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FERTILE FUTURES

SCENARIO ANALYSIS ON THE INTERCONNECTED DYNAMICS OF FERTILISER AND AGRICULTURAL MARKETS

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BETTER POLICIES FOR BETTER LIVES

Fertile Futures: Scenario Analysis on the Interconnected Dynamics of Fertiliser and Agricultural Markets

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Fertilisers are crucial components of food systems, with impacts beyond agricultural markets. This study utilises the OECD-FAO Aglink-Cosimo model to examine the intricate interplay between fertiliser markets, policies, and their repercussions on agricultural markets, food security, and environmental sustainability over the medium term. Two distinct scenario analyses reveal significant insights. The first scenario shows that while short-term disruptions in fertiliser supply can be mitigated by existing stocks, prolonged deficits will increase global food prices by up to 6%, posing long-term threats to agriculture. In the second scenario, the removal of fertiliser subsidies in India leads to reduced domestic use, resulting in decreased agricultural production and exports coupled with increased imports. Although this will cause a modest 0.8% increase in global food prices, it will substantially cut agricultural greenhouse gas emissions by 7 million tonnes of CO2 equivalent, highlighting the pivotal role of domestic policies in attaining global environmental sustainability goals.

Key words: Food security, agricultural support, Greenhouse Gas (GHG), partial equilibrium modelling

JEL codes: C54, Q11, Q17, Q18, Q56

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Key messages

- Fertilisers are indispensable for enhancing agricultural yields and ensuring food security. Recent price hikes have underscored their critical role.
- Given their far-reaching impacts on food systems, economic stability and the environment, fertiliser markets are extensively regulated. However, challenges lie in designing policies that effectively bolster affordability while mitigating the adverse environmental impacts associated with excessive usage.
- This report presents two separate scenario analyses: one examining potential supply shortages of fertiliser, and the other exploring the hypothetical elimination of fertiliser support in India. These analyses aim to assess these hypothetical shocks on agricultural markets, food security, and environmental sustainability over the medium term.
- The results of the supply shortage scenario indicate that the existence of stocks somewhat mitigates the negative short-term impacts on yields However, prolonged shortages can have lasting adverse effects on the agricultural sector. Hence, it is imperative to understand and effectively manage the duration of potential shortages to uphold a resilient and sustainable agricultural ecosystem.
- Eliminating fertiliser support in India prompts a rapid reduction in domestic fertiliser use, which leads to a decrease in agricultural production and exports, while simultaneously causing an increase in imports. The decline in nitrogen prices and rise in rice prices, influenced by India's substantial role as both a nitrogen user and rice supplier, have only a modest impact on global food prices and minor adverse impacts on food security worldwide.
- Results suggest that global agricultural greenhouse gas emissions would decrease notably, due to the substantial reduction in fertiliser application in India and the moderated increase in fertiliser use elsewhere. This highlights the crucial link between domestic policies and global environmental sustainability goals.

1. Introduction

Few elements are as crucial to agricultural productivity as fertilisers, which promote faster and more abundant crop growth. Fertilisers provide three of the main essential nutrients to crops – nitrogen (N), phosphorus (P), and potassium (K) – and they can be found in either natural (e.g. manure, compost, bone meal, etc.) or synthetic fertilisers[1] (e.g. urea, ammonium nitrate, superphosphate, potassium chloride, potash, etc.). Since the advent of the green revolution, modern agriculture has relied on synthetic fertilisers to feed a growing global population. According to some estimates (Erisman et al., 2008[1]; Smil, 2002[2]), without the application of synthetic fertilisers about half of the world population would go hungry.

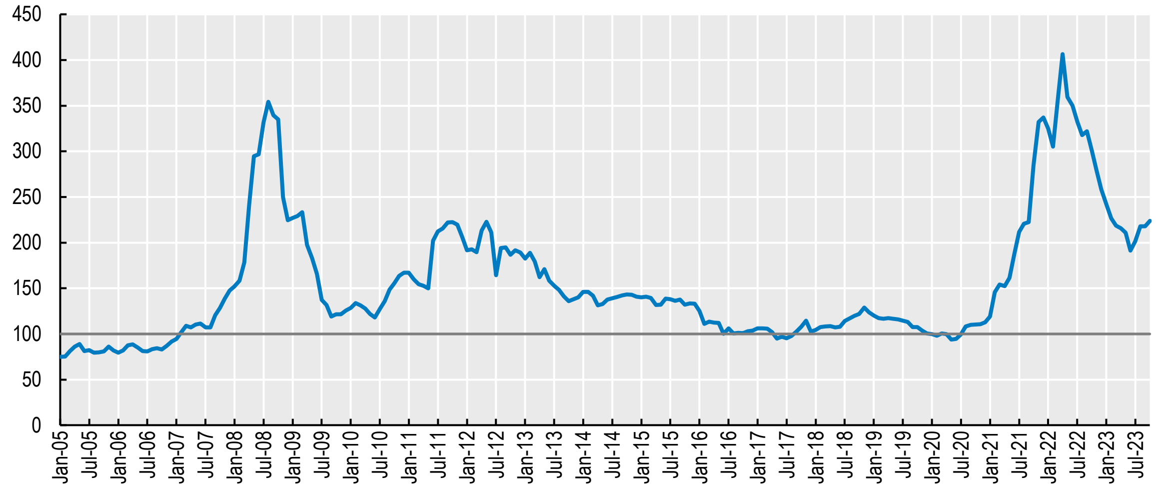
The production of synthetic fertilisers is intricately linked to factors such as natural resource availability, industrial capabilities, and strategic decisions to promote agricultural self-sufficiency. The production is concentrated in a handful of countries, namely People's Republic of China (hereafter "China"), India, the United States, Canada and the Russian Federation (hereafter "Russia"). Fluctuations in fertiliser availability or affordability can impact farmers' decisions regarding crop selection and planting. Consequently, the resilience of fertiliser supply plays a pivotal role in preventing cascading effects on food security, as farmers

[1] This report exclusively addresses synthetic fertiliser, which are manufactured from minerals, gases, and inorganic waste material. While natural fertilisers derived from organic sources (plants or animals) are important for agriculture and the environment, they are beyond the scope of this report. Henceforth, any reference to "fertiliser" implies a discussion specifically pertaining to synthetic varieties.

are better equipped to absorb shocks and maintain consistent production, thereby safeguarding against disruptions in the agricultural sector.

Fertiliser markets recently gained attention when prices began a sharp ascent in 2020 (Figure 1.1), reaching a fourfold increase by April 2022. Prices have eased from their peaks but have persisted at elevated levels. These escalating prices are attributed to a convergence of disruptive factors, including export restrictions and geopolitical events affecting fertiliser production and distribution, and surging input costs. Supply chain disruptions originally stemmed from rising energy and transport costs associated with the recovery in demand following the COVID-19 pandemic. Prices climbed further due to Russia's war of aggression against Ukraine and the subsequent sanctions imposed on Russian origins, as the Black Sea region has historically played a major role in fertiliser exports. Supply concerns have been exacerbated by China's extension of export restrictions on fertilisers.

Figure 1.1. Fertiliser price index, Jan 2020 = 100



Note: Weights used in the World Bank Commodity Price Index (in Percent): 16.9 natural phosphate rock, 21.7 phosphate, 20.1 potassium, 41.3 nitrogenous. Underlying data come from Phosphate rock, f.o.b. North Africa; DAP (diammonium phosphate), spot, f.o.b. US Gulf; Potassium chloride (muriate of potash), Brazil CFR granular spot price from January 2020; previously, f.o.b. Vancouver; TSP (triple superphosphate), spot, import US Gulf; Urea, (Ukraine), prill spot f.o.b. Middle East, beginning March 2022; previously, f.o.b. Black Sea.
Sources: World Bank monthly commodity prices data "Pink Sheet" November 2023.

Given their broader implications for food systems and economic stability, fertiliser markets are subject to extensive regulation. Many countries offer subsidies to encourage and support agricultural practices based on the use of fertilisers with the aim of ensuring food security and supporting farmers' livelihoods. The *Agricultural Policy Monitoring and Evaluation 2023* (OECD, 2023[3]) reports that countries responded heavily to the war in Ukraine and subsequent inflationary pressures by increasing their support to farmers for rising fertiliser costs.[2] Crop yields and fertiliser application typically show a strong positive relationship.

[2] "Chile both provided fertiliser and gave per hectare payments to compensate for rising variable input costs as part of the country's Sow for Chile (*Siembra por Chile*) programme. India increased its fertiliser subsidies twice during 2022 and Mexico increased its subsidy by 16-fold across 2022 and 2023. The Philippines implemented subsidies for fertiliser in the form of fertiliser discount vouchers as part of its Plant, Plant, Plant Part 2 programme. Switzerland released 20% of its strategic reserves of fertiliser in 2021 in response to early supply difficulties in international and kept the measure in place throughout 2022 to mitigate the market effects of Russia's war of aggression, equal to roughly one third of the country's annual needs for crop production. Japan subsidised transportation and storage costs for fertiliser manufacturers to compensate for costs associated with changing suppliers. The United States announced the new Fertiliser Production Expansion Program to increase domestic fertiliser availability" (OECD, 2023[3]).

While making fertilisers more affordable can bring immediate benefits to farmers by enhancing yields, it can also lead to an excessive use of fertilisers resulting in significant environmental degradation.[3]

In this context, the international community has renewed efforts to understand the links between fertilisers and agricultural commodities markets. This report seeks to explore the resilience of fertiliser markets, using the Aglink-Cosimo model as a comprehensive analytical tool. As of the *2023-2032 OECD-FAO Agricultural Outlook* (OECD/FAO, 2023[4]), the Aglink-Cosimo model explicitly incorporates the use of the three main mineral fertiliser nutrients N, P and K into the yield equations that determine the supply of crop commodities. This new feature separates the costs of fertilisers from those of other production inputs (energy, seeds, machinery, labour and other tradable and non-tradable inputs) and enables deeper analysis of their role in food security. The model makes use of estimated historical data series for fertiliser use by crop that have been developed by combining existing information on total use from FAOSTAT with per crop estimates from surveys by the International Fertilizer Association (IFA).

The first practical application of the newly integrated fertiliser representation was conducted for the *2023-2032 Outlook* to demonstrate how rising fertiliser costs can lead to higher commodity prices, which would threaten food security. The scenario shows that for each hypothetical 10% increase in N-, P- and K-based fertiliser prices, agricultural commodity prices are estimated to increase by 2% on average. The scenario anticipates a more significant impact on commodity prices for crops directly dependent on fertilisers as primary inputs (an average of 3.7% for cereals), compared to livestock products (1.4% on average), which indirectly utilise fertilisers through feed. Even for crops with lower fertiliser requirements, such as soybean, which inherently fixes nitrogen, a notable 2.9% price increase is expected. Impacts on livestock products also vary depending on feeding practices. Particularly, poultry and pigmeat are likely to face significant impacts (2.5% and 4.1% respectively) due to their reliance on compound feed[4] derived from fertiliser-intensive crops such as maize, compared to a 1.1% impact on beef, which is predominantly grass-fed. Overall, higher commodity prices can increase food insecurity rates in agricultural-based economies where consumers are more vulnerable as they spend a high share of their household budget on food and whose diet is mostly based on basic agricultural crops.

