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Fertilizer, soil health, and economic shocks: A synthesis of recent evidence ☆

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ABSTRACT

Most countries, at all stages of development, adopt policies to improve agricultural productivity through the application of inorganic fertilizer and the management of soil health. Unfortunately, global and local economic shocks can quickly erode the impact of these policies, as was evident during the global food, fuel, and fertilizer price crisis that began in 2020. This paper synthesizes recent evidence on the magnitude and distribution of—and responses to— the recent shocks to international fertilizer markets, building on evidence from this Special Issue of *Food Policy* and other recent contributions to the literature. The available evidence suggests that although international fertilizer prices increased dramatically in 2020–2022 and remained above their pre-COVID-19 pandemic level through 2024, the medium-term effects on global fertilizer demand were relatively modest. However, global aggregates obscure important short-term effects, including reduced fertilizer use and lower farm profits in smallholder production systems in many low- and middle-income countries. Although these effects varied considerably by country, dependence on fertilizer imports and vulnerability to idiosyncratic domestic shocks likely played a key role in driving these effects. The evidence synthesized in this paper reveals varying responses (across countries and farmers) and patterns of price transmission (across local and international markets) while also highlighting the potential of fertilizer subsidy programs and other policy interventions to mitigate the effects of fertilizer price volatility and improve soil health, particularly in the midst of a climate crisis that adds uncertainty to agricultural production. From a longer-term perspective, much research is still needed to unpack the effects of this crisis—and the possible effects of future crises—on the international transmission of fertilizer price shocks, policy response options to both immediate shocks and more protracted threats, farm-level strategies to increase resilience to these shocks and to encourage more judicious fertilizer use and soil health management.

1. Introduction

Between 2020 and 2024, global commodity markets witnessed an episode of major turbulence due to a combination of factors, including trade and supply chain disruptions triggered by the COVID-19 pandemic and the Russia-Ukraine war (Glauber and Laborde, 2023; Arndt et al., 2023; Alexander et al., 2023; Kee et al., 2023; World Bank, 2022; Beeler et al., 2024; Vos et al., 2025). These shocks contributed to significant and rapid increases in prices for inorganic fertilizers alongside a surge in food and energy prices. When combined with more localized and idiosyncratic shocks at the country level, it is hard to imagine a period during the last 50 years when the global food system was under such duress. While the oil price crisis in 1973–74 and the food price crises of 2007–08 and 2011–12 are standouts in the historical record, the simultaneous increases in food, energy, and fertilizer prices during this most recent episode were a strong reminder of the broad vulnerability of many parts of the agrifood system to shocks in a highly integrated global economy.

In most high-income countries (HICs), these fertilizer price shocks were monitored closely to inform policy responses, including support to firms and farms adversely affected by the rapid change in production costs (e.g., Beeler et al., 2024; Wongpiyabovorn and Hart, 2024). In most HICs, these policy interventions—combined with favorable production conditions—resulted in what appeared to be a relatively muted

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effect of fertilizer price shocks on farm profits and agricultural production (Vos et al., 2025, in this issue). However, many low- and middle-income countries (LMICs) had a different experience during this period for several reasons, including limited fiscal space to maneuver with policy responses, insufficient market intelligence, and vested interests in the fertilizer and agriculture sectors.

Even as farmers and consumers in HICs managed to weather the storm, LMICs' inability to follow suit came just as new (and sometimes rather dismal) research on LMIC agriculture and soil health were coming to light. Several new studies showed that agricultural productivity growth is stagnating in many such countries, particularly those in sub-Saharan Africa (Suri and Udry, 2022; Wollburg et al., 2024a; b). Others demonstrated declining fertilizer response rates and acute nutrient-use inefficiencies due to unbalanced fertilizer use, poor soil management practices, erosion, climate change, and many other factors (Nkonya et al., 2016; Nyondo et al., 2023). The attention given to these issues by scientists, policymakers, and farmers themselves is fueling concerns about the world's capacity to feed a growing population under the threat of climate change.

More to the point, the use of inorganic fertilizers has garnered attention both for its overuse in some LMICs and its underuse in others, both of which are detrimental to food security, environmental sustainability, and resilience to climate change. While fertilizers are undoubtedly important for plant nutrition and have been associated with sustained increases in crop yields and food security outcomes (Cassman et al., 2003; Pingali, 2012), they have also been linked with a wide range of negative externalities.

When excess reactive forms of nitrogen and phosphorus escape from agricultural soils, they can contaminate groundwater and cause eutrophication of aquatic ecosystems (Conley et al., 2009; Galloway et al., 2003; Smith et al., 1999). They also emit nitrous oxide, a potent greenhouse gas that contributes to climate change (Mosier et al., 1998; Reay et al., 2012). Of further concern are the possible human health issues associated with excess nitrogen and phosphorus in agriculture, although most of the evidence shows the effects to be indirect and complex, and are often confounded by other environmental conditions. For example, increased abundance of pathogens that transmit diseases such as malaria and West Nile Virus have been linked to nitrogen and phosphorus enrichment in ecosystems (Johnson et al., 2010; Rohr et al., 2019). Direct exposure to nutrients such as nitrates in drinking water has been shown to cause reproductive health issues and some cancers (Johnson et al., 2010; Rohr et al., 2023).

Consequently, policies that aim to address inorganic fertilizer use and soil health need to strike a careful balance between productivity and environmental impacts. Often, this requires a range of context-specific policies that help farmers to tailor their nutrient management practices in ways that simultaneously enhance fertilizer use-efficiency, make better use of complementary management practices, maintain or regenerate soil nutrients and biomes, and reduce environmental harm. But this balance is difficult to achieve in the presence of global and local market volatility, adverse weather events and climate change, and other drivers of risk and uncertainty.

This paper aims to synthesize recent evidence on the implications of price shocks in the international fertilizer market between 2020 and 2024, the policy options pursued in response to the situation, and the farm-level strategies employed to cope with the shocks. This synthesis expands on prior policy research on the role of fertilizer, soil health, and public policy in addressing productivity, sustainability, and welfare outcomes across different countries and agricultural production systems. It builds on new evidence presented in this Special Issue of *Food Policy*, while highlighting other recent contributions to the literature. It also builds on prior syntheses of the large body of research on fertilizer policy, particularly on LMICs (e.g., Jayne and Rashid, 2013; Jayne et al., 2018; Holden, 2019), as well as recent cross-country analyses and country-specific case studies (cited throughout the paper).

With this objective in mind, our paper summarizes the big picture story from the (still limited) available empirical data, while highlighting the need for more in-depth research on the social, economic, and environmental impacts of the recent price shocks in the international fertilizer market. Our interest is in how these shocks affected fertilizer use, soil health, and agricultural productivity in different production systems, and in identifying the policy interventions needed to navigate periods of market volatility. In doing so, we pose several questions that we believe are central to addressing both current and future challenges. First, what were the effects of the recent fertilizer price shock, and how heterogeneous were they across countries and regions? Second, were these price shocks transmitted to farmers and, if so, how did they affect their crop production and soil management strategies? Third, is there evidence of emerging innovations that might help to mitigate the impact of short-term shocks to fertilizer prices and availability, or of the longer long-term trends such as declining soil health?

In addressing these questions, we also explore the broader sustainability challenges that are increasingly recognized as problematic aspects of fertilizer-based intensification policies, especially those promoted in many LMICs. We consider whether strategies for sustainable growth are appropriately accounting for the private and external benefits of soil health in the policy design process (Stevens, 2018; Sterner et al., 2019). This leads to our fourth question: what are the policy options available to increase resilience to fertilizer price shocks, accelerate innovation in soil health management, and maintain agricultural productivity growth in an environmentally and socially sustainable manner?

