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Land Scarcity and Input Intensification in Smallholder Irrigated Agriculture in Egypt

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Increasing population pressure and population density in many African countries are inducing land scarcity and land constraints. These are expected to trigger various responses and adaptation strategies, including agricultural intensification induced by land scarcity, as postulated by the Boserup hypothesis. However, most empirical evaluations of the hypothesis come from rainfed agriculture and mostly from sub-Saharan Africa, where application of agricultural inputs remains historically low. Agricultural intensification practices and the relevance of the Boserup hypothesis in irrigated agriculture (and where application of improved inputs is high) remains unexplored.

We investigate the implication of land scarcity on agricultural intensification and the relevance of the Boserup hypothesis in the context of Egypt, where agriculture is dominated by irrigation and input application rates are much higher than elsewhere in Africa. We find that land scarcity increases overapplication of nitrogen fertilizer relative to crop-specific agronomic recommendations. This implies that land constraints remain as important challenges for sustainable agricultural intensification. Finally, we find suggestive evidence that such overapplication of nitrogen fertilizers is not yield-enhancing, but, rather, yield-reducing. We also document that land scarcity impedes mechanization of agriculture.

Research on agricultural intensification in irrigated agriculture remains scant

Agricultural intensification, in the form of higher use of agricultural inputs and a high labor-land ratio, has been long-debated as a response to population pressure. The debate revolves around whether the Boserup (1965) hypothesis, which argues that population growth induces agricultural intensification, holds or not. This is particularly relevant for African countries, where rural populations continue to increase, even in land-constrained countries (Chamberlin et al., 2014; Jayne et al., 2014; Headey and Jayne, 2014). Several recent studies fail to find evidence to support the Boserup hypothesis in Africa (Holden and Yohannes, 2002; Binswanger-Mkhize and Savastano, 2017) while other studies find such evidence (e.g., Pender and Gebremedhin, 2007; Headey et al., 2014; Josephson et al., 2014; Ricker-Gilbert et. al, 2014; Abay et al., 2020). Almost all of these studies empirically examining the Boserup hypothesis in Africa come from rainfed agriculture and mostly from south of the Sahara.

The relevance of the Boserup agricultural intensification hypothesis remains unknown in the context of irrigated agriculture in the Middle East and North African (MENA) region. Compared to rainfed agriculture, smallholder irrigated agriculture involves different farming techniques and somewhat different economic constraints and farming environments. Examining the intensification hypothesis in the context of Egypt is interesting for several reasons: (i) the country's increasing population growth is threatening the sustainability of the water and land resources; (ii) agriculture is mainly dependent on irrigation, given the nearly complete absence of rainfall; (iii) agricultural yields and input application rates in Egypt are high on a global scale; and (iv) fertilizer and input subsidies are important input policy instruments that are meant to trigger agricultural intensification.

To fill this gap in the literature on agricultural intensification, we examine the relevance of the Boserup hypothesis by studying agricultural intensification practices in Egypt. We also examine whether agricultural input intensification, induced by land scarcity, is consistent with agronomic recommendations and profit maximization objectives. This is particularly crucial in the context of Egypt where farmers are shown to be using above recommended rates of chemical fertilizers (Kurdi et al., 2020). This study therefore serves the dual objectives of assessing the relevance of the Boserup hypothesis and whether such potential intensification is consistent with agronomic recommendations and yield or profit maximization objectives.

Agriculture continues to play an important role in the Egyptian economy

The share of the agricultural sector in GDP and employment in Egypt is more than in many middle-income countries. Agriculture accounts for 12.1 percent of GDP – going up to 18.2 percent if we consider agro-processing industries. It also accounts for 5.6 percent of exports, while agro-processing accounts for 14.2 percent (El-Enbaby et al., 2016). In addition, nearly a quarter of the population works in agriculture.