The Aglink-Cosimo model also includes indicators for estimating direct Greenhouse Gas (GHG) emissions from agricultural production. These indicators are based on the FAOSTAT Emissions-Agriculture database and adhere to the Tier 1 approach outlined by the Intergovernmental Panel on Climate Change (IPCC), which only includes direct emissions in agricultural production. Incorporating details related to the specific use of fertilisers at the crop commodity level in the model is therefore pertinent from an environmental perspective.

While fertilisers play a pivotal role in boosting agricultural yields and food security, their use may have adverse impacts on the environment.[5] By reporting direct GHG emissions, the Aglink-Cosimo model covers the release of nitrous oxide during the fertilisation process, a potent greenhouse gas that contributes to climate change. Under the baseline model, the anticipated growth in agricultural production will result in a 7.5% increase in direct global GHG emissions over the next decade, with livestock production and mineral fertilisers accounting for 79% and 11% of the overall increase respectively. This estimate does not include emissions associated with the production of fertilisers which amount to similar levels as the use of mineral fertilisers.

This paper endeavours to further delve into the relationship between fertiliser markets and agricultural commodity markets. Leveraging the Aglink-Cosimo fertiliser module, the paper offers a nuanced understanding of the intricate interplay and trade-offs among food security, farmers' livelihoods, and

[3] "Internationally, a group of countries announced the Global Fertiliser Challenge in 2022. The challenge seeks to both strengthen food security and reduce agricultural emissions by advancing fertiliser efficiency and alternatives in low- and middle-income countries. It hopes to achieve this challenge through innovation and knowledge sharing on fertiliser-efficient farming practices. US and European officials announced at the 2022 United Nations Climate Change Conference (COP27) that USD 135 million in funding had been raised for the effort" (OECD, 2023[3]).

[4] Compound feed is a mixture of various ingredients, mainly based on grains and meals along with additive nutrients. It is formulated to provide a balanced diet for animals, typically livestock, to meet their nutritional needs for growth, maintenance, and production.

[5] Although water pollution through nutrient runoff, soil acidification or energy-intensive production add to the carbon footprint of fertilisers, they are not integrated to the model.

environmental goals across two scenarios. The first scenario entitled "*supply shortages*" investigates potential supply shortages of nitrogen, phosphorus, and potassium, and their subsequent impacts on global agricultural and food markets. The second scenario entitled "*fertiliser support in India*" explores the implications of eliminating fertiliser support in India on both fertilisers and commodities markets, within and outside India.

In the next section the report briefly describes the main components of the Aglink-Cosimo model and the underlying methodology of the newly integrated fertiliser module. The two scenarios are then presented in separate sections, each delineating the rationale behind the scenario assumptions and presenting the corresponding analysis results.

2. A Global fertiliser module for the Aglink-Cosimo model

The main analytical tool used in this study is the Aglink-Cosimo model, an economic model designed to analyse the global supply and demand dynamics of agriculture. Managed jointly by the Secretariats of the OECD and the FAO, this model is employed to generate consistent baseline projections featured in the *OECD-FAO Agricultural Outlook* and for conducting policy scenario analyses.

Aglink-Cosimo is a recursive-dynamic, partial equilibrium model used to simulate medium-term developments of annual market balances and prices for the main agricultural commodities produced, consumed and traded worldwide. The Aglink-Cosimo country and regional modules cover the whole world. The OECD and FAO Secretariats in conjunction with country experts and national administrations are responsible for developing and maintaining the projections. Several key characteristics are as follows:

- *Exogenous non-agricultural markets*: Aglink-Cosimo is a partial equilibrium model for the main agricultural commodities, as well as biodiesel and bioethanol. Other non-agricultural markets are not modelled and are treated exogenously to the model. This means that the hypotheses regarding the trajectories of key macroeconomic variables are predetermined and do not account for feedback from developments in agricultural markets to the broader economy.
- *Competitive agricultural markets*: World markets for agricultural commodities are assumed to be competitive, with buyers and sellers acting as price takers. Market prices are determined through a global or regional equilibrium in supply and demand.
- *Non-spatial trade*: Domestically produced and traded commodities are viewed to be homogeneous and thus perfect substitutes by buyers and sellers. In particular, importers do not distinguish commodities by country of origin as Aglink-Cosimo is not a spatial model. Imports and exports are nevertheless determined separately, influenced by domestic price versus international price movements. For a given country/region, they may exist contemporaneously, due to non-price factors such as geography.
- *Recursive-dynamic markets*: market outcomes for one year influence those for the next years, notably through herd investment lags, due for example to biological factors affecting sizes or to changing dynamic expectations and behavioural responses. The *Outlook* provides a projection over ten years for purposes of forward-looking policy analysis and planning, but model projections are currently up to 2040 to assess long term implications.

The Aglink-Cosimo modelling framework is continuously enhanced to strengthen its ability to reflect future market developments and provide a more comprehensive analysis beyond the market outcomes.[6] As part of these improvements, the fertiliser market model was developed. This model includes production, non-agricultural use, trade and stockholding for N, P, K nutrients, such that domestic and international markets for these nutrients are balanced through price determination. The module expands the capabilities of the baseline model to analyse the impacts of shocks occurring in fertiliser markets on agricultural markets. Vice versa, it enables the examination of feedback mechanisms, allowing for an assessment of how

[6] The latest detailed documentation of Aglink-Cosimo model is available on the official website of the *OECD-FAO Agricultural Outlook*: www.agri-outlook.org.

changes in the agricultural sector may influence fertiliser markets. A detailed description of this module is presented in Annex A.

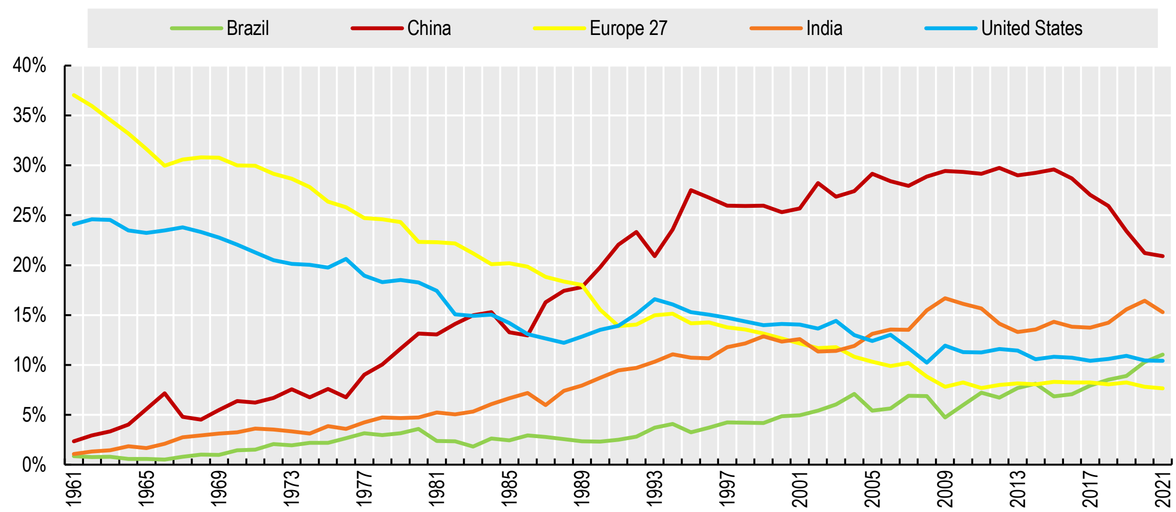
3. Supply shortages scenario

3.1. Background

Supply shortages of fertilisers are a major concern for many countries not only since the war between Russia and Ukraine started, but also due to the broader geopolitical uncertainties affecting global trade and commodity markets. The ongoing conflict has disrupted the supply chains and production of key fertilisers, leading to increased volatility in prices and availability. The recent prices spike, reminiscent of the 2008 global food crises (Figure 1.1), raised questions on the resilience of international fertiliser markets.

In recent decades, pressure on fertiliser prices has been fuelled by increasing demand from emerging markets striving for self-sufficiency in food production. Additionally, the heightened global utilisation of corn, a crop with substantial fertiliser requirements, for biofuel production has further contributed to this pressure. For instance, China has consistently held its leading position in the global use of fertilisers since becoming a member of the WTO in 2001. Moreover, India and Brazil have steadily increased their use of fertilisers to surpass the Unites States and claim the second and third-ranking position in global fertilisers use. (Figure 3.1).

Figure 3.1. Countries' share of fertilisers use from 1961-2021, only showing countries appearing in the top 5 users

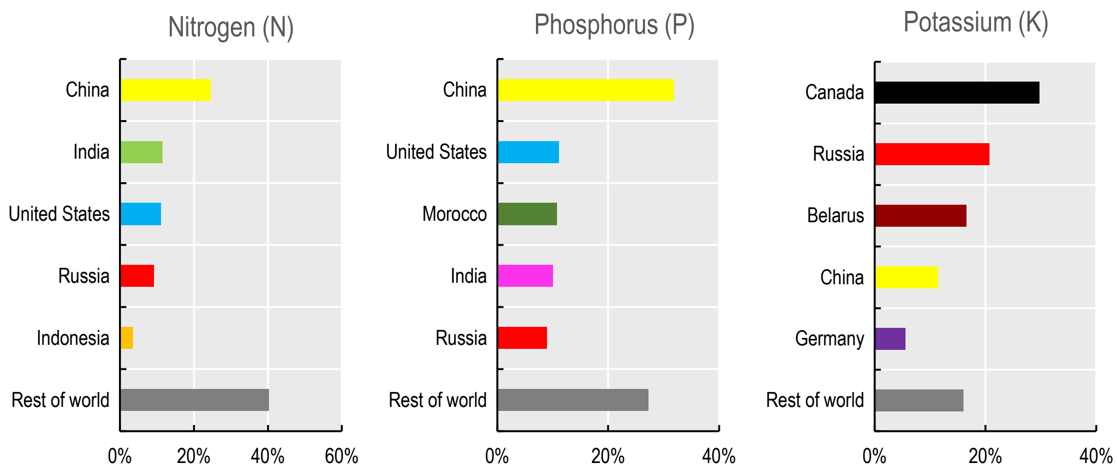


Note: Shares represent the sum of N-, P-, K- fertilisers quantities consumed.
Source: FAOSTAT.

The industrial production of nitrogen-based fertiliser relies heavily on natural gas. Due to the constraints posed by the availability and cost of natural gas, many countries face limitations in their capacity to undertake extensive production of nitrogen-based fertiliser. Additionally, phosphorus and potassium fertilisers are processed from mined minerals, which are not widely available in many countries. Consequently, the global production of fertilisers remains markedly concentrated, particularly in the cases of phosphorus and potassium. While emerging countries are increasingly contributing to global production of fertiliser nutrients, the sector remains dominated by a few countries. In the early 2000s, the top 5 producers contributed to more than 83%, 82% and 85% of the global output of N-, P-, K-fertilisers, these shares have dropped to an average of 60%, 73% and 84% respectively over 2018-2021 (Figure 3.2).