Thematically and geographically, the papers assembled in this Special Issue tackle a wide range of important challenges. Multiple papers examine efforts to increase the uptake and adoption of inorganic fertilizers in low-input farming systems in sub-Saharan Africa, specifically, Ethiopia, Ghana, Malawi, Nigeria, Rwanda, Tanzania, and Uganda. Several papers explore efforts to leverage both policy and technology solutions to reduce the overuse of fertilizers in high-input farming systems, as in the case of China and Bangladesh. Other papers examine fertilizer use in fragile and conflict-affected food systems such as Myanmar and Ethiopia. Still other papers in this Special Issue aim to decompose changes in fertilizer prices into changes in energy prices and food prices, to examine policy responses such as export and import restrictions. Considering the coterminous nature of the food, fertilizer, and fuel price shocks witnessed over the last four years,

The studies in this Special Issue also draw from a diverse empirical toolkit—often employed under the duress of policymakers' urgent demands for guidance—to unpack the effects of economic shocks. This includes the integration and analysis of multiple layers of proprietary and public data, including high-frequency price data, spatial data, panel data, and unique datasets on conflict and violence. It also includes analyses that apply different empirical strategies to measure the effects of fertilizer subsidies, tariffs, and other policy instruments on a range of outcomes such as fertilizer prices, uptake rates, and productivity measures. Additional methods highlighted in this Special Issue highlight the role of value chain analyses in understanding bottlenecks at key nodes in the fertilizer supply chain; text-mining analysis to construct a novel fertilizer supply index to measure supply disruptions; and simulation models to provide forward-looking policy guidance.

Taken together, the research themes, data, and methods featured in this Special Issue enrich the body of research on economic shocks that affect fertilizer production, trade, and use. Our expectation is that this evidence will not only shed light on the consequences of the recent shocks, but will also inform future policy responses and identify strategies to address remaining knowledge gaps. Additionally, by identifying where important empirical knowledge gaps remain, this work helps to inform the applied research agenda around this topic in coming years.

The remainder of this paper is organized as follows. Section 2 discusses the background and context for this paper and the Special Issue. Section 3 focuses on the linkages between global and domestic fertilizer markets, and how they shaped the diverse experiences of LMICs during the recent crisis. Section 4 takes the discussion into farmers' fields to examine their responses to fertilizer price shocks. Section 5 explores technological solutions to address soil health and mitigate future shocks in farmers' fields. Section 6 returns us to the policy perspective with a set of options to accelerate fertilizer uptake and improve soil health. In Section 7, we conclude by proposing priority areas for future research and policy analysis.

2. Context and motivation

Looking across the four-year period beginning in 2020 and ending in 2024, a clear record of considerable volatility in the international fertilizer market can be seen. The World Bank's fertilizer price index began in January 2020 at 72—about 18 points below the index's base (2010) value—before peaking at 294 in April 2022 and returning to 120 by December 2024 (Fig. 1). During the 12-month period beginning in March 2020, the price of diammonium phosphate (DAP) and triple superphosphate (TSP) increased by 91 % and 85 %, respectively, while urea prices increased by 45 % and muriate of potash (MoP) by 24 % (World Bank, 2025).[1]

It may seem intuitive to simply attribute these price shocks to the COVID-19 pandemic, which was officially declared by the World Health Organization in March 2020, or on the Russian invasion of Ukraine, which began in February 2022. However, the underlying drivers of the crisis are more complex, as is their timing. For example, beginning in mid-2020, prices for natural gas in Europe began to rise slowly before gathering momentum driving prices to a 23-fold increase by late 2021 (World Bank, 2025). This contributed to higher European production costs for ammonia, a primary component in nitrogenous fertilizers such as urea. Meanwhile, prices for potash began increasing steeply in mid-2021 after the European Union and the United States imposed sanctions and other restrictive measures on potash imported from Belarus (European Union, 2022). At roughly the same time, China introduced export restrictions on phosphates and urea to shore up supplies for its own agriculture sector, resulting in significant reductions in supplies available to the international market (Kee et al., 2023; also see Hu et al. (2025) in this issue).

After a short-lived decrease in prices for several key fertilizers (Fig. 1), the Russia-Ukraine war sent another shock wave into the international market. Ukraine, Russia, and Belarus are all key producers and exporters of fertilizers (Fig. 2), and the economic sanctions and trade restrictions that followed the invasion contributed to a second spike in fertilizer prices. In early 2022, the European Union introduced a ban on fertilizers from both Russa and Belarus, and Canada imposed a 35 % tariff on Russian fertilizers, while Russia introduced its own ban on the export of nitrogenous fertilizers (Glauber and Laborde, 2023; Vos et al., 2025). Natural gas prices in Europe similarly spiked over the period (World Bank, 2025), further increasing production costs for nitrogenous fertilizers.

During the 36 months that followed, the economic sanctions, tariffs, import bans, and export bans were further modified to accommodate changing outlooks on raw material supplies, agricultural production, food security, and the conflict itself (Kee et al., 2023; Morão, 2025). While trade patterns between countries shifted as they sought to secure fertilizers from other sources during this period, international fertilizer prices in late 2024 were still slightly higher than they were prior to 2020 (Fig. 1).[2]

Although we still lack detailed export and import data from all global fertilizer trade partners, recent import data from fertilizer-importing countries suggest that countries that had previously relied on fertilizer imports from Russia and Belarus were able to meet their needs through increased imports from other countries (Glauber and Laborde, 2023; Vos et al., 2025). While the overall impact of the trade and economic sanctions on Russia and Belarus may have limited impact on the overall volume of fertilizer trade in global markets (Vos et al., 2025), fertilizer prices remained above pre-COVID-19 levels until early 2024, especially in LMICs. For example, while international fertilizer prices continued to stabilize, domestic fertilizer prices remained higher than pre-pandemic levels in many African countries (Fig. 3; see also Ricker-Gilbert, 2025; Ricker-Gilbert et al., 2024b). Furthermore, although the impact on overall volume of fertilizer traded may be limited, the trade disruptions and surge in fertilizer prices are likely to affect import-dependent countries and these effects are likely to vary across countries depending on their vulnerability and reliance on fertilizer imports (Abay et al., 2023; Zhang et al., 2023; Vos et al., 2025).

At the country level, prices were further influenced by tariffs, nontariff barriers, subsidies, taxes, and other policy instruments that were introduced, changed, or withdrawn during the period. In the United States, for example, the spike in phosphate prices was partly driven by countervailing duties imposed on Moroccan phosphate imports in 2021 (Beeler et al., 2024). During the same year, Sri Lanka removed its subsidies on fertilizers in conjunction with a national policy initiative meant to move the country away from chemical input use in farming. The headline results—a 30 % decrease in rice production between 2021 and 2022—were almost immediate (Niwarthana et al., 2023; Ghose et al., 2023).

Country-level experiences are also marked by considerable heterogeneity. The magnitude of shock transmission varies with a country's degree of dependence on fertilizer imports, its ability to mobilize foreign exchange to purchase fertilizer from the international market, and the severity of earlier COVID-19 restrictions that impacted farming, labor mobility, and the movement of fertilizer and agricultural commodities, among other factors (Abay et al., 2023; Zhang et al., 2023; Ayalew et al., 2025; Vos et al., 2025). For example, while landlocked fertilizer-importing countries in Africa such as Malawi, Rwanda, and Zambia had to contend with shocks to both fertilizer and transport costs during the crisis, several fertilizer-exporting countries posted gains as a result of increased revenues and profits for their commercial fertilizer companies (ECIU (Energy Climate Intelligence Unit), 2023).

All these experiences suggest that the fertilizer price shocks experienced during this period represent a complex set of policy interventions that affected production, trade, and use in many ways around the world. And when policy interventions combine with more idiosyncratic events such as adverse weather, civil conflict, or war, they can introduce a significant amount of uncertainty that can echo to farmers and

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[1] DAP prices are measured at spot free on board (FOB) US Gulf prices, while TSP is measured at US Gulf import prices (World Bank, 2025). Urea prices are measured for prilled urea at spot FOB Black Sea prices to February 2022 and at FOB Middle East prices beginning in March 2022 (World Bank, 2025). MoP (potassium chloride) prices are measured at Brazil cost and freight (CFR) granular spot prices.

[2] Note that the phosphate prices decreased only in late 2023, approximately 18 months after other fertilizer prices began to decline (Fig. 1). The decrease in phosphate prices is associated with the release of phosphate inventories from China that were previously held back from the international market, a reduction in US tariffs on Moroccan phosphate exports, and several other factors specific to the global phosphate market.