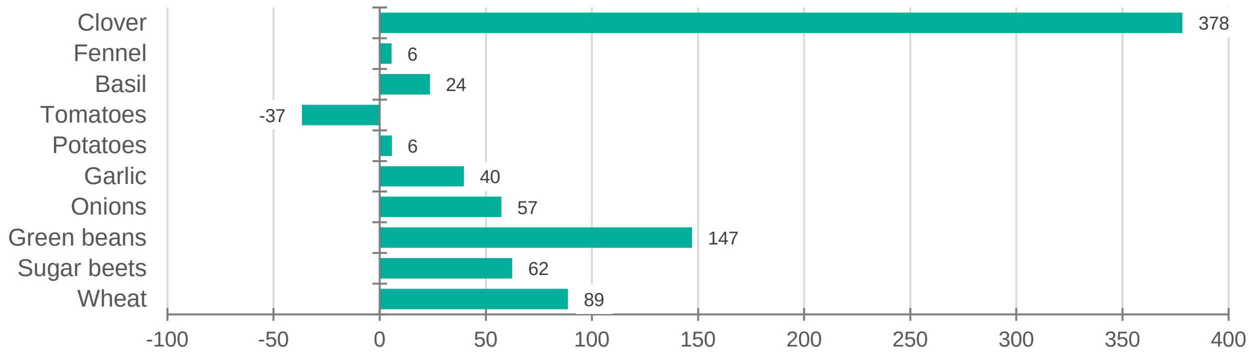
Egyptian agriculture is characterized by two types of land. The first type is "old lands", which represent 85 percent of Egypt's agricultural land and is mostly located in the Nile Valley and Delta. These farming areas are dominated by smallholders with the majority of landholdings being less than 5 feddans (Kheir El-Din and El-Laithy, 2008). Since Egypt's "old lands" cannot be expanded, improvements in agricultural productivity are the only way to increase agricultural output from them. The second type of land is "new lands", which is reclaimed land in the desert. Landholdings on the new lands are larger in size, and farming on them is done using more capital-intensive technologies (Kheir El-Din and El-Laithy, 2008).

Given the relevance of the old lands for agricultural production in Egypt, the study utilizes a dataset that surveys smallholder households farming old lands in Upper Egypt. The study is based on a farm household survey which was collected from 2,246 farm households in Assiut, Beni-Suef, Luxor, Menya, Qena and Sohag, between April and May 2018. The survey was restricted to farm household that owned less than 10 feddans of land and also cultivated horticultural crops. Farming activities were surveyed for both the summer 2017 and winter 2017/18 seasons. For the purpose of this study, we focus on the winter sample. The average farm size of surveyed households is 2.77 feddans (1.16 ha), while the average plot size in our sample is 1.56 feddans (0.66 ha). The sample for this study consists of 4,379 land plots.

Nitrogen fertilizers application exceeds requirements

The amount of nitrogen fertilizer applied by the farmers surveyed exceeds the requirements for all crops, except tomatoes. For some crops, such as fennel, over-application is only by about 6 percent. Yet, for other crops, there exists substantial over-application, as shown in Figure 1.

Figure 1: Average difference between actual and recommended nitrogen fertilizer application, kg/feddan



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

Over-application of nitrogen fertilizers may be related to the government's nitrogen fertilizer subsidy (Kurdi et al., 2020). Yet, over-application of non-subsidized nitrogen fertilizer is more prevalent than over-application of subsidized fertilizer (Table 1). Farmers behavior may not be driven by the subsidy alone. One possible scenario is agricultural intensification, whereby farmers are pressured to increase their productivity due to land scarcity. It is important to note that the access of farmers to subsidized nitrogen fertilizers is administered through agricultural cooperatives and is a function of the size of their landholding and the crops they cultivate.

Table 1: Fertilizer use by farmers surveyed in Upper Egypt

Variable of interest	Mean	Standard deviation
Total nitrogen fertilizers, kg/feddan	130.20	85.76
Non-subsidized nitrogen fertilizers, kg/feddan	99.02	85.34
Subsidized nitrogen fertilizers, kg/feddan	31.18	50.25
Overapplication of total nitrogen fertilizer, 0/1	0.65	0.48
Overapplication of non-subsidized nitrogen fertilizer, 0/1	0.49	0.50
Overapplication of subsidized nitrogen fertilizer, 0/1	0.15	0.36

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

Boserup hypothesis applies to irrigated land

The analysis shows that smaller plots receive higher amount of nitrogen fertilizer. This holds for all types of nitrogen fertilizers. A one percent increase in plot size is associated with between 0.31 and 0.35 kg/feddan reduction in nitrogen application. The response to land constraints is more pronounced for non-subsidized fertilizer than for subsidized fertilizers. These results suggest that the Boserup hypothesis extends to irrigated agriculture, a dominant farming system in most of the MENA region. Results from Kurdi et al. (2020) also show that owned plots receive higher amounts of subsidized nitrogen fertilizer and receive less amounts of commercial fertilizers. Plot owners have relatively easier access to subsidized fertilizer than do tenants, as the latter are required to submit a rental contract and to obtain the landlords' consent in order to obtain subsidized fertilizer.

