owned at least one field, 0/1	0.19*** (0.03)	18.85*** (5.09)	26.67*** (3.88)	-1.82 (2.58)
New lands (desert), 0/1	-0.12*** (0.04)	13.74 (11.52)	-12.34* (6.15)	-0.72 (4.52)
Field size, feddan	0.02 (0.01)	-24.04*** (6.46)	-4.39** (2.16)	-4.46*** (1.39)
Field size-squared	-0.00* (0.00)	1.09** (0.42)	0.15 (0.13)	0.25*** (0.09)
Irrigation water available at least every five days, 0/1	-0.04 (0.04)	6.71 (8.53)	-1.71 (4.93)	9.76** (4.23)
Total consumption, EGP per capita for one month	-0.00 (0.00)	-0.02*** (0.01)	-0.00 (0.01)	0.01** (0.00)
Livestock assets, TLU	0.00 (0.01)	3.16** (1.57)	0.70 (1.34)	0.31 (0.59)
Household head has a non-agricultural occupation, 0/1	0.02 (0.03)	1.12 (5.99)	3.26 (4.85)	-1.39 (2.31)
Age of household head, years	0.00*** (0.00)	0.13 (0.21)	0.60** (0.24)	-0.10 (0.10)
Education of household head, has prep education or more, 0/1	0.10*** (0.02)	-2.02 (5.44)	10.13*** (3.22)	0.69 (2.18)
Crop-level fixed-effects?	Yes	Yes	Yes	Yes
Farmer fixed-effects?	No	No	No	No
R-squared	0.153	0.285	0.169	0.167
Observations	2,584	2,767	2,768	2,766

Source: Analysis of 2018 baseline survey of smallholder farmers in Upper Egypt.

Notes: The dependent variable in the first column is the share of subsidized urea and ammonium nitrate in total urea and ammonium nitrate. The outcome variables in the remaining columns represent nutrient levels coming from specific types of fertilizers. All specifications control for crop fixed-effects. Standard errors clustered at village level are given in parentheses.

* p < 0.10, ** p < 0.05, *** p < 0.01.

Table A3: Field ownership and field preparation costs

Explanatory variable	(1) Field preparation costs (EGP/feddan)	(2) Field preparation costs (EGP/feddan)
Field owned, 0/1	1.13 (9.72)	4.99 (14.22)
New lands (desert), 0/1	-25.76 (42.04)	-113.73*** (27.70)
Field size, feddan	-65.08*** (17.24)	-53.67*** (16.90)
Field size-squared	3.41*** (0.81)	2.96*** (0.98)
Irrigation water available at least every five days, 0/1	-12.23 (21.90)	25.09 (46.56)
Total consumption, EGP per capita for one month		0.02 (0.04)
Livestock assets, TLU		-1.73 (6.90)
Household head has a non-agricultural occupation, 0/1		27.79 (26.52)
Age of household head, years		0.14 (0.83)
Crop-level fixed-effects?	Yes	Yes
Farmer fixed-effects?	Yes	No
R-squared	0.061	0.049
Observations	2514	2514
Mean dependent variable	575.4	575.4

Source: Analysis of 2018 baseline survey of smallholder farmers in Upper Egypt.

Notes: The first column controls for household fixed-effect, while the second controls for crop fixed-effects. Standard errors clustered at village level are given in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01.

ABOUT THE AUTHORS

Sikandra Kurdi is an Associate Research Fellow with the Egypt Strategy Support Program (ESSP) of the International Food Policy Research Institute (IFPRI), based in Cairo. At the time this research was done, **Mai Mahmoud** was a Senior Research Assistant with IFPRI's ESSP in Cairo, but has since begun studies for a PhD in Economics and Public Policy at Tufts University in USA. **Kibrom A. Abay** is a Research Fellow and **Clemens Breisinger** is a Senior Research Fellow, both with IFPRI's ESSP, based in Cairo.

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INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

1201 Eye St, NW | Washington, DC 20005 USA
T. +1-202-862-5600 | F. +1-202-862-5606
Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

IFPRI-EGYPT

World Trade Center, 1191 Corniche El Nile, Cairo, Egypt
T: +20(0)225778612
<http://egyptssp.ifpri.info/>

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