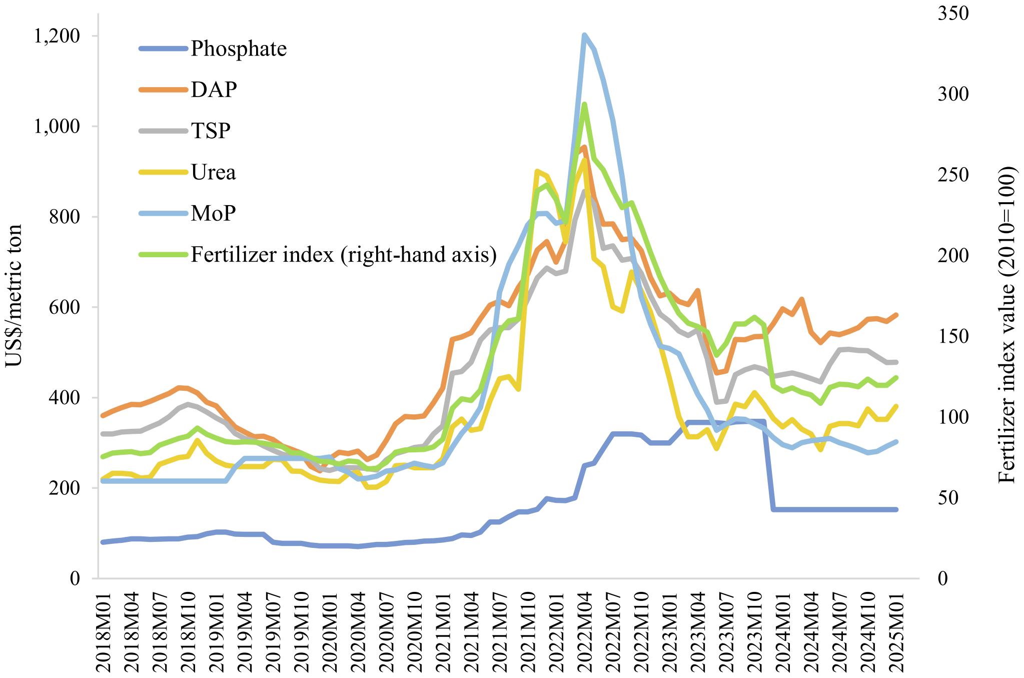
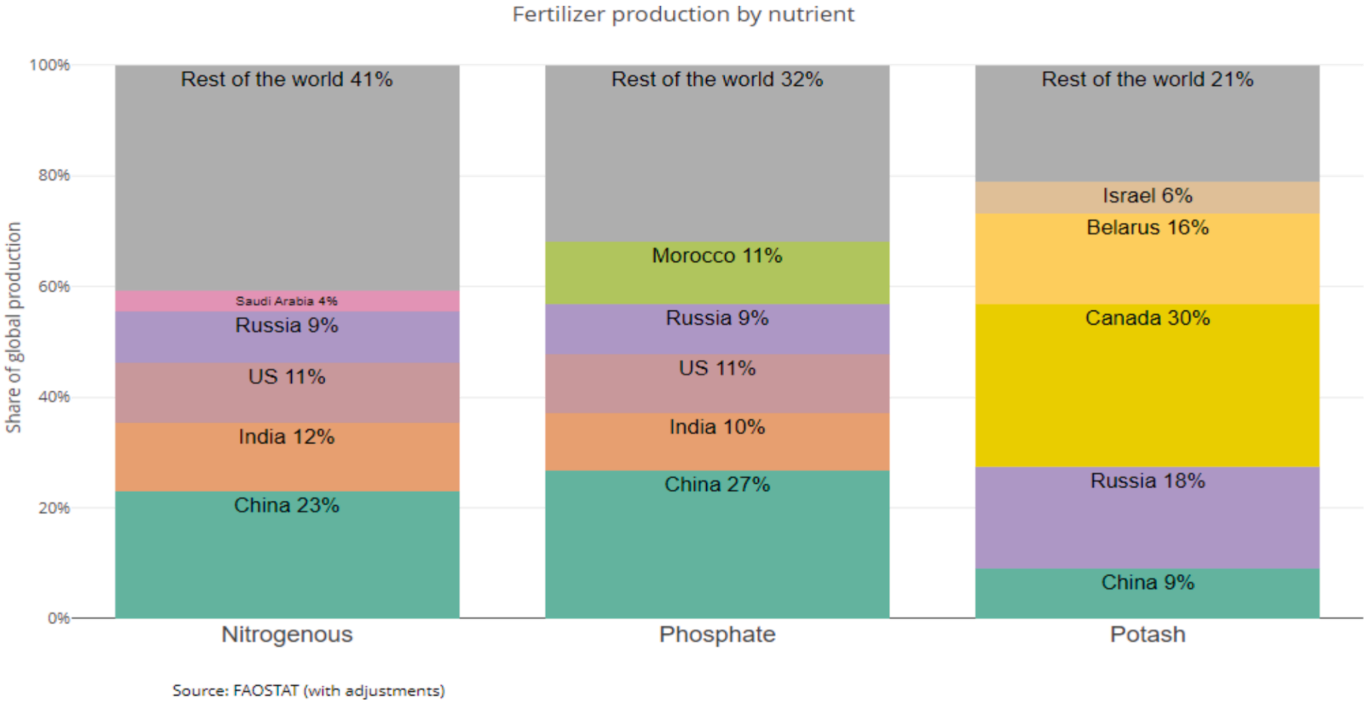


Fig. 1. Monthly fertilizer prices, 2018–2024 (nominal US$/metric ton). Source: World Bank (2025). Note: All fertilizer product prices are measured on the left-hand axis; fertilizer index values are measured on the right-hand axis. “Phosphate” denotes phosphate rock prices at FOB North Africa; “DAP” denotes diammonium phosphate at spot FOB US Gulf prices; “TSP” denotes triple superphosphate at US Gulf import prices; “MoP” indicates muriate of potash (potassium chloride) at Brazil cost and freight (CFR) granular spot prices; and urea is at spot FOB Black Sea prices to February 2022 and at FOB Middle East prices beginning in March 2022. Fertilizer index is based on monthly indices based on nominal US dollars, 2010 = 100. See World Bank (2025) for details.



Source: FAOSTAT (with adjustments)

Fig. 2. Concentration of global fertilizer production Note: These numbers and shares are assembled from FAOSTAT. In cases where production is less than net exports + domestic use, production was calculated as follows: export quantity − import quantity + agricultural use.

consumers alike. This is seen in Ethiopia, Nigeria, and Myanmar, where the global price shock combined with civil conflict to negatively affect fertilizer usage and agricultural production (Ayalew et al., 2024; Amare et al., 2025; also see Assefa et al. (2025) and Takeshima et al. (2025) in this issue).

Against this backdrop, one might argue that the recent fertilizer price crisis expands the standard historical debate—how to increase agricultural production to feed a growing population while conserving the natural resource base—to encompass the question of how to prepare for the unexpected and navigate through increasingly frequent periods of volatility, risk, and uncertainty. One way of informing this debate and navigating future turbulence is to close the evidence gap on how to increase fertilizer use and improve soil health through public policy interventions.[3] This means using data-driven analysis to identify policy instruments that improve fertilizer use-efficiency, improve soil organic matter, and deliver information that farmers can use to pursue requisite practices. It also means addressing trade and economic policy issues such as tariffs and subsidies on fertilizer, or public investment in agricultural research and development, extension and advisory services, and market infrastructure. These policy instruments are especially relevant for sub-Saharan Africa, where evidence gaps remain even after many countries committed to increasing their fertilizer use rates to 50 kg/hectare by 2025 under the 2014 Malabo Declaration (African Union, 2014). The African Union member states are now pursuing a new set of goals and targets inspired by the 2024 Africa Fertilizer and Soil Health Summit and the 2025 Kampala Declaration (see, e.g., Vanlauwe et al., 2023), making these issues even more salient to the continent's policy agenda for agricultural development.

Similar evidence gaps also exist across much of Asia, Latin America, and the HICs, where research has demonstrated the human and environmental threats posed by high-input agricultural systems and imbalanced fertilizer use (e.g., Vitousek et al., 2009; Sutton et al., 2011; FAO (Food and Agriculture Organization of the United Nations, 2019; Snapp et al., 2024). Many of these countries are developing strategies, policies, and technologies aimed at restoring soil health and other ecosystem services affected by the misuse of chemical inputs (Sela et al., 2024; Sterner et al., 2019; Zhang et al., 2013). Other countries are grappling with issues that revolve around how to address fertilizer industry concentration (Bekkerman et al., 2020).