Land scarcity induces overapplication of nitrogen fertilizers

Our results show that a one percentage point increase in plot size is associated with a 0.1 percentage point reduction in the probability of overapplication of nitrogen fertilizer. In addition, land scarcity is associated with a positive deviation in the level of fertilizer application, whereby smaller plots receive nitrogen fertilizers at levels above recommendations. This is consistent across all types of nitrogen fertilizers. These findings imply that land scarcity not only induces intensification of nitrogen fertilizer, but also encourages overapplication. The Boserup type of intensification in this context is thus associated with fertilizer use beyond a level that is agronomically recommended, which has several negative implications.

Land scarcity impedes sustainable input intensification

Our findings suggest that increasing population pressures and population density in Africa may soon be a challenge for sustainable agricultural intensification. This prospect calls for broader rural transformation strategies. In contexts where additional agricultural productivity growth cannot be achieved by further intensification, it is important to consider other responses to land scarcity, including diversification of crops, e.g., from cereals to higher value crops, like fruits and vegetables, or out of agriculture, including through fostering migration into less populated areas. In Egypt, the majority of smallholders already earn a substantial share of their income from non-farm activities and the potential for agro-industrial development is large (El-Enbaby et al. 2016). Therefore, supporting smallholders to exit agriculture can be an important element of a broader rural transformation strategy.

Revitalizing agricultural extension services may improve farm-level fertilizer management

Overapplication of nitrogen fertilizer is inefficient from an economic cost-benefit perspective and has negative health and environmental impacts. Agronomic recommendations are associated with best practices and maximum yield gains, implying that farmers may be incurring additional costs of fertilizer with little gain in yields (Yadav et al., 1997; Ju et al., 2009). Overapplication of nitrogen fertilizers can have a negative impact on yields (World Bank, 2007). While nitrogen fertilizers are associated with positive marginal yield contributions, overapplication is associated with significant yield reduction. This yield response pattern to application levels implies that nitrogen fertilizers are yield-increasing up until some level, but can adversely affect yield when applied beyond agronomic recommendations. In addition, overapplication of nitrogen fertilizers can adversely affect human, soil, water, and environmental health (Sutton et al., 2011; Von Blottnitz et al., 2006; Van Grinsven et al., 2013; Sterner et al., 2019; Zhang et al., 2013).

This highlights the need to improve the effectiveness of rural agricultural extension services. Revitalizing the effectiveness of the extension sector and associated R&D investments can improve and optimize the application of nitrogen fertilizers by farmers and their input management practices in general.

Land scarcity affects application of other inputs

Land scarcity is also associated with increased application of other inputs, such as labor, machinery, and pesticides. In terms of labor, smaller plots receive higher amount of labor per unit of land, implying that operating smaller plot is relatively costly. Similarly, land scarcity impedes mechanization of agriculture, which is intuitive given the economies of scale associated with mechanization and the cost of machinery use (e.g., Otsuka et al., 2013; Foster and Rosenzweig, 2017; Takeshima, 2017). Finally, the Boserup hypothesis extends to other chemical inputs, including pesticides. As pesticides are also known for their adverse health impacts (e.g., Sheahan et al., 2017), agricultural intensification induced by land scarcity that involves significant pesticide use can have important health implications.

Summary of findings

- Land constraints induced by population growth can imped sustainable agricultural intensification in contexts where application of chemical fertilizers remains high.

- Evidence that smaller plots receive above recommendation level of fertilizer imply that agricultural extension services need to pay attention to farmers with smaller plots to ensure sustainable agricultural intensification. Improving the effectiveness of agricultural extension systems can particularly benefit the rural poor, since smaller plots are likely to be managed by poorer farmers.
- In contexts where additional agricultural productivity growth cannot be achieved through further intensification, policy makers and individuals may need to consider other responses to land scarcity. Such strategies may include crop diversification from cereals to higher value crops, like fruits and vegetables; promoting livelihoods outside of agriculture for poor smallholder farming households; or encouraging the migration of such households to less populated areas.

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