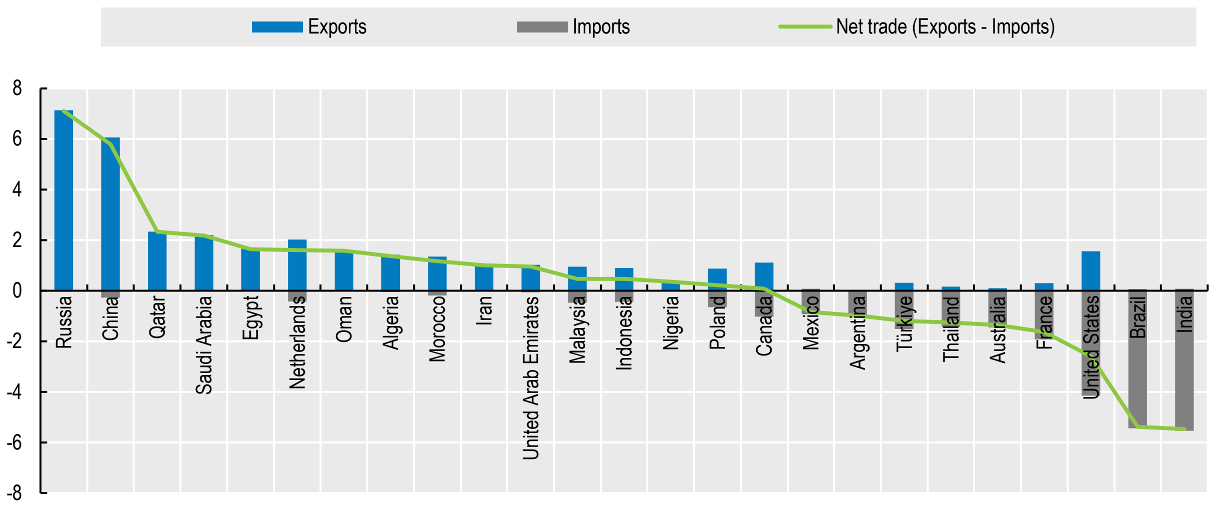
Although fertiliser production is concentrated, fertiliser use is distributed globally in response to the unique characteristics of soils and the requirements of diverse crops. The global fertiliser markets rely extensively on trade to meet the demand of countries that do not produce fertilisers domestically or face constraints in production (Figure 3.3). The concentration of fertiliser production in a limited number of countries makes the sector vulnerable to trade shocks.

Figure 3.2. Major global fertiliser producers and average global shares of production between 2018-2021



Notes: Average production 2018-2021.
Source: FAOSTAT.

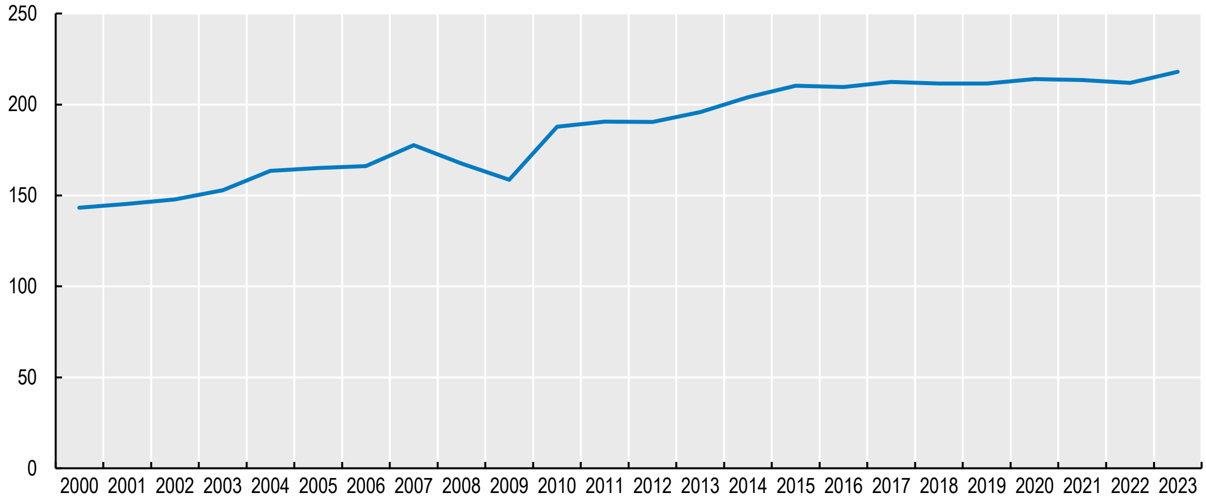
Figure 3.3. Average quantities of nitrogen exported and imported between 2018 and 2021, million tonnes



Note: Selection corresponds to the biggest net exporting and net importing countries.
Source: FAOSTAT.

Despite the uncertainty generated by Russia's war against Ukraine, which contributed to the recent fertiliser prices rally, global supply remained unaffected (Figure 3.4). This stability was maintained thanks to the Memorandum of Understanding between Russia and the Secretariat of the United Nations on facilitating unimpeded access of food and fertiliser products originating in Russia to global markets. The fertiliser markets demonstrated that local supply shocks could be absorbed, albeit at the expense of affordability.

Figure 3.4. Global fertiliser production, million tonnes



Source: 2023-2032 Outlook baseline results.

In order to analyse the potential response to a global supply shock, the following scenario includes several sub scenarios in which global supply of the three fertiliser components N, P and K is restricted for different periods of time. A shift of fertiliser supply curves of -20% is applied across all countries supplying fertilisers. This can be best interpreted as an increase in marginal production costs (which could, for example, occur through energy price shocks) by 20% across the world. The shock is first applied in 2025 only, and in a second scenario in both 2025 and 2026. This shock was chosen to achieve a similar price shock as observed in 2022.

3.2. Results

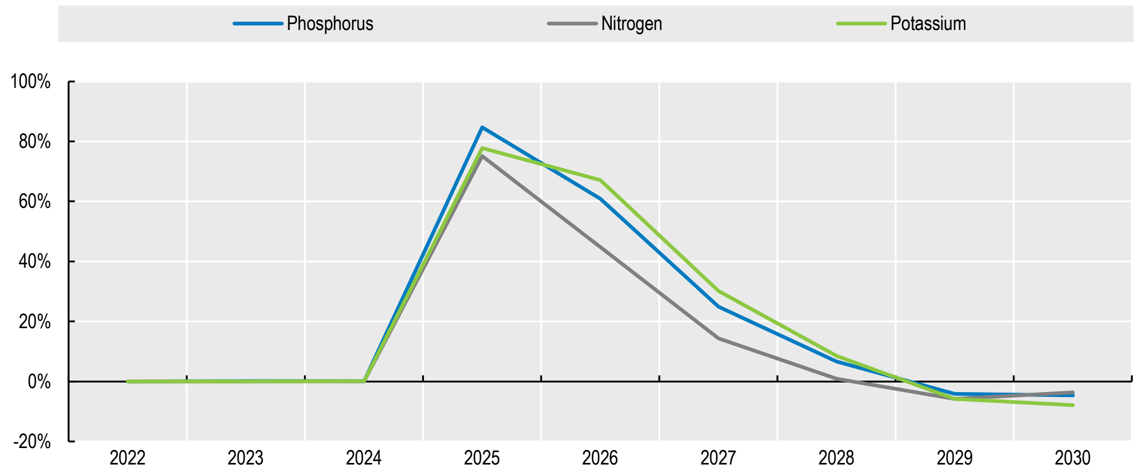
Figure 3.5 shows the effective fertiliser supply reduction that results from the introduced 20% shock in 2025 only. The responses are moderated compared to the initial shock, reflecting the adjustment of supply to the price increase induced by the shock. Moreover, the effective reduction in fertiliser supply varies across the different nutrients, with a 10% decrease for N and a greater 12% reduction for P and K. This discrepancy is attributed to the varying elasticities of supply for these nutrients that highlight the market's ability to adjust differently to changes in supply.

Importantly, the analysis of fertiliser demand patterns reveals a key factor explaining the market dynamics. Fertiliser demand is characterised as relatively inelastic, meaning that price changes have little impact on the quantity demanded. Consequently, the price increases triggered by the shock are notably strong, reaching up to 80% compared to the baseline in the year the shock manifests and they stay elevated in the following year (Figure 3.6).

Figure 3.5. Global fertiliser supply, relative change to baseline

Note: The three lines refer to the three scenarios where fertiliser components were shocked separately.
Source: Aglink-Cosimo simulations.

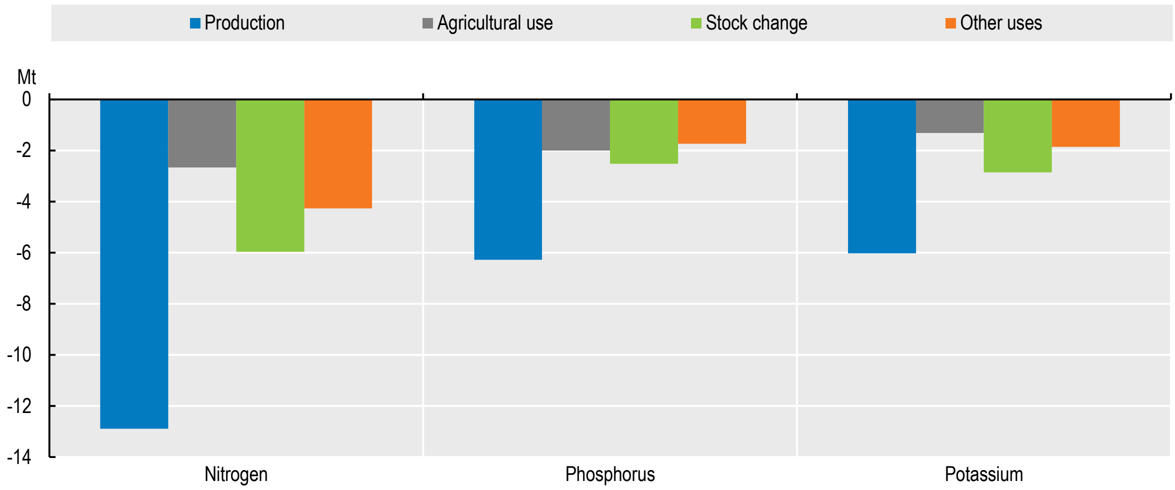
Figure 3.6. World fertiliser prices, relative change to baseline



Note: The three lines refer to the three scenarios where fertiliser components were shocked separately.
Source: Aglink-Cosimo simulations.

At the global level, three variables can adjust to the fertiliser supply shock outlined in this scenario: stocks, agricultural use and other uses. While the primary use of fertilisers is in agriculture, these essential compounds also find applications in other areas for example in landscaping and gardening, forestry, turf management or aquaculture. In aquaculture, fertilisers are sometimes used to enhance nutrient levels in water bodies, promoting the growth of algae and phytoplankton, which, in turn, can support the growth of fish and other aquatic organisms. According to Figure 3.7, stocks play the most significant compensatory role for the supply shock across all three nutrients. Additionally, other uses are substantially affected, although the absolute proportion of other uses in total utilisation remains below 20%. In other words, only a portion ranging from 20% (nitrogen, potassium) to 30% (phosphorus) of the initial supply shock is passed through to agricultural use. These balance adjustments lead to a reduction in total nitrogen application by 2.5%, and for potassium and phosphorus, the reductions are 2% and 1.5%, respectively.