While the nature of the policy problems facing different countries may vary radically by context, evidence-based policy options for building resilience to economic shocks, and for jointly stimulating agricultural productivity growth and environmental sustainability, are high on the policy agenda. In many HICs, policy instruments may still be required to strike a better balance between the interests of profit-maximizing farms and firms in the agriculture sector with social and environmental objectives (e.g., DeBoe, 2020; Lankoski and Thiem, 2020). In many LMICs, policies may still be needed to: increase the use of inorganic fertilizers where they are currently underutilized (Vanlauwe et al., 2014; van Ittersum et al., 2016; Jayne and Sanchez, 2021); promote more judicious use where they are inappropriately applied (Dobermann et al., 2002; Jat and Gerard, 2014; Snapp et al., 2024); and more carefully manage them where implementation falls short of intention (Jayne et al., 2018).

It is also important to keep in mind that fertilizer and soil health policies are not simply about economic choices. Rather, they are highly contested and politicized subjects (e.g., Resnick, 2024). For example, in LMICs where fertilizer is distributed under large-scale subsidy policies and programs, long-held concerns about sociopolitical frictions (Mason et al., 2017; Birner et al., 2011) sit alongside issues relating to rent seeking and leakages (Ricker-Gilbert et al., 2013; Gulati and Banerjee, 2015), private sector crowding out (Ricker-Gilbert et al., 2011; Spielman et al., 2010), and the incentivization of deforestation and other unsustainable production practices (e.g., Morgan et al., 2019; Pelletier et al., 2020). In many HICs, equally contested discourses exist, including those related to economic distortions induced by these (e.g., Stuart et al., 2014; Anderson and Strutt, 2023).

Why revisit these issues now? Have the research questions and policy options changed? We argue that the global economic shocks experienced over 2020–2024 reveal new vulnerabilities that threaten the resilience of global and domestic markets for fertilizer, food, and agricultural products. The transmission of information about prices, expectations, and predictions—ranging from food shortages to environmental externalities—tends to travel much faster than even a decade ago. Likewise, policy interventions may be more sensitive to this information than in previous crises.

Part of the policy experience during this recent crisis may reflect the increased availability of analytical tools and better communication of research and analysis to policymakers. Today, we have better data and newer methods to investigate old questions in new ways, to address questions that have not yet been examined, or to generate results more quickly than in the past. For example, the increased availability of longitudinal data on farm households spanning a decade or more[4] now makes it feasible to empirically assess the drivers of outcomes such as changes in crop and land use choices, declining nutrient-use efficiencies at the farm level, and heterogeneity across crops, systems, and contexts (Binswanger-Mkhize and Savastano, 2017; Sheahan and Barrett, 2017; Holden, 2018; Holden, 2019). Spatial data layers aligned with household data enrich these analyses as do new impact evaluation techniques that expand the possibilities of working with panel data (Roth et al., 2023). New data and methods also allow us to explicitly capture spatial variability to inform localized or context-specific fertilizer use recommendations, soil health investments, and broader policy and program options, as demonstrated by several papers in this Special Issue (e.g., Spielman et al., 2025).

Equally important is the growing evidence of scientific innovation and technical progress around fertilizer use, soil health, and nutrient management. These include digital decision support tools that encourage learning about soils and precision application of inorganic and organic fertilizers (Ayalew et al., 2022; Oyinbo et al., 2022). An example featured in this Special Issue explores the impact of site-specific soil tests using a handheld reflectometer as a starting point for in-depth discussions with extension agents about soil management in Malawi (Nyondo et al., 2025). Other innovations address dimensions such as farm management practices, crop genetics, or the use of waste materials to boost agricultural productivity, increase fertilizer use-efficiency, or restore long-term soil health. These types of innovations—among many others—can potentially offset the need for additional inorganic fertilizers of both major nutrients (N, P, and K) and the traditionally overlooked micronutrients (B, Zn, Mn, Fe, Cu, Mo, CI) that are required to increase agricultural productivity, especially in the low-input production systems found across the Global South.

3. The linkage between global and domestic fertilizer markets

Next, we explore the linkage and transmission of price shocks from the global economy to local economies and the role of policy in mitigating those shocks and their associated productivity and welfare outcomes. The recent fertilizer price crisis demonstrates that price transmission from global to domestic fertilizer markets depends on several factors: (i) the level of concentration and consolidation of global fertilizer production and trade; (ii) the nature and causes of shocks to international fertilizer markets; (iii) the breadth and strength of integration between international and domestic markets; and (iv) domestic and international policy responses. Global fertilizer trade and markets are characterized by high (and increasing) levels of concentration and

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[3] For a review and mapping of evidence gaps in agricultural innovation agricultural-led growth in LMICs, see the International Initiative for Impact Evaluation (3ie) evidence gap reports and maps by Lopez-Avila et al. (2017) and Engelbert et al. (2023).

[4] The most notable examples are the nationally representative Living Standards Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA) conducted in eight countries in sub-Saharan Africa with support from the World Bank. See Amankwah et al. (2025) in this issue. Countries such as China also collect longitudinal survey data, for example, the National Fixed-Point Survey, which has collected data from rural households since 1986 through the Research Center for Rural Economy (RCRE) of the Chinese Ministry of Agriculture. See Xu et al. (2025) in this issue.

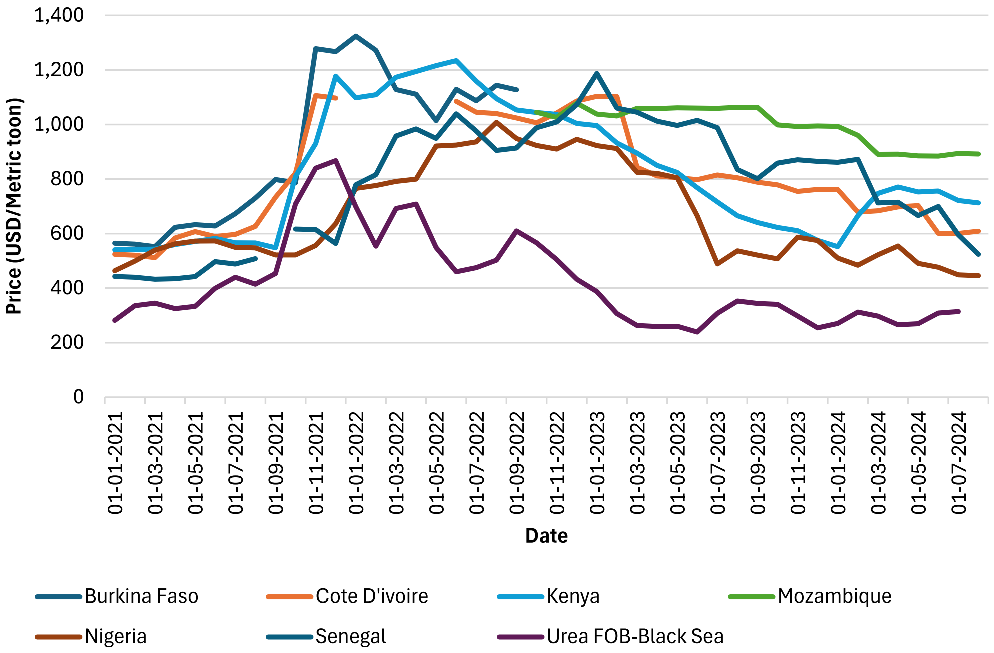

Fig. 3. International price of urea compared to retail prices in selected African countries, 2021–2024. Source: AfricaFertilizer (2024).

consolidation, with production and export originating from a small number of large firms in a small number of countries (Fig. 2). As shown in Fig. 2, a limited number of countries supply a large share of the global production of major nutrients (N, P, and K). At the country level, imports and distribution in many countries—particularly LMICs—are similarly concentrated among a small number private and state actors with outsized influence and considerable capacity to shape fertilizer supply and prices (Hernandez and Torero, 2013; Hernandez et al., 2024; see Morão (2025) and Vos et al. (2025) in this issue).

The extent to which LMICs can use domestic policy instruments to mute the transmission of global price shocks is seemingly limited. Beyond the actual export restrictions and trade disruptions caused by the sanctions, the shocks to global food-fertilizer-fuel markets created economic policy uncertainties and precautionary demand effects, which can affect and distort equilibrium prices implied by the demand for and supply of fertilizer (Janzen et al., 2018; Baker et al., 2016; Morão, 2025). Baker et al. (2016) demonstrate that economic policy uncertainty generated by different shocks can increase price volatility and reduce investments in relevant sectors. Building on Baker et al. (2016), Morão (2025) constructs an index to capture shifts in global fertilizer policy using text-mining approaches covering more than 30 countries. Focusing on Portugal, Morão (2025) demonstrates that the fertilizer shortage index predicts output prices, with fertilizer scarcity associated with higher output prices.

The COVID-19 pandemic as well as the subsequent Russia-Ukraine war upended food and energy prices, including those of natural gas and crude oil. While an increase in food prices can increase demand for fertilizer, a surge in energy prices is likely to increase the cost of fertilizer production. Natural gas is an important input to produce nitrogen and ammonia fertilizers.[5] Russia is a major producer and exporter of natural gas and the trade sanctions on Russia as well as export restrictions from other countries increased the cost of fertilizer production. The linkage between domestic food and fertilizer prices and international energy price is well documented. For example, Dillon and Barrett (2016) show that the linkage between global oil prices and local maize prices in Africa is stronger than that between global and domestic maize prices, highlighting the role of transportation cost. Similarly, Wongpiyabovorn and Hart (2024) estimate pass-through rates of natural gas and corn price changes to fertilizer prices and show that the effect of changes in natural prices recently dominated those arising from changes in corn prices. More recently, Vos et al. (2025) estimate pass-through rates of international natural gas prices to international nitrogen fertilizer prices and argue that energy prices triggered significant influence on fertilizer prices. Another study by Hu et al. (2025) decomposes changes in urea prices in China into four structural shocks: changes in energy prices, changes in crop prices, demand shocks, and idiosyncratic shocks. Following this exercise, Hu et al. (2025) demonstrate that rising energy costs and idiosyncratic shocks were the main factors driving movements in urea price in China in 2018–2023.

Finally, the implication of shocks to global fertilizer markets on domestic fertilizer markets depends on underlying integration and price transmission between international and domestic markets. Although we lack rigorous and recent analyses on the degree of transmission of global shocks to local fertilizer markets, previous studies characterizing such linkages before the recent shocks suggest that they were not strong. For example, Shimeles et al. (2015) show a large and persistent gap between domestic retail prices and import prices in fertilizer in Africa even after accounting for transportation cost, a deviation they attribute to market power by importers/suppliers and associated market imperfections. Similarly, Bonilla-Cedrez et al. (2020) compile retail fertilizer prices and uncover considerable spatial variation in fertilizer prices within African countries, with such spatial variations being larger among those countries without national fertilizer subsidy programs. The interaction and transmission between international and domestic fertilizer prices are likely to be weaker in developing countries, where the trade networks and infrastructure may be weak. For example, Ceballos et al. (2017) characterize price transmission from international prices to domestic markets among 41 domestic food products across 27 developing countries in Africa, Latin America, and South Asia and observe significant

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[5] The surge in global oil prices can also affect the distribution and availability of fertilizers in domestic markets by increasing transportation cost (Dillon and Barrett, 2016).

price transmission in only a few cases and markets.[6] Finally, focusing on China, Hu et al. (2025) demonstrate that Chinese fertilizer markets are not fully integrated with international fertilizer markets and prices, partly attributable to the disparity between coal prices and international natural gas prices.[7]

The price transmission between international and domestic fertilizers may also follow asymmetric patterns, with both prices co-moving quickly when rising and slowly when falling (Meyer and von Cramon-Taubadel, 2004; Etienne et al., 2016; Dillon and Barrett, 2016; Loy et al., 2016; von Cramon-Taubadel and Goodwin, 2021; Willwerth et al., 2025). For example, Willwerth et al. (2025) show that domestic prices in Kenya were faster to respond to increases in international prices than corresponding declines. Other recent work show that while fertilizer prices in much of the developed world returned to near pre-spike levels in 2023, this was not the pattern observed in sub-Saharan Africa where countries are less well integrated with global markets (Ricker-Gilbert, 2025; Ricker-Gilbert et al., 2024b).

Some of the features of fertilizer markets, including the consolidation and concentration of market power among few actors, can contribute to asymmetric price transmission in fertilizer markets (Meyer and von Cramon-Taubadel, 2004; Etienne et al., 2016; Loy et al., 2016; von Cramon-Taubadel and Goodwin, 2021; Willwerth et al., 2025). Although formal and empirical tests for asymmetric price transmission in fertilizer markets remain missing, some descriptive data from Africa suggest domestic prices quickly responded to increases in international fertilizer prices, but they failed to follow suit when international prices started falling (Fig. 3). The underlying reasons for such asymmetric integration patterns remain unclear, as do potential policy responses.

4. Implications on farm-level decision-making and productivity outcomes

Next, we explore how price shocks may have shaped farmers' choices and their on-farm productivity outcomes. We do so considering the fact that: (i) improving agricultural productivity through improved fertilizer use-efficiency in ways that maintain or improve soil health and long-term sustainability is a major challenge, with some consensus around the need for better integration of organic and inorganic fertilizer management (Snapp et al., 2024; Kishore et al., 2021), as well as complementary natural resource management practices for water; and (ii) farm-level data from various countries and regions suggest that insufficient progress is being made toward achieving these goals (Ladha et al., 2020; Suri and Udry, 2022).

The impacts of coterminous food, fertilizer, and fuel price shocks on fertilizer usage and related productivity outcomes in a given country or local economy are not necessarily straightforward to predict a priori. Fertilizer price increases could be compensated for by food price increases if they remain roughly proportional and are transmitted over the same period.[8]

However, if fuel prices also increase, we expect a rise in the variable cost of getting fertilizer to the farm gate and bringing farm output to urban markets. At any given set of prices, farmers will not find fertilizer use to be profitable beyond some threshold of distance to markets. Such a threshold may be pulled closer to markets under fuel price increases, effectively locking out a larger share of relatively remote farmers from profitable input and output market participation.

But detailed empirical evidence on how this played out in the recent period remains limited. Ricker-Gilbert et al. (2024a) assemble estimates of fertilizer-maize price ratios in several countries in SSA, finding substantial increases in 2021–2022, indicating worsening profitability. The most direct evidence of corresponding impacts on fertilizer demand in smallholder farms in Africa comes from phone survey data. Assefa et al. (2025, in this issue), using data from Ethiopia, and Amankwah et al. (2025, in this issue), using data from Burkina Faso, Ethiopia, Malawi, Nigeria, Tanzania and Uganda, assemble evidence of fertilizer use declines in response to price increases, with smaller farms relatively more responsive to changes in fertilizer prices. Amankwah et al. (2025) show a substantial rate of dis-adoption of chemical fertilizer following the surge in fertilizer prices, with such disadoption being more pronounced among poorer farmers. Assefa et al. (2025) also find such effects to be larger for households operating smaller farms. Both Amankwah et al. (2025) and Assefa et al. (2025) report affordability being a major reason for such reduction in chemical fertilizer use. However, Assefa et al. (2025) find little evidence that fertilizer demand is responsive to output prices, which they attribute to the partially subsistence orientation of many production strategies of Ethiopian smallholders. Both studies find the negative effects of fertilizer price increases to be most pronounced at the intensive margin of fertilizer usage, with smaller and largely insignificant effects at the extensive margin. This suggests that farmers who use fertilizer rely on it to meet minimum production needs. Amankwah et al. (2025) assemble evidence that many farming households (especially poorer ones) coped with increased fertilizer prices by reducing application rates and areas, and in some cases sold assets or borrowed money to meet fertilizer consumption needs, strategies that may have increased their exposure to shocks in subsequent periods. Although these findings are important, they stop short of estimating aggregate productivity and welfare impacts at national and regional levels, which remain largely unknown.

Furthermore, we still have no direct microlevel evidence to date of how these shocks played out with farmers in other regions. Recent studies on impacts in other regions either focus on market price data transmission (e.g., Hernandez et al. (2024) for Latin America) or modeling exercises (e.g., Alexander et al. (2023) for global impact estimates of welfare and environmental outcomes). It is also worth noting that in addition to these shocks associated with global markets, smallholder farmers in many parts of the world continue to grapple with weather and climate related shocks, which can also shape or amplify their responses and vulnerability to international price volatility. For example, smallholder farmers in Africa are likely to reduce fertilizer use in response to drought (Ahmed, 2025; Mulungu et al., 2025, both in this issue) or warmer temperatures (Jagnani et al., 2021).