Figure 3.7. Global fertiliser balance adjustments, 2025

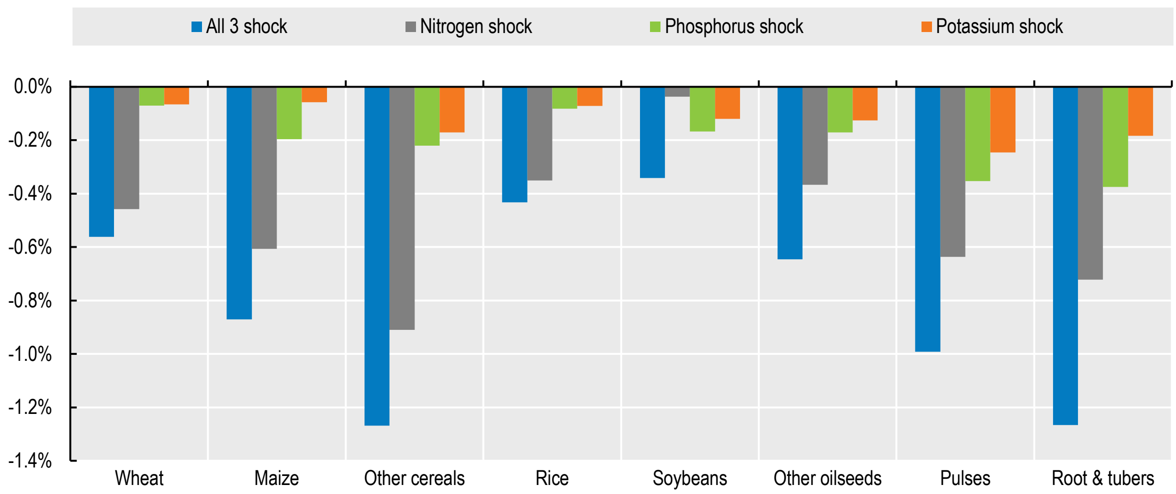


Note: Other uses encompass the use of fertilisers in various sectors, including but not limited to landscaping and gardening, forestry, turf management, erosion control, and aquaculture.
Source: Aglink-Cosimo simulations

The reduction in nutrients application have a direct impact on yields. Figure 3.8 shows the changes in global output per planted hectare for selected crops, comparing outcomes where all three nutrients experience a simultaneous supply shock with outcomes where each nutrient is shocked individually. For most crops, nitrogen plays the predominant role in influencing yields. An exception is soybeans, a nitrogen-fixing crop, where phosphorus emerges as the limiting factor for yields.

The average yield results depicted in Figure 3.8 mask important geographical variations that might contribute to the differences across crops. Moreover, the average global yield impact in these scenarios seems limited as yields decrease by only 0.3% to 1.3%. However, the regional distribution is uneven. In the combined scenario, total fertiliser application reductions vary from -0.1% in India, where the fertiliser support policy helps mitigate most of the supply shock, to -8% in certain African regions. This variation translates into a range of yield reductions, for example, for maize, spanning from -0.2% to -5%.

Figure 3.8. Global yield impacts of supply shock scenarios, 2025

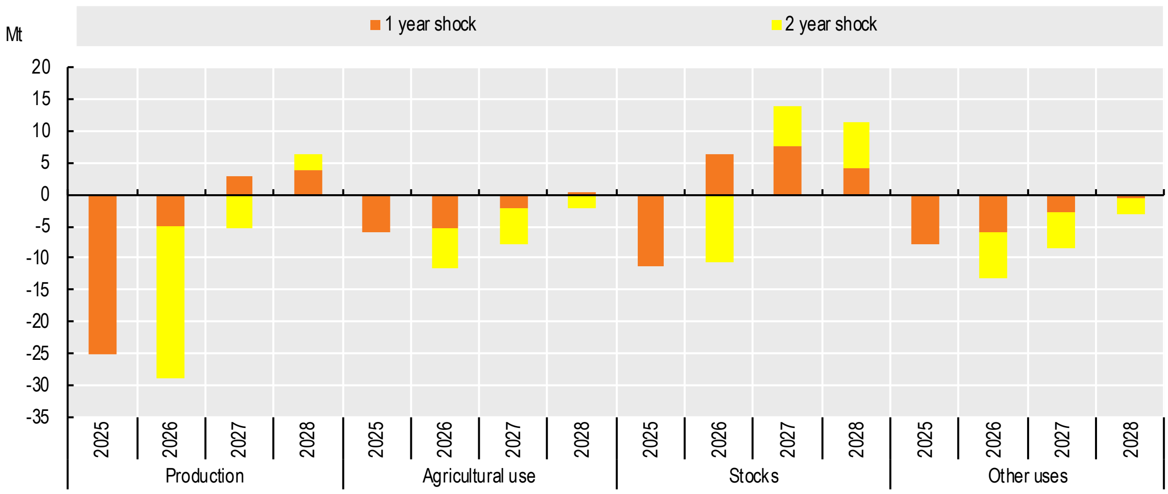


Source: Aglink-Cosimo simulations

The impacts on yields in these scenarios extend beyond the year of the shock for two reasons. Firstly, some farmers may have stockpiled fertilisers, using those purchased in 2024 when prices were lower. Consequently, they are likely to acquire fertilisers for 2026 at higher prices, impacting yields in that year as well. Secondly, the consequences of reduced fertilisation, particularly of P and K, might only become evident in the second year following the application deficit. Both effects are incorporated into the model, resulting in yield reductions of a comparable magnitude in 2026.

To further analyse these dynamics a consecutive supply shock in 2025 and 2026 was simulated for the combined shock only. Figure 3.9 shows the global fertiliser balance again, but this time for total fertiliser only and from 2025 to 2028. Per construction, the shock in 2025 is the same for both scenarios but the two-year shock becomes visible in 2026. The production effect is larger in 2026 indicating that the impact of a consecutive shock becomes larger in the second year of shock. This effect is even larger for agricultural use. This is mainly due to limited possibilities to reduce stocks when starting stocks are already low. Stock change in 2026 is even lower than in 2025, so the additional production reduction must be covered by agricultural and other uses. Even in 2027, agricultural use reductions are larger than in 2025 due to the lagged effects but also because stocks must be rebuilt.

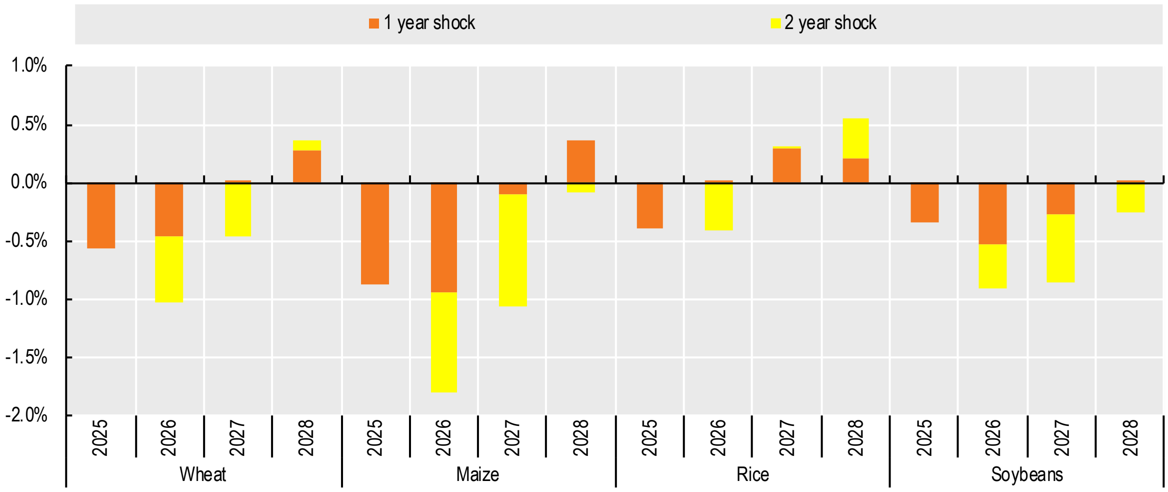
Figure 3.9. Global fertiliser balance: 1-year shock and 2-year shock, difference to baseline



Source: Aglink-Cosimo simulations.

Continuing the examination of agricultural usage dynamics, a parallel pattern is discernible in global crop yields (Figure 3.10). The effects on yields are most pronounced during the second year of the shock, underscoring the system’s greater resilience in handling a single-year shock compared to consecutive shocks.

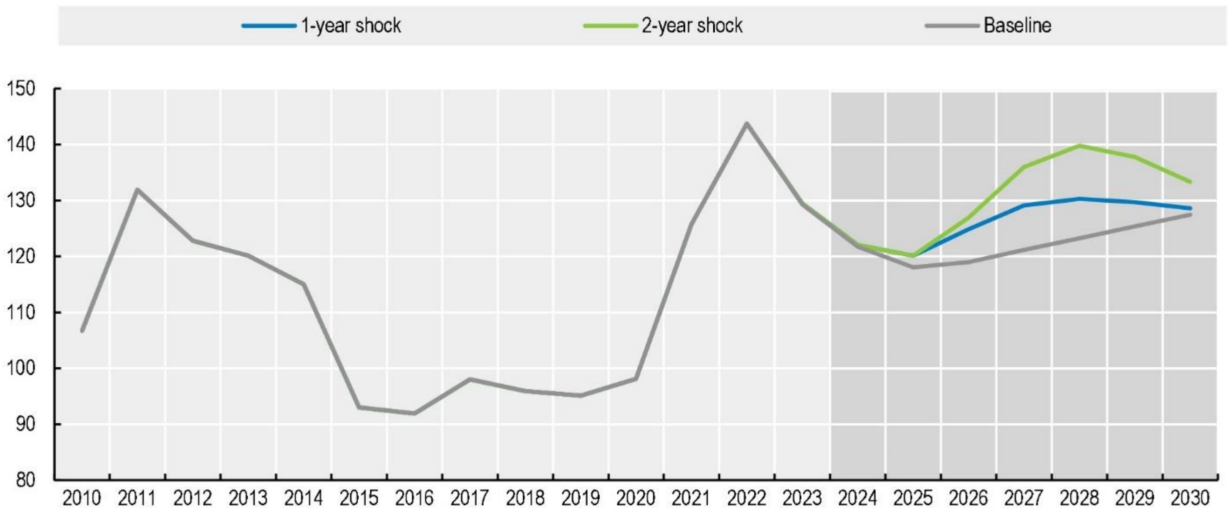
Figure 3.10. Global crop yields: 1-year shock and 2-year shock, percentage difference to baseline



Source: Aglink-Cosimo simulations.

While the percentage reductions in yield may appear modest, the resulting production shortfall significantly drives up food prices. Figure 3.11 shows that in a scenario where all three fertilisers are simultaneously affected within a single year (blue line), the FAO food price index[7] could rise by as much as 6% between 2025 and 2028. In contrast, a scenario involving two consecutive shocks (green line) would lead to a more pronounced increase, pushing prices up to 13% over the same period.

Figure 3.11. FAO food price index



Source: Aglink-Cosimo simulations.

[7] Although the name suggests something different, the FAO food price index is a commodity price index. Final consumer prices will behave differently depending on the pass through of commodity prices to the final food product prices.

Additionally, it's crucial to note that the initial impact on food prices remains minimal during the first year of the shock's occurrence. The significant factor influencing this outcome is stockholding behaviour. While stocks may witness a reduction for one or two seasons initially buffering prices, they must be replenished thereafter. This subsequent rebuilding of stocks contributes to a notable escalation in prices from the year 2027 onward.