Ragasa et al. (2025, in this issue) take a broader view to updating the literature on maize yield responses to fertilizer use in six sub-Saharan African counties (Ethiopia, Ghana, Malawi, Nigeria, Tanzania, and Uganda), updating an empirical literature with a long history with nationally representative data spanning much of the last decade. They find evidence that fertilizer-grain price ratios have generally been declining (except in some countries affected by exposure to the shocks associated with the Ukraine invasion in the last few years), and that despite relatively low nitrogen yield responses in many countries, apparent fertilizer profitability is at odds with the low levels of usage in most countries. Importantly, however, these are average estimates, which mask important variation. Assefa et al. (2025) estimate that fertilizer is not profitable for as many as one-half of the maize and teff producers in their sample, and this share increases after the recent surge in fertilizer prices.

But even these estimates may fail to reflect the incentives that face would-be fertilizer users in risk-prone, resource-poor settings. Marginal

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[6] Similarly, Antonio et al. (2025) assess price movements and transmission in Africa and Asian retail markets in response to India's export restrictions on non-basmati rice.

[7] While much of global urea production relies on natural gas, China's urea production relies mostly on coal.

[8] Although parallel increases in international fertilizer and agricultural commodity prices may mean that farmers can repurpose gains from the latter to invest in fertilizers, this depends on several factors and constraints, including farmers' elasticity of demand to changes in fertilizer and food prices (e.g., Assefa et al., 2025, in this issue).

and average value-cost ratio estimates, with profitability summarized as the share of farms exceeding some threshold[9] in a sample, are typically derived from production functions that generalize responses across heterogenous populations.[10] However, as memorably documented by Suri (2011), even when average returns are high, heterogeneity in production conditions and managerial capacities may mask high variability in investment returns. Furthermore, self-reported responses in farm survey data are prone to potentially nonclassical measurement error (e.g., Abay et al., 2019; Gourlay et al., 2019; Abay et al., 2021). Input and output price data are typically only observed for market participants, and may be biased toward more favorable price ratios obtained by those who participate relative to nonparticipants.

Better farm survey data collection efforts should help improve our estimates of agronomic and economic returns to fertilizer usage. Recent methodological work uncovering sources of bias in measurement are very relevant (Abay et al. 2019, 2021, 2023; Burke et al. 2023) and may help improve the accuracy of individual response measurements, leading to better estimates of response variability in samples. However, information about local input and output prices is still notoriously thin in most LMICs (Aker, 2011; Zanello and Srinivasan, 2014; Bonilla-Cedrez et al., 2021; Baulch et al., 2024). This is hard to assemble from survey data, due to noise and patchiness, and there are good reasons to believe that average prices estimated in this way for a large area may systematically overestimate profitability for many farmers. New work on predicting prices in data-sparse environments is promising (Bonilla-Cedrez et al., 2020; Chamberlin et al., 2024; Madaga et al., 2024).

5. Emerging innovations for sustaining soil health

Next, we consider the role of innovation in improving soil health and building resilience against future shocks related to fertilizer prices, adverse weather events due to climate change, or more idiosyncratic events. This is a topic that receives considerable treatment in the Special Issue, and thus warrants further attention here.

Soil health is a multidimensional, dynamic concept in which soil functions as a living ecosystem (Lehmann et al., 2021). Soil health is influenced not only by its inherent physical, biological, and chemical properties, but also by agricultural inputs, tillage methods, crop rotations and other farm management practices. There are considerable disparities in soil health management practices across countries and regions. For example, under-fertilization, common in low-input systems in sub-Saharan Africa, is linked with poor soil health, nutrient mining, and land degradation. Continuous cultivation with insufficient addition of external nutrients results in nutrient mining (Vanlauwe et al., 2023) with corresponding declines in soil health and productivity. On the other hand, excessive fertilizer application, often observed in production systems in high-, middle-, and low-income countries, is associated with losses of nutrients from agricultural land, causing environmental pollution and, indirectly, human health issues (Galloway et al., 2003). Evidence suggests that improved soil organic carbon stocks and other measures of soil health can improve fertilizer use-efficiencies and, thus, the profitability of fertilizer investments by farmers (e.g., Chamberlin et al. 2021). Improving fertilizer responses will also improve the returns to fertilizer subsidy investments at the national level, as the yield and production gains to a given volume of public fertilizer expenditures will increase (Jayne et al. 2018). As such, R&D and extension investments to develop and scale innovative solutions to maintain and improve soil health can and should be aligned with shorter term productivity goals for agriculture.

A promising pipeline of innovative agronomic solutions exists for soil health, including microbial inoculants or processed human waste products (e.g., Simons et al., 2014; Powers et al., 2019; Magwaza et al., 2020; Simons et al., 2023). Other innovations aim to enhance soil biomes, plots, systems, and landscapes through sustainable, regenerative, or agroecological strategies.[11] Still others take a similar approach by advancing circular bionutrient systems that generate synergies and co-benefits between food production, soil health, and nutrient conservation. A relevant example is the use of planting pits—a practice that draws on traditional knowledge and practice in West Africa—to increase soil organic matter content and moisture in arid and semi-arid agroecologies (Aker and Jack, 2023). Other innovations seek to increase fertilizer use-efficiency by introgressing nitrogen use-efficiency traits into field crop breeding pipelines (Garnett et al., 2009).

While this pipeline of innovations is no doubt critical to soil health and climate resilience, it suggests the need for a long-term horizon for strategic policy decisions. But when faced with fertilizer price volatility, policymakers often require solutions with shorter time horizons. One class of soil health innovations that might be particularly relevant in this context contains those that focus on managing both the spatial and temporal variability of agricultural production to improve yields, reduce costs, and minimize use of scarce natural resources. For example, farmers in highly commercialized mechanized production systems are making increased use of systems that integrate remote sensing, machine learning, artificial intelligence, and other information technologies with automated equipment, robotics, wireless sensor networks, and drones to improve the timing and precision of crop production and management (e.g., Cisternas et al., 2020). A key potential advantage of such approaches is they can help to optimize farm management such that economic returns to soil health investments are maximized for different contexts.

But in many LMIC smallholder production systems, such decision support infrastructure remains rare. Instead, considerable attention is being given to more context-appropriate innovations for smallholder systems: site-specific nutrient management (SSNM) and, in particular, digital decision support tools (DSTs) for SSNM.[12] These tools build on prior scientific efforts to develop field-, season-, and crop-specific solutions that take spatial heterogeneity into consideration, for example, integrated soil fertility management (ISFM) (Vanlauwe et al., 2010; Vanlauwe et al., 2023), 4R nutrient stewardship (Johnston and Bruulsema, 2014), and site-specific nutrient management (Dobermann, et al., 2002), the latter of which inspires the name that we use to describe this broad class of innovations. Their digital versions are often built around relatively simple smartphone-based apps with backend analytics that use locally calibrated models to optimize yields or profits according to attributes such as crop variety, soil type, fertilizer costs, agroecological zone, and location.

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[9] An average value cost ratio (AVCR) of two is a frequently used indicator of the level at which fertilizer is considered sufficiently profitable to overcome risk and various other hidden costs not explicitly accounted for in the AVCR calculation. See Assefa et al. (2025) and Spielman et al. (2025), both in this issue.

[10] In fact, many of the recent studies that draw on new data and innovative methods suggest that even where returns to fertilizer investments are positive in expectation, averages mask considerable heterogeneity and suboptimal incentives facing risk-averse farmers, particularly in rainfed production systems in developing regions (Marenya and Barrett, 2009; Suri, 2011). More recently, the literature has started to use data and methodological advances to unpack the sources of this heterogeneity with better estimates of spatially varying soil conditions and fertilizer responses (Marenya and Barrett, 2009; Harou et al., 2017; Burke et al., 2017, 2022; Emran et al., 2019; Liverpool-Tasie et al., 2017; Liverpool-Tasie, 2017; Chamberlin et al., 2021), along with spatial heterogeneity in input and output prices (McCullough et al., 2022; Bonilla Cedrez et al., 2020).

[11] For a thoughtful review on the genealogy of sustainable agriculture narratives and terminologies, see Bless et al. (2023).

[12] Examples include Rice Crop Manager (https://cropmanager.irri.org), RiceAdvice (https://www.riceadvice.info/en/), Nutrient Expert (https://www.nutrientexpert.cn/), and Virtual Agronomist (https://www.isda-africa.com/virtual-agronomist/), among others.

Extensive agronomic research has demonstrated that where SSNM approaches have been adopted in Asia and Africa, they can potentially generate triple gains of increased yields, profits, and nutrient use-efficiency, albeit with variations in the magnitudes across these outcomes depending on country and context (Chivenge et al., 2021; 2022; Sida et al., 2023). Several applied economics studies have also demonstrated that SSNM approaches—including, in some cases, digital DSTs—can generate significant yield and profit effects under farmers' real-world conditions (Arouna et al., 2021; Ayalew et al., 2022; Oyinbo et al., 2022, 2024; Nyondo et al., 2025, in this issue). Adoption and returns to SSNM practices are likely to be heterogeneous across farm sizes because of structural and economic barriers and costs. For somesmall-scale farmers the fixed costs of adopting SSNM practices and associated technologies may outweigh the potential benefits, which in turn, justifies non-adoption. However, there are still few studies that explore the impact and cost-effectiveness of SSNM practices and DSTs that are on a pathway to scaling as part of a government program or commercial venture (Oyinbo et al., 2024 is a recent exception) and the absence of evidence of successful scaling is telling (Sida et al., 2023). This lack of evidence has implications for public policy. Without sufficient evidence on impact, cost-effectiveness, and feasible scaling pathways, it is difficult for policymakers, private investors, or entrepreneurs to allocate resources to advance innovations such as digital DSTs for SSNM. The same may be said for many of the longer-horizon, system-level innovations such as minimum tillage, agroecology, or regenerative agriculture, or even small-scale, shorter-horizon technologies that have been around for some time, such as fertilizer microdosing, urea deep placement, planting pits, and composting.

One key potential benefit of SSNM approaches is that they may help to address some of the negative environmental externalities associated with fertilizer over-application, e.g., water pollution associated with run-off, GHG emissions, and acidification. The latter issue highlights one of the ways in which not only are crop responses to fertilizer conditioned by soil health, but soil health in turn may be affected by fertilizer decisions. Local institutions and policies can support such efforts to reduce negative externalities associated with overuse of chemical fertilizers by facilitating sustainable land and soil health management practices. For example, Xu et al. (2025, this issue) show that agricultural production organizations in China help to reduce overuse of inorganic fertilizer..

Relatedly, sustainable SSNM and broader agronomic advisory approaches may help to deliver locally viable recommendations for integrated soil fertility management (ISFM), which focuses on the combined application of organic resources and mineral fertilizers, with adoption of improved seeds and local adaptation (Vanlauwe et al., 2010). The ISFM approach has been shown to improve productivity and soil health through increased soil organic carbon (Chivenge et al., 2011; Kihara et al., 2020; Vanlauwe et al., 2023) and is a practical solution for farmers who have both organic resources and fertilizers but in limited quantities. ISFM has also been shown to improve agronomic nutrient use efficiency and thus reduce nutrient losses to the environment (Vanlauwe et al., 2011). A review by Kihara et al. (2020) showed up to a four-fold increase in crop yields with the adoption of ISFM with reduced greenhouse gas emissions, whereas there was overall improvement of soil health through increased soil infiltration, reduced runoff and soil erosion, and increased soil biodiversity. A similar approach, integrated nutrient management, has also been shown to increase crop yields, improve grain quality and soil health while reducing nutrient losses to the environment and greenhouse gas emissions (Wu and Ma, 2015). Much of the existing ISFM literature emphasizes the evaluation of agronomic and soil health returns; further work evaluating the economic costs, benefits, and constraints to adoption of ISFM will be important to clarify viable scaling pathways and supporting policies. Furthermore, such cost-benefit analyses associated investments in soil health should consider and account for both private benefits and external environmental benefits (Stevens, 2018).

6. Public policy options to ensure sustainable fertilizer and soil health management

Finally, we consider the public policy response options to the recent fertilizer price crisis or similar future crises. We focus on three major policies: (i) fertilizer subsidies; (ii) fertilizer market competitiveness; and (iii) public investment in innovation at scale.[13] Fertilizer subsidies are central to the fertilizer market narrative in many LMICs. Considerable evidence indicates that previous generations of fertilizer production and consumption subsidy programs have underperformed in terms of boosting productivity, and have generated sizable negative environmental externalities in the process in much of Asia (Gulati and Banerjee, 2015) and Africa (Jayne and Rashid, 2013; Ricker-Gilbert et al., 2011, 2013). This includes even the "smart subsidies" or targeted programs rolled out in several African countries to make fertilizer widely available and affordable to high-potential smallholders (Dorward et al., 2008). These subsidies have also incurred high fiscal and transaction costs and created political and social liabilities (Gulati and Narayanan, 2000; Mason et al., 2017; Kyle et al., 2017) such that they are increasingly perceived as a poor use of scarce public resources relative to other options (e.g., Gulati and Banerjee, 2015; Ali et al., 2016; Nhlengethwa et al., 2022). Returns-on-investment estimates for national fertilizer subsidies in SSA have generally found benefit-cost ratios to be relatively low and sometimes less than one (e.g., Ricker-Gilbert et al., 2024a for Zambia and Malawi). Indeed, several studies show that reallocation of public spending from input subsidies (including fertilizer subsidies) to other agricultural investments and sectors could generate significant gains (e.g., Aragie et al., 2022; Nhlengethwa et al., 2023). However, removing or reallocating these subsidies in the middle of an economic crisis requires careful analysis. For example, it is partly because of these reasons that subsidy reforms were postponed in Rwanda in 2021–22 (Spielman et al., 2025, in this issue) and fertilizer import restrictions were abandoned in Sri Lanka in 2021 (Niwarthana et al., 2023; Ghose et al., 2023). This suggests the need for not only rigorous economic policy analysis but also careful political economy considerations (Resnick, 2024).

The role of fertilizer and related input subsidy programs amid surges in international fertilizer prices is particularly important, although direct evidence remains limited. The fundamental rationale for subsidizing fertilizer—to make fertilizer affordable to small-scale and resource-poor farmers—is more appealing in the context of shocks to international fertilizer markets.[14] However, besides affecting affordability of fertilizer in domestic markets, input subsidy programs can affect market integration while also crowding out private sector actors in the value chain (Ricker-Gilbert et al., 2011; Ricker-Gilbert et al., 2024b; Spielman et al., 2010; Ayalew et al., 2025; Willwerth et al., 2025). Direct evidence for this comes from Kenya, where the government introduced the National Fertilizer Subsidy Program (NFSP) in response to the crisis in 2022, with the objective to provide short-term relief to farmers and achieve long-term food security goals.[15] The program absorbed a significant share of the surge in fertilizer prices and hence increased adoption of fertilizer and agricultural productivity (Ayalew et al., 2025). Willwerth et al. (2025, this issue) show that the

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[13] In terms of purpose, most public policies are either price-oriented or supply-oriented or income-oriented (Benson et al., 2013; Antonio et al., 2025). While most input subsidy programs aim to protect transmission of rising international price to local markets, governments are also involved in strategic cooperation and trade arrnagments to ensure sufficient and essential supply of inputs.

[14] Consistent with this hypothesis, several studies show that fertilizer subsidies increase adoption of fertilizer and complementary inputs, despite some variations across contexts (e.g., Kurdi et al., 2020; Gignoux et al., 2023; Ricome et al., 2024; Hazrana et al., 2025).

[15] The NFSP covers up to 72.7% of the market price of fertilizer (Ayalew et al., 2025).

Kenyan NFSP slowed price transmission from international to domestic markets, suggesting that the program may have protected farmers and local markets from volatility in fertilizer prices. However, evaluations of the NFSP also indicated only moderate rates of return, and some evidence of crowding-out (Ricker-Gilbert et al. 2024b; Ayalew et al. 2025). Furthermore, the NFSP's untargeted nature may have limited its effectiveness in reaching resource-constrained farmers who are relatively less likely to use fertilizer, thus attenuating aggregate fertilizer use and productivity gains (Ricker-Gilbert et al. 2024b).