In summary, this scenario underscores the significant impact of fertiliser availability restrictions on the intricate dynamics of agricultural markets. It brings attention to the heightened sensitivity of these markets, demonstrating that when constraints on fertiliser availability are imposed, the repercussions are profound and far-reaching. The scenarios emphasise that the duration of these restrictions plays a pivotal role in shaping market responses, indicating that prolonged limitations can lead to intensified and potentially enduring consequences for the agricultural sector. This heightened sensitivity underscores the delicate balance and interdependence within agricultural markets, wherein disruptions to a critical input like fertiliser can trigger a cascade of effects, influencing not only immediate yields but also medium-term market stability. Therefore, understanding and managing the duration of such restrictions becomes crucial for maintaining a resilient and sustainable agricultural ecosystem.

3.3. Limitations

The foundation of the fertiliser market module is grounded in the fundamental economic principle of perfect competition. This conceptual framework assumes a market structure characterised by numerous small firms, homogeneous products, free entry and exit, and perfect information. However, deviations from this ideal scenario can occur, particularly with the possibility of supply concentration giving rise to oligopolistic market structures. In an oligopolistic fertiliser market, the actions and decisions of a few major suppliers carry substantial weight, influencing pricing strategies, output levels, and overall market dynamics. Interactions among these key players become pivotal, often leading to strategic considerations, such as price leadership, collusion, or competitive rivalries. These strategic behaviours can result in outcomes distinct from those anticipated in a perfectly competitive market.

Unlike crop markets which operate on a yearly production cycle, fertiliser markets exhibit a more dynamic responsiveness to market shifts and price changes due to their distinct production and distribution dynamics. For instance, the process of stock building, essential for stabilising market conditions, could be accomplished at an accelerated pace This would warrant further exploration as it underscores the potential for more efficient market operations and strategic decision-making within the fertiliser industry.

The Aglink-Cosimo model's non-spatial nature may obscure significant trade impacts, especially concerning phosphorus and potassium, which originate from minerals. This mineral sourcing contributes to countries specialising in production and subsequent export of these nutrients. Increased regionalism, marked by strengthened ties among members and surges of protectionist measures against non-members, could alter the distribution of the impact of supply shortages of fertilisers. However, such dynamics cannot be captured in a non-spatial setting.

These scenario outcomes exhibit high sensitivity to the selected model parameters. These parameters encompass the characteristics of the yield equation, dictating how yields respond to variations in application rates, as well as the parameters of the fertiliser demand equations, determining how fertiliser usage reacts to changes in fertiliser and agricultural commodity prices. These parameters rely on a limited number of available estimates from the literature, which are then generalised to all countries, as detailed in Annex A. While up to date data is not available for all parameters, this approach allows for initial estimates to be calculated and insights to be drawn. Nevertheless, it is recommended that future analyses should attempt to update the estimated of these parameters and include a sensitivity analysis to enhance the robustness of the model.

4. Fertiliser support in India scenario

4.1. Background

Since India's independence in 1947, ensuring food security has been a central objective of the country's agricultural and trade policies. The imperative to address food shortages in the early 1960s prompted a focus on increasing agricultural output. However, given the limitations on expanding arable land, the emphasis shifted to enhancing crop productivity as a primary policy goal. This shift led to the transformative adoption of improved technologies and new seed varieties, accompanied by the expanded utilisation of agro-chemicals, particularly fertilisers.

According to the latest Agricultural Policy Monitoring and Evaluation (OECD, 2023[3]) the consistent increase in total support directed to agriculture over the past 20 years has been driven by emerging economies (accounting for 58% of the current USD 851 billion total support per year) – with China and India accounting for 36% and 15% respectively. In India, payments to support producers are dominated by large subsidies based on variable input use, including on fertilisers – amounting to USD 49 billion in 2022.

India is the second largest user and producer, and first importer of nitrogen-based fertilisers. It is also the second largest user, producer and importer of phosphorus-based fertilisers and the fourth largest user and importer of potassium-based fertilisers. Despite the intended objectives on food security, the fertiliser subsidy system in India has daunting challenges. First, it distorts markets and interacts with other policies in place that have different market effect, such as trade impeding policy measures. Second, it induces over-reliance on certain types of fertilisers (especially urea), leading to inefficient use of fertilisers and soil nutrient depletion. Third the system guaranteeing low price for farmers is not keeping pace with economic developments (i.e. adjustments to inflation).

Through its Ministry of Chemical and Fertilizers, the Government of India operates a major and complex subsidy program for its agricultural producers.[8] Subsidies vary within a given year according to the two different growing seasons, and according to movements in fertiliser prices. Compensation may also be offered for their transportation through Special Freight Subsidy Reimbursement Scheme for the supply of fertilisers in difficult areas. Moreover, Indian fertiliser subsidies are extremely large relative to consumer prices – particularly for urea.

At present, there are 32 urea manufacturing units operating in India, of which 30 use natural gas. The Ministry of Chemical and Fertilizers establishes maximum retail price (MRP) for urea. The difference between the delivered cost of fertilisers at farm gate and MRP payable by the farmer is given as subsidy to the fertiliser manufacturer/importer by the Government of India to cover the costs of their sale. The MRP for urea has remained unchanged for the past nine years at Rs 5360/t.

Phosphorus and potassium fertilisers were subsidised in the same way until their decontrol in the early 1990s, as part of broader economic reforms initiated by the government to liberalise and open the Indian economy. The decontrol of P&K fertilisers was a step toward reducing government intervention and subsidy burden and encouraging private sector participation. However, to counter the sharp price increases of the decontrolled P&K fertilisers in the market, which led to an imbalance use of the nutrients N, P and K, the government introduced the Concession Scheme and, later on, the Nutrient Based Subsidy (NBS) Scheme to promote fertilisation of the soil in a balanced manner to boost agricultural output and improve farm returns. Under the NBS scheme, each grade of subsidised P&K fertilisers receives a fixed level of subsidy determined annually, depending on their nutritional content. The implicit MRPs of P&K fertilisers has been left open under this scheme, but manufacturers are required to submit certified cost data in order to justify their choice of MRPs. The implicit subsidies set by the NBS policy for nitrogen (found in NPK compound fertilisers), phosphorus and potassium nutrients are indicated in Table 4.1.

[8] See https://www.fert.nic.in/.

Table 4.1. Nutrient Base Subsidies for N, P, K (Rs per t) in 2022

	2022 Autumn crops	2022 Winter crops
Nitrogen	91960	98020
Phosphorus	72740	66930
Potassium	25310	23650

Source: Government of India, Department of Fertilisers (2023[5]).

The scenario analysis conducted with the Aglink-Cosimo model requires adjustments to the policies described above. Given that the model defines fertiliser prices on a nutrient basis, the Rs 5360/t MRP value for urea has been converted to Rs 11690/t of pure nitrogen and indexed with inflation for future years. To define the baseline, a virtual consumer price (without subsidies) for nitrogen was set according to the model template equation (Annex A). Then the selection of the effective consumer price is set at the minimum of the MRP and the virtual consumer price that would reflect production and retail costs.

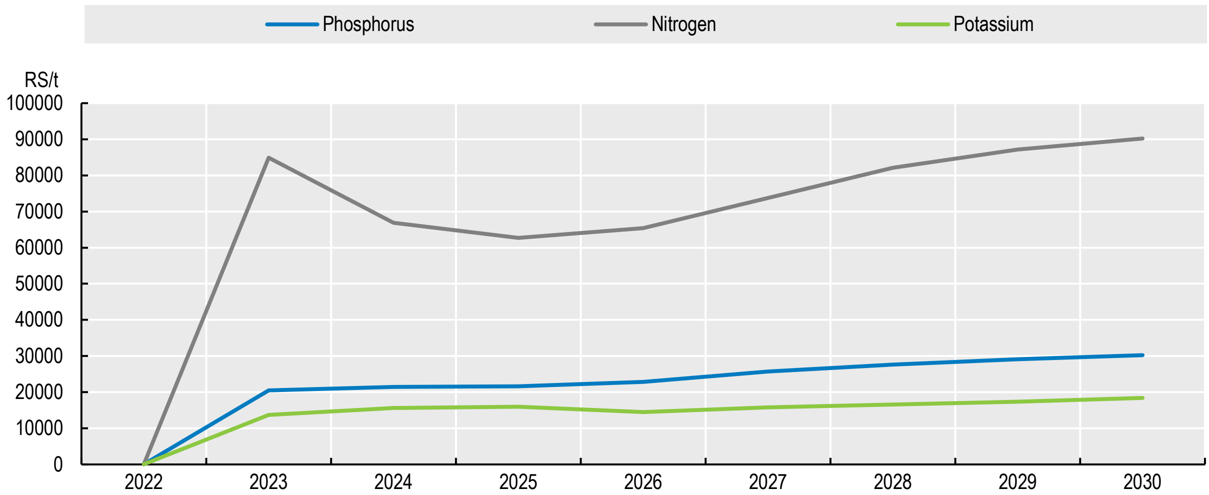
For phosphorus and potassium, a negative tax was added to the consumer price according to the NBS subsidy rates of Table 4.1 and moving in line with the producer price of P and K. This implementation does not distinguish between nitrogen bought in urea and nitrogen applied in other compound fertilisers. It assumes 100% urea application which in turn will overestimate the actual subsidies for nitrogen.

This scenario simulates an elimination of fertiliser subsidies by (1) setting the maximum retail price for nitrogen well above the prevailing global market price, which deactivates the MRP mechanism and (2) eliminating the negative tax for potassium and phosphorus. The simulation horizon for this scenario is 2023 to 2030.

4.2. Results

The significant burden of the Indian fertiliser subsidy stems from a policy aimed at addressing growing fertilisation demands through domestic production, where manufacturers are assured a retention price for fertilisers, while concurrent policies maintain fertiliser prices for farmers below their actual production costs. Therefore, eliminating fertiliser subsidies in India means in the first place that the prices at which farmers buy fertilisers will strongly increase which is confirmed in Figure 4.1. Costs for nitrogen increase by about Rs 80000/t and those for phosphorus and potassium by around Rs 25000/t and Rs 15000/t respectively.

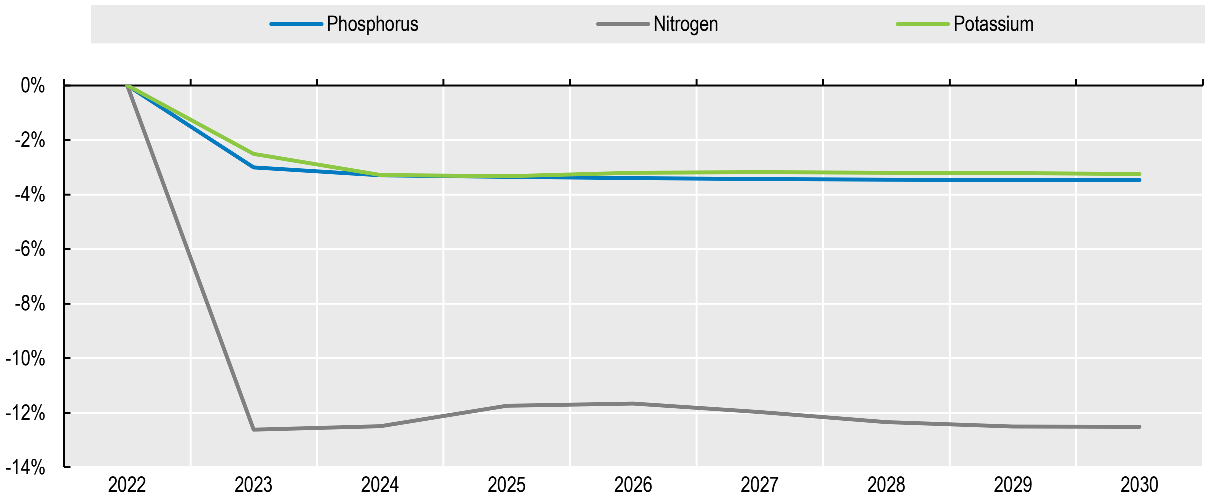
Figure 4.1. Indian fertiliser prices paid by farmers, absolute difference scenario vs baseline



Source: Aglink-Cosimo simulations.

This large shock leads to a strong and immediate reduction in fertiliser use in Indian agriculture as illustrated in Figure 4.2. As subsidies for nitrogen usage outpace those for phosphorus and potassium, the elimination of subsidies inevitably results in a decline of approximately 3% in the utilisation of phosphorus and potassium, while nitrogen use witnesses a more substantial decrease of 12%.

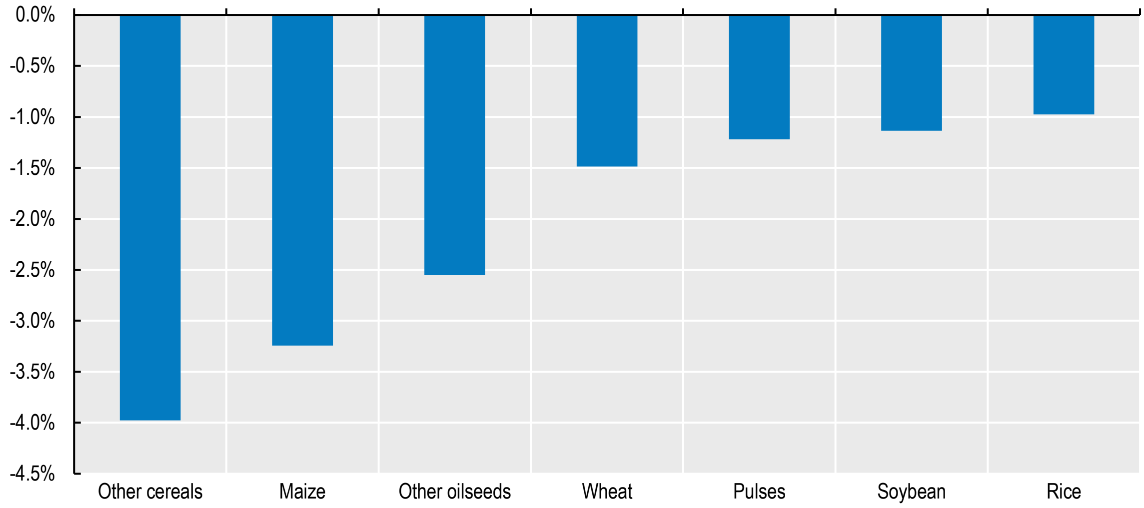
Figure 4.2. Indian fertiliser consumption by farmers, scenario vs baseline



Source: Aglink-Cosimo simulations.

The application of nitrogen fertilisers is critical for crop yields in the short run and the effectiveness depends on the timing of its application. Application of N-based fertilisers cannot be delayed in response to price changes. In contrast the application of P- and K-based fertilisers can be delayed in order to optimise variations in overall input costs since P and K nutrients remain in the soil for a longer period of time. In the long run however reduced application of these nutrients also has a significant impact on plants' growth. Figure 4.3 shows the relative drop in Indian yields for major crops in the final simulation year (2030). The different impacts on yield are most likely due to the differing nitrogen requirements across crops. The threefold greater drop in corn yield compared to soybean yield after reducing fertilisers application can be explained by the fact that corn has a higher nitrogen demand during its growth stages while soybeans can naturally fix nitrogen from the atmosphere making it less dependent on external nitrogen inputs.

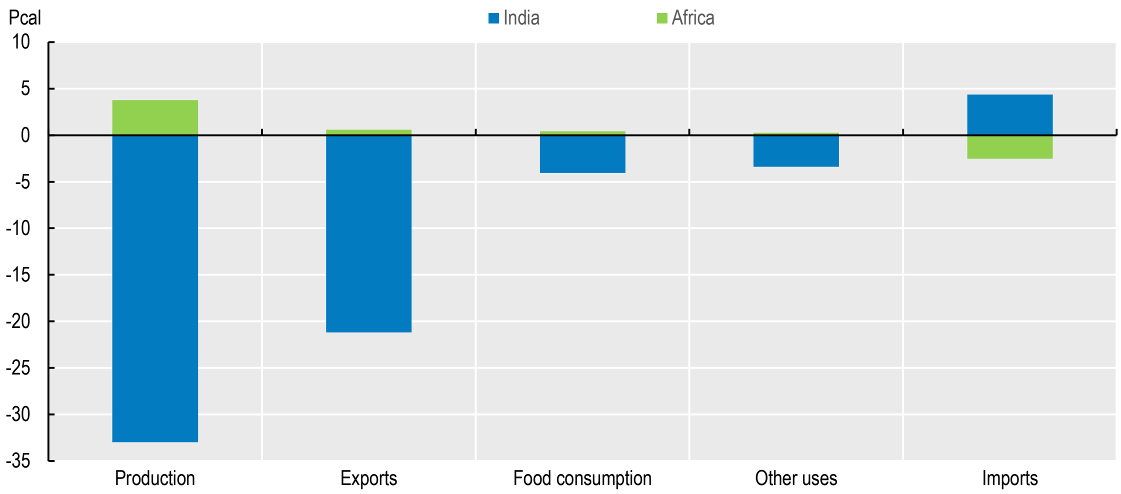
Figure 4.3. Relative change of Indian yields in scenario vs baseline, 2030



Source: Aglink-Cosimo simulations.

The Indian market necessarily adjusts for the lower production caused by lower yields. Figure 4.4 shows a strong reduction in total production of the major crops in calorie terms (-30 $e10^{15}$ calories). In relative terms this is only 2% of total crop production. The majority of the production shock experienced in the domestic market is mitigated through trade, marked by reduced exports (mainly rice, maize and sugar) and increased imports (mainly pulses soybeans and vegetable oils). The overall impact on global food consumption is modest, with a marginal decrease of -0.3%, attributed to increased imports and a reallocation from feed, biofuels, and other utilisation categories (other uses). On global average food is only 1% more expensive in the scenario, which results in relatively small impacts in the rest of the world.

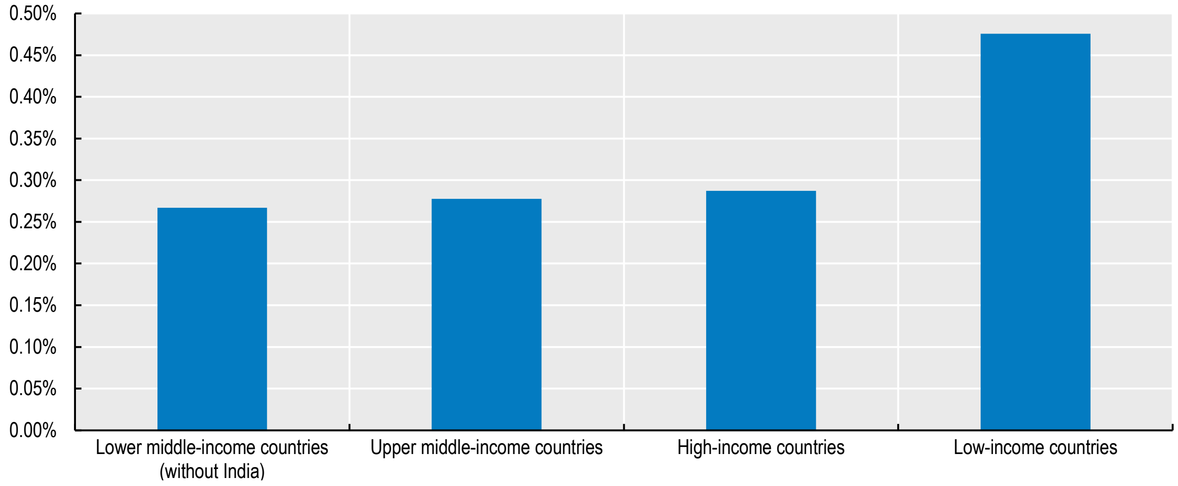
Figure 4.4. Absolute change of Indian and African calorie balances in scenario vs baseline, 2030



Note: Average for major crops.
Source: Aglink-Cosimo simulations.

Given its position in global markets, India's adjustments in the fertiliser and agricultural commodity balances have a noteworthy impact on global prices. In the realm of fertilisers, a decline in demand from India results in a corresponding decrease in world prices for fertilisers, as illustrated in Figure 4.6. This, in turn, may stimulate higher fertiliser application in other parts of the world (Figure 4.5).

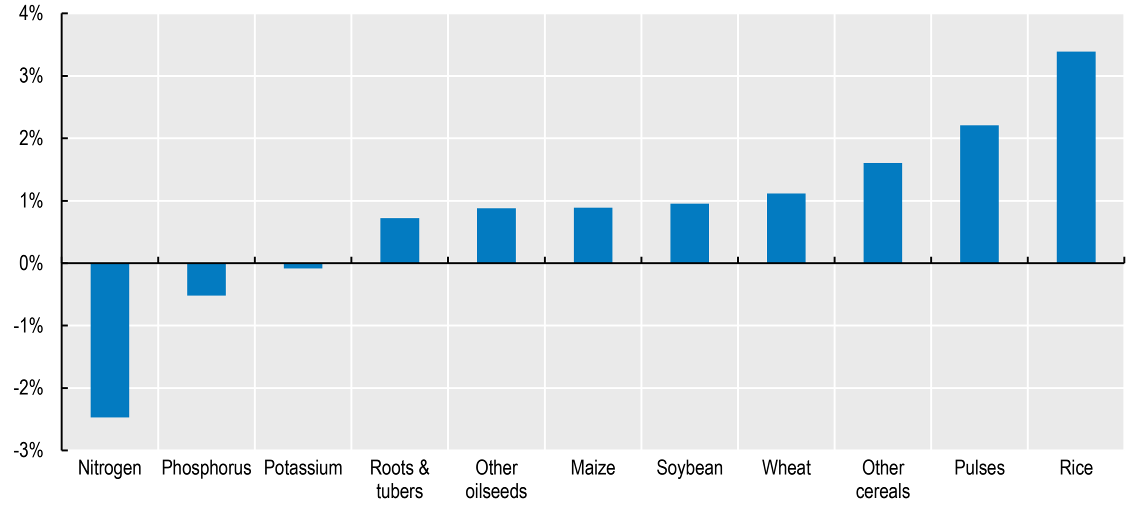
Figure 4.5. Relative change of fertiliser consumption by farmers in the rest of the world, scenario vs baseline, 2030



Source: Aglink-Cosimo simulations.

Conversely, in the case of agricultural commodities, the global developments from the scenario are reversed. India's reduced role in global net trade has significant repercussions, particularly in the markets for rice and pulses. As the largest exporter of rice in 2022, India's diminished presence leads to increased prices worldwide. Similarly, as the largest importer of pulses in 2022, India's changing net trade position influences global prices for pulses stronger than for other commodities, as illustrated in Figure 4.6.

Figure 4.6. Relative change of world prices in scenario vs baseline, 2030



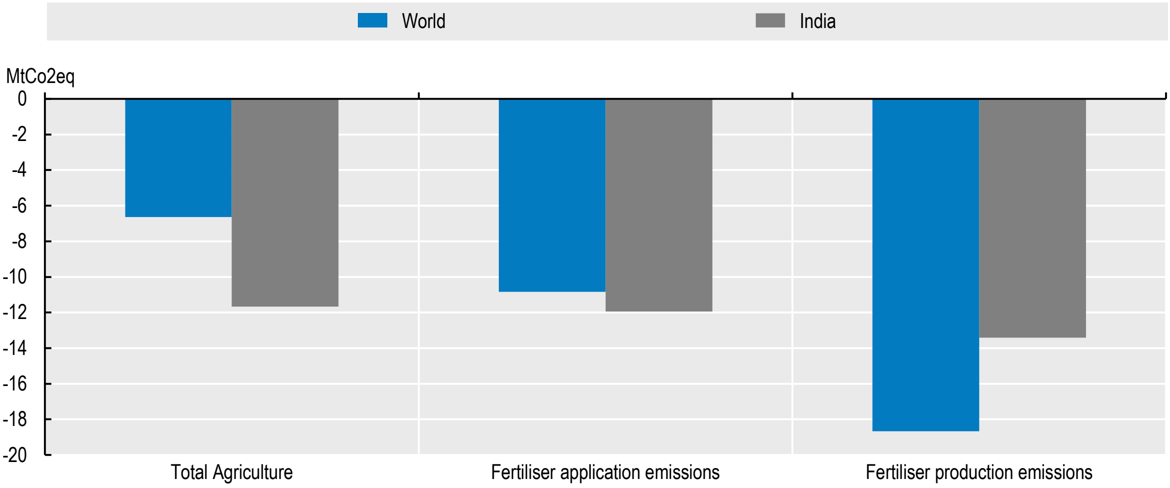
Source: Aglink-Cosimo simulations

However, average international commodity prices, measured by the FAO Food Price Index are only 1% higher in 2030 compared to the baseline scenario so that in the medium-term negative food security impacts in the rest of the world are small. This is supported by Figure 4.4, which shows both the calorie balance in India and in Africa. There is almost no visible impact on food calorie availability, but calorie self-sufficiency of the continent increases as cheaper fertilisers lead to higher production and thus fewer imports.

The scenario results in a decrease of GHG emissions which aligns with expectations (Figure 4.7). In India, the total GHG emissions decline by approximately 12 million tonnes of CO2 equivalent in 2030. This reduction corresponds to 1.3% of the country's total agricultural emissions or 9.5% of emissions specifically associated with fertiliser application.

The positive environmental impact in this scenario is amplified when changes in emissions that are generated during fertiliser production are also included. The new fertiliser module in Aglink-Cosimo allows to trace those emissions as well. Notably, emissions linked to fertiliser production witness a substantial decrease of 13 million tonnes of CO2 equivalent. On a global scale, the effect on the agricultural sector is mitigated as the reduction in fertiliser use in India engenders an increase in other parts of the world. The world GHG emissions from fertiliser application decrease by 11 million tonnes of CO2 equivalent, while total agricultural GHG emissions see a 7 million tonnes of CO2 equivalent reduction. This nuanced outcome is attributable to the fact that decreased production in India is compensated by increase production in the rest of the world. Additionally, the scenario's influence on heightened crop prices directs demand more prominently towards animal products.

Figure 4.7. Change of GHG emissions in scenario vs baseline, 2030



Source: Aglink-Cosimo simulations.

In summary, the scenario underscores the significant and wide-ranging consequences that would arise from the elimination of fertiliser support policies in India, particularly impacting the country's agricultural sector. The anticipated escalation in fertiliser costs is expected to lead to a reduction in fertiliser application, subsequently affecting crop yields and causing a decline in domestic production. This, in turn, is likely to trigger a complex set of responses, including a decrease in rice exports and an upswing in the importation of pulses, influencing India's trade balance.

Moreover, the scenario's effects have noteworthy repercussions in international markets. The reduction in fertiliser prices globally could reshape dynamics in the agricultural commodity arena, potentially resulting in an increase in agricultural commodity prices, however with limited impact on food security. This highlights the interconnectedness of the global agricultural system and the potential for policy changes in one region to reverberate across the broader international market.

The overall impact on greenhouse gas emissions is anticipated to be favourable, as the reduction in fertiliser use has the potential to contribute to a decrease in emissions. This aligns with broader environmental sustainability goals, illustrating the nuanced relationship between agricultural policies, production dynamics, and environmental outcomes. In essence, the scenario serves as a comprehensive case study demonstrating the multifaceted interplay between domestic policies, trade dynamics, and global environmental considerations in the context of the Indian agricultural sector.

4.3. Limitations

The structure of the model cannot completely capture the complexity of Indian food security policies. Although this study focuses on the implications of fertiliser support policies, it is essential to acknowledge that other related policies, such as the minimum support prices (MSP) system for wheat and rice, as well as the in-kind grain distribution system, have been simplified in the baseline model. Consequently, the model's reactions are based on an assumption of market competitiveness that may not reflect the nuanced realities of the Indian agricultural landscape.

The minimum support prices play a pivotal role in ensuring remunerative returns for farmers by establishing a floor price for certain key crops. The in-kind grain distribution system, on the other hand, involves the provision of subsidised food grains to vulnerable populations, forming a crucial component of India's broader food security initiatives. However, the relative underdevelopment of these aspects of India’s policy environment means that the model's stylized representation may miss some intricacies of the Indian food security framework.

In order to provide a more comprehensive and accurate representation, future iterations of this work would benefit from incorporating a more detailed analysis of the broader food security policy landscape in India as it was done in Chapter 2 of OECD (2018[6]).

Annex A. A global fertiliser module for the Aglink-Cosimo Model

Background

Fertiliser is a critical input to agricultural production, where in many countries it is considered responsible for up to half of crop yields, and in many developing countries, an important source of agricultural growth and food security. The functioning of fertiliser markets is integrated with energy markets on its supply side and to agricultural markets on the demand side, increasing the linkage of these two critical markets which are critical to multiple policy objectives, including food security, rural livelihoods and environmental sustainability. This annex[9] describes a module of fertiliser markets in detail which has been integrated into the Aglink-Cosimo model, and includes supply, demand, export, import and price determination in global and national markets, linked appropriately to crop markets and the drivers of fertiliser production.

Module specification

The specification of the module follows functional forms and styles similar to the Aglink-Cosimo model, using a templated approach wherever possible. This involves the specification of the markets for aggregate fertiliser nutrients — nitrogen, phosphorus and potassium (N,P,K). The activities include production, use, stocks, exports and imports linked by international, import, export, primary and retail prices that enable market activities to clear domestically and globally. A critical element is the breakdown of nutrient agricultural use by crops so that the interaction of agricultural markets and the fertiliser markets can be fully exploited.

The model description is represented by the set of equations expressed in terms of for fertiliser nutrient equivalent *p*, in country/region *c*, and where appropriate, for crop *k*, in time period *t*. Country/region refers to the set of countries and regions of the Aglink-Cosimo model.[10] In cases of parameterised functions, each equation has an *R.n* variable which is used to calibrate the equation to historical data, and as a shifting mechanism for projection.

Domestic price formation

Consumer price margin for fertiliser nutrients

$$ln(MAR_{c,p,t}) = \alpha_{c,p} + \beta^{1}_{c,p} ln(GDPD_{c,t}(1 + LA_{c,p,t})) + ln(R.MAR_{c,p,t})$$

where *GDPD* is the GDP deflator, *LA* is a labour adjustment where appropriate.
Parameters $\alpha_{c,p}$ estimated for calibration 2018 − 2021,
Parameters $\beta^{1}_{c,p} = 1$

[9] Module proposed by Merritt Cluff under contract for TAD/OECD. This work draws heavily on consultancy work by W. Thompson and M. Rosenbohm of the University of Missouri, undertaken for EST/FAO in respect of fertiliser demand in 2022 (Thompson and Rosenbohm, 2022[8]). Advice from Marcel Adenauer (TAD/OECD), Holger Matthey (EST/FAO) and SergioRene AraujoEnciso (EST/FAO) also form input to the specifications. Richard Downey provided comments on parameters. Benefit has been made from a Webinar with interested experts held in September 2023. Errors and omissions are the author's responsibility. Comments on all aspects of this paper are sought. This version dated November 2023.

[10] Countries included are ARG, AUS, BRA, CAN, CHE, CHL, CHN, COL, EGY, ETH, GBR, IDN, IND, IRN, ISR, JPN, KAZ, KOR, MEX, MYS, NGA, NOR, NZL, PAK, PER, PHL, PRY, RUS, SAU, THA, TUR, UKR, USA, VNM, ZAF.

Regions are Africa Least Developed (other), Other Africa, North Africa, North Africa Least Developed., Asia Least Developed, Other Asia Developing, Other Asia Central, EUE, European Union-, E14, EU-New Member States, Other Near East, Other Oceanic Developing, Other Oceanic Least Developed, Other South American Developing.

Consumer price of fertiliser nutrients

$$CP_{c,p,t} = (MAR_{c,p,t} + PP_{c,p,t})(1 + TAX..REL_{c,p,t}) + TAX..ADD_{c,p,t}$$

where *PP* is the producer/wholesale nutrient price, *TAX..REL* and *TAX…ADD* are *ad valorem* or fixed taxes (positive) or subsidies (negative)

Aggregate consumer price for fertiliser

$$CP_{c,t}^{FT} = SUM_p\ (SHR_{c,p,t}CP_{c,p,t})$$

where: *SHR* are value weighted nutrient shares determined over 2014-16

Nutrient production

Nutrient production responds weakly to current price/cost incentives, but in the long term (mean lag of 5.7 years) with an elasticity of 1, for each nutrient, and for all countries/regions.

$$ln(QP_{c,p,t}) = \alpha_{c,p} + \beta_{c,p}^{1} ln(PP_{c,p,t}/((PPoil_{c,t}\hat{}SHEN_{c,p,t}) * GDPD_{c,t}\hat{}(1 - SHEN_{c,p,t}))\ + \beta_{c,p}^{2} ln(QP_{c,p,t-1}) + ln(R.QP_{c,p,t})$$

where
Parameters $\alpha_{c,p}$ estimated for calibration 2018 − 2021.
Parameters $\beta_{c,k}^{1}$ are templated at 0.2 for N and 0.15 for P, K .
Parameter $\beta_{c,k}^{2}$ is templated at 0.8 for N and 0.85 for P, K .

Nutrient agricultural use

Nutrient consumption by crop (two types those with crop yield/cpci or not). Nutrient demands are currently independent.

Nutrient consumption per hectare by crop

For k ϵ [YLDset][11]

$$ln(QCHA..k_{c,p,t}) = \alpha_{c,p} + 0.8 * \beta_{c,p}^{2} ln\left(\frac{CP_{c,p,t}}{PP..k_{c,t} + EPY..k_{c,t}}\right) + 0.2 * \beta_{c,p}^{2} ln\left(\frac{CP_{c,p,t-1}}{PP..k_{c,t-1} + EPY..k_{c,t-1}}\right) + \beta_{c,p}^{3} ln\left(\frac{CP_{c,p,t-1}}{CPCI..k_{c,t-1}}\right) + \beta_{c,p}^{t} trnd + ln(R.QC..k_{c,p,t})$$

where *QCHA..k* is nutrient consumption of crop *k* per hectare, *PP* is farm price of *k* and *EPY* is expected crop payment per tonne
Parameters $\alpha_{c,p}$ estimated for calibration 2018 − 2021,
Parameters $\beta_{c,p}^{t}$ estimated with constrained interval $-0.01 < \beta_{c,p}^{t} < 0.01$
Parameters $\beta_{c,p}^{2}$ are templated at − 0.1 for N, and − 0.2 for P, K
Parameters $\beta_{c,p}^{3}$ are templated at 0 ; more research needed

$$QC..k_{c,p,t} = QCAH..k_{c,p,t} * AH..k_{c,p,t}$$

For k ϵ [nYLDset]

$$ln(QC..k_{c,p,t}) = \alpha_{c,p} + \beta_{c,p}^{2} ln\left(\frac{CP_{c,p,t}}{IP..k_{c,t}}\right) + \beta_{c,p}^{t} trnd + ln(R.QC..k_{c,p,t})$$

[11] YLDset depends on country and may contain wheat, maize, rice, other coarse grains (barley, oats, rye, sorghum), other cereals, soybeans, other oilseeds (sunflower, rapeseed, groundnuts), pulses, sugar cane, sugar beets, roots, cotton, coconut, palm and jatropha. nYLDset contains pasture and “other agricultural” crops including fruit, vegetables and other crops, which will be split out in future versions.

where *IP* is expected return per hectare
Parameters $\alpha_{c,p}$ estimated for calibration 2020 − 2022,
Parameters $\beta^{t}_{c,p}$ estimated with constrained interval $-0.01 < \beta^{t}_{c,p} < 0.01$
Parameters $\beta^{2}_{c,p}$ are templated at − 0.1 for N, P, K

$$QC..k_{c,p,t} = QCAH..k_{c,p,t} * LU..k_{c,p,t}$$

Total nutrient consumption

$$QC_{c,p,t} = SUM_k \left(QC..k_{c,p,t}\right)$$

Total fertiliser consumption

$$QC_{c,t} = SUM_p \left(QC_{c,p,t}\right)$$

Crop yields (replacing existing model crop yield functions)

Crop yield for each crop is determined by the crop's price deflated by a cost index of non-fertiliser inputs, and the application rates of each fertiliser nutrient.

$$\begin{aligned} ln\left(YLD_{c,k,t}\right) = \alpha_{c,p} + \beta^{1}_{c,k} ln\left(\frac{PP_{c,k,t} + EPY_{c,k,t}}{\mu CPCI_{c,k,t} + (1-\mu) CPCI_{c,k,t-1}}\right) + \beta^{2}_{c,k} ln\left(\frac{QC_{c,ftn,t}}{AH..k_{c,k,t}}\right) \\ + \beta^{3}_{c,k} ln\left(0.5\left(\frac{QC..k_{c,ftp,t}}{AH..k_{c,t}} + \frac{QC..k_{c,ftp,t-1}}{AH..k_{c,p,t-1}}\right)\right) + \beta^{4}_{c,p} ln\left(0.5\left(\frac{QC..k_{c,ftk,t}}{AH_{c,p,t}} + \frac{QC..k_{c,ftk,t-1}}{AH_{c,p,t-1}}\right)\right) \\ + \beta^{t}_{c,p} trnd + ln\left(R.YLD_{c,k,t}\right) \end{aligned}$$

where:
Parameters $\alpha_{c,p}$ estimated for calibration 2018 − 2021,
Parameters $\beta^{t}_{c,p}$ estimated with constrained interval $-0.01 < \beta^{t}_{c,p} < 0.01$
Parameters $\beta^{1}_{c,k}$ and *are templated at* (+ 0.03).
Parameters $\beta^{2}_{c,p}$, $\beta^{3}_{c,k}$ and $\beta^{4}_{c,p}$ are set at values provided by (Rosas, 2011[7]).
AH: harvested area
PP: producer price
CPCI: Cost of production index excluding fertilisers
EPY : output based subsidies
QC..xx: Agricultural use of fertilisers

Non-agricultural use of nutrients

Non-agricultural use is expressed as a function of real retail price and national income.

$$ln\left(OU_{c,p,t}\right) = \alpha_{c,p} + \beta^{1}_{c,p} ln\left(\frac{CP_{c,p,t}}{GDPD_{c,t}}\right) + \beta^{2}_{c,p} ln(GDPI_{c,t}) + \beta^{t}_{c,p}(trnd \quad) + ln\left(R.OU_{c,p,t}\right)$$

where *GPDI* is an index of real GDP
Parameters $\alpha_{c,p}$ estimated for calibration 2018 − 2021,
Parameters $\beta^{t}_{c,p}$ estimated with constrained interval $-0.01 < \beta^{t}_{c,p} < 0.01$
Parameters $\beta^{1}_{c,p}$ and *are templated at* (− 0.6).
Parameters $\beta^{2}_{c,p}$ and *are templated at* (+0.6).

Stocks of nutrients

The standard Aglink equation is used for stock demand.

$$ln(ST_{c,p,t}) = \alpha_{c,p} + \beta^1_{c,p} ln(MAX\{QP_{c,p,t}, QP_{c,p,t}\} + ST_{c,p,t-1}) + \beta^2_{c,p} ln\left(\frac{3PP_{c,p,t}/GDPD_{c,t}}{\frac{PP_{c,p,t-1}}{GDPD_{c,t-1}} + \frac{PP_{c,p,t-2}}{GDPD_{c,t-2}} + \frac{PP_{c,p,t-3}}{GDPD_{c,t-3}}}\right) + \beta^2_{c,p} trnd + ln(R.ST_{c,p,t})$$

where:
Parameters $\alpha_{c,p}$ estimated for calibration $2020 - 2022$,
Parameters $\beta^t_{c,p}$ estimated with constrained interval $-0.01 < \beta^t_{c,p} < 0.01$
Parameters $\beta^1_{c,p}$ are templated at (0.2).
Parameters $\beta^2_{c,p}$ are templated at (−0.2).

Trade

Standard templated equations from the Aglink model (different from the "Cosimo" component) are used for exports and imports.

Nutrient trade border prices

$$EXP_{c,p,t} = XP_{c,p,t} XR_{c,p,t}$$
$$IMP_{c,p,t} = XP_{c,p,t} XR_{c,p,t}$$

where *XP* are world references prices and XR exchange rates.

Nutrient exports

$$ln(EX_{c,p,t}) = \alpha_{c,p} + \beta^1_{c,p} ln(PP_{c,p,t}/(EXP_{c,p,t}(1 - TAVE_{c,p,t}/100)) + + ln(R.EX_{c,p,t})$$

where:

Parameters $\alpha_{c,p}$ estimated for calibration $2018 - 2021$,
Parameters $\beta^1_{c,p}$ are templated at (−10).

Nutrient imports

$$ln(IM_{c,p,t}) = \alpha_{c,p} + \beta^1_{c,p} ln(PP_{c,p,t}/(IMP_{c,p,t}(1 + TAVI_{c,p,t}/100)) + ln(R.IM_{c,p,t})$$

where:
Parameters $\alpha_{c,p}$ estimated for calibration $2018 - 2021$,
Parameters $\beta^1_{c,p}$ are templated at (+10)

Domestic Market Clearing

$$0 = QP_{c,p,t} + IM_{c,p,t} + ST_{c,p,t-1} - QC_{c,p,t} - OU_{c,p,t} - EX_{c,p,t} - ST_{c,p,t}$$

World Market Aggregation

$$QC_{wp,t} = SUM_c\ (QC_{c,p,t})$$
$$QP_{wp,t} = SUM_c\ (QP_{c,p,t})$$
$$OU_{wp,t} = SUM_c\ (OU_{c,p,t})$$
$$ST_{wp,t} = SUM_c\ (ST_{c,p,t})$$
$$EX_{wp,t} = SUM_c\ (EX_{c,p,t})$$
$$IM_{wp,t} = SUM_c\ (IM_{c,p,t})$$

World Market Price Clearing

$$0 = EX_{w,p,t} - IM_{wp,t} - SD_{w,p,t}$$

where *SD* is the global statistical difference of exports and imports.

Data

Fertiliser balances by country

Fertiliser aggregate nutrient data are taken from the FAO/FAOSTAT database for N,P and K equivalents. Since the production/export/import data do not match with the agriculture use data, an algorithm identifying non-agricultural use and stocks has been designed to complete a balance sheet by country and region. These constructs are arbitrary and involve three basic steps. The first is to derive "other consumption" as a trend line through the calculated difference by country DIFF= production+imports-exports. Then OU=trend(DIFF). From the calculated OU, derive an estimate for the change in stocks: VST =DIFF-OU. Finally, find an initial stock value that assures that stocks to not fall below 5% of the minimum of production and agricultural use, and use ST=ST(-1)+VST to generate a timeseries of ending stocks. These estimates are arbitrary and should be improved/discussed. It is considered that other use and stock estimates are important for market behaviour since they may impart considerable elasticity to market responses. However, they should be verified/assessed.

Production capacity estimates have been considered important given that supply in a given country may take considerable time to come on stream if operating near maximal output, given that investment horizons are long. Data for capacity have been generated for each nutrient using a simple "peak" method whereby it is equal to the peak/maximum of the current and previous five-year production levels. If available, more precise estimates of capacity would be more appropriate.

Agricultural use data has been allocated by crop within each country using an algorithm written by consultants at the Food and Agriculture Policy Research Institute at the University of Missouri/Colombia. More detail on this algorithm will be provided shortly. Essentially the algorithm uses area harvested and moving average yield data to dynamically allocate agricultural use, calibrated by IFA survey information, and technical coefficients where possible.

Updating balances

A critical issue concerns data update requirements, since FAO data are only available with a lag of about two years. Procedures for updating production, trade and agricultural use are therefore critical. Currently production by country is updated using a ten-year trend estimate, adjusted to fit the latest available data point. Trade by country is estimated using monthly trade data provided by the Trade Data Monitor by converting HS 6-digit codes included in 3102, 3103, 3104 and 3105, using N,P,K percentages for each code. This process is still a work in progress. Updates to total agricultural use for each nutrient are generated using prices elasticity estimates of total agricultural use, as provided by Professor Rosenbohm (University of Missouri) and may need further refinement but are broadly consistent with expectations from the current model.

Prices

World reference fertiliser price data for each nutrient has need drawn from the World Bank Pink sheet information, with the nitrogen price formed from the Eastern Europe/Middle East urea price (46,0,0), Diammonium Phosphate (DAP) (0.18,0.46,0), US Gulf and Potassium Chloride (MOP) (0,0,0.60), Vancouver. These prices have been converted to nutrient equivalents for each of N, P and K, using the nutrient content indicated. The calculation for P requires that the price of N be first calculated, such that price of P= (DAP-0.18N)/0.46. National prices for each nutrient are calculated implicitly assuming full price transmission from world prices into domestic markets subject to exchange rate, MTN tariffs and export taxes where applied. The transmission to domestic prices depends also on the net trade basis of each nutrient, which always for a maximal 12.5% transaction charge on either side of the international price which effectively, without tariffs or taxes, puts an export floor price at 12.5% below the international price, or an import ceiling at 12.5% above the international price. This methodology is consistent with that used in the Aglink-Cosimo model for producer/wholesale price estimation where it does not exist. Applied tariff data is taken from the WTO-WITTS database