Next, we consider the issue of industry structure, market concentration, and anticompetitive firm behavior. It is not easy to empirically identify a causal relationship between highly concentrated international or domestic fertilizer markets, on the one hand, and productivity or welfare outcomes at the farm or household level, on the other hand. But there is clear evidence that the structure of the fertilizer industry can potentially hinder policy interventions from having an effect during a crisis if, for example, fertilizer-exporting countries, export firms, or domestic fertilizer companies have greater market power than farmers, farm enterprises, or even policymakers. The export restrictions imposed by China and Russia, while potentially beneficial to their farmers, were a major destabilizing factor in international markets in 2021–22 (Hu et al., 2025; Vos et al., 2025, this issue).

Finally, there is the issue of public investment in agricultural research, development, and scaling. Many of the innovative solutions to improving soil health and increasing resilience to fertilizer price shocks will require long research and development runways and considerable investments in scaling. This is particularly the case where innovations have public good characteristics and are not remunerative to private companies, thereby requiring government promotion and distribution. Many of the innovations described in the previous section may fall into that category, although examples are emerging of social enterprises and community-based organizations investing in, for example, DSTs for SSNM, with the dual aim of generating social benefits and private returns. When and where governments choose to invest in these types of goods depend partly on having sufficient evidence on impact, cost-effectiveness, and viable pathways to scaling. Increased investment in generating and communicating credible evidence is critical to this decision-making process.

7. Concluding remarks

As the recent fertilizer price crisis demonstrates, global, national, and local shocks are changing public policy discourses on fertilizer and soil health policies. In many LMICs, the narrative may be shifting from a discussion of what levers are best employed to stimulate fertilizer uptake and increase national food production to questions about what set of investments can help navigate frequent bouts of uncertainty and market volatility while accelerating sustainable growth without sacrificing soil health, accelerating greenhouse gas emissions, or exceeding planetary boundaries. In many HICs, the questions may be more about how to maintain competitive markets and encourage innovation while adjusting agriculture to a more sustainable, climate-neutral, or regenerative footprint. In many LMICs, the questions expand the discourse beyond fertilizer subsidies to a much more complex set of issues, often under serious fiscal constraints.

As a consequence of these maturing narratives, there is growing interest in identifying how fertilizer policies may be complemented by interventions that encourage more sustainable, resource-conserving, and climate-resilient agricultural practices (e.g., Otsuka et al., 2024). With a more integrated perspective on these issues, it is hoped that evidence-based policy options can contribute to greater input use efficiencies, farm-level profitability, and overall agricultural productivity growth without exacerbating the environmental and climatic effects observed to date. But even where there is broad consensus around the major objectives—agricultural productivity growth, environmental sustainability, and resilience to shocks—there are many possible paths to achieve these objectives and evidence-based policy guidance will be critical for strategic decision-making.

Attention to many of these issues was amplified by the recent food, fuel, and fertilizer price shocks that began in 2020 during the COVID-19 pandemic and continued with the Russia-Ukraine war. While the current coterminous food, fertilizer, and fuel crisis complicates how we evaluate and respond to future challenges, it does offer an opportunity to compare, contrast, and learn from country experiences. Although we still lack nuanced evidence, the evidence synthesized in this study shows that while the overall global traded volume of fertilizer exhibited only modest declines in the aftermath of the crisis, the implications of these recent trade disruptions and the surge in fertilizer prices vary across countries, depending partly on their vulnerability and reliance on fertilizer imports. The recent surge in international fertilizer prices and associated public policy responses are likely to have reduced adoption and profitability of fertilizer in LMICs. For example, while landlocked fertilizer-importing countries in Africa such as Malawi, Rwanda, and Zambia had to contend with shocks to both fertilizer and transport costs during the recent crisis, several fertilizer-exporting countries gained from the situation. These lessons—along with the empirical patterns associated with the nature of price transmission between international and domestic fertilizer markets—offer important insights to protect vulnerable countries and farmers against similar shocks. To the extent that global and regional crises—whether stemming from civil conflict or climatic events—become increasingly common disruptors of globally connected agrifood systems, there is a need for short- and long-term national policy options to diversify strategies related to fertilizer trade, production, and use. At the farm level, such efforts could entail better integration of organic and inorganic fertilizer management (Kishore et al., 2021; Snapp et al., 2024; Nyondo et al., 2023), as well as complementary management practices (e.g., improved water use management). The evidence on the role of fertilizer subsidies to absorb volatility and slow down price transmission suggests the important potential role of public policy interventions to make these instruments more effective. Indeed, this suggests that policymakers have some important instruments to salvage inefficient fertilizer subsidies and distortionary tariffs. There are also opportunities to improve and apply the data and methods used to generate evidence on the costs and benefits of alternative policy actions, the returns to and impact of soil health innovations, and the cost-effectiveness of delivery and scaling strategies.

Finally, the rapid onset and ripple effects of global market shocks, as witnessed over the last four years, suggest that real-time data and new analytical methods are potentially important vehicles to respond to emerging trends and address fertilizer and soil health concerns shared by governments and other actors. Today, more than ever, policymakers and researchers need to pay more attention not only to global food security, environmental sustainability, and climate resilience, but also to preparedness for increasingly frequent periods of volatility, risk, and uncertainty. This is especially pertinent for global and domestic markets for inorganic fertilizer and for national policies aimed at increasing balanced fertilizer use and improving soil health.

Although this review covers important dimensions of responses and implications of the recent shock to global fertilizer markets, empirical evidence on some important aspects remains missing. First, more evidence on farmer-level responses and impacts is needed to ascertain the ultimate and domestic impact of shocks to global fertilizer markets. This includes evidence on farm-level productivity and profitability as well as farmers' decision-making processes in risky investment portfolios involving volatility in input prices (McCullough et al., 2022; Chamberlin et al., 2024). This would certainly include the inherent vagaries of rainfed production systems, which are further magnified by poor soils and other resource endowment limitations, but may also include uncertainties associated with pests and diseases, input and output market price fluctuations, and other sources of uncertainty.[16] Second, the implications of shocks to global fertilizer markets on national macroeconomic indicators remain missing. Third, the political economy implications of shocks to domestic fertilizer prices and associated public policy responses remain understudied. Fourth, the role of local markets and institutions to build resilience against shocks to global markets merits further investigation. For example, this may entail analysis of fertilizer industry structure and market power concentration (Hernandez and Torero, 2013; Ali et al., 2016) and subsidy and extension service targeting (e.g., Oyinbo et al., 2022; Ayalew et al., 2022). Finally, the environmental consequences of shocks to global and domestic fertilizer markets are insufficiently accounted for in policy efforts to promote agricultural productivity growth and food security. Similarly, there is still very little evidence of the effectiveness of policy interventions designed to successfully curtail these consequences, for example by internalizing the costs of greenhouse gas emissions that exacerbate climate change or of water pollution that contributes to aquatic resource degradation and reduced amenity values (Foley et al., 2011).

In conclusion, even as we continue to collectively fill evidence gaps on the effects of recent global market shocks, there is a need to advance new research on the topics, data, and methods identified in this Special Issue (and beyond) to inform policy responses to future shocks in a timely and credible manner. Continued research can help shape future policy discussions away from short-term interventions—such as ad hoc fertilizer export restrictions, import bans, or spending on inconsequential subsidies—to a more precise focus on responding at scale to heterogeneous contexts, and to a longer-term focus on integrating fertilizer use with soil health and nutrition management strategies. Sufficiently disaggregated diagnoses of such crises combined with carefully nuanced policy responses are essential to continuously improve agricultural productivity in a sustainable manner for countries at all stages of development.

CRediT authorship contribution statement

Kibrom A. Abay: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing. **Jordan Chamberlin:** Data curation, Formal analysis, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing. **Pauline Chivenge:** Conceptualization, Formal analysis, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing. **David J. Spielman:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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[16] Some of these uncertainties may arise from farmer misperceptions and learning about fertilizer and soil quality (Berazneva et al., 2018; Chavas and Nauges, 2020; Michelson et al., 2021, 2023), which can lead to a mismatch between soil nutrient deficiencies and fertilizer application (Abay et al., 2022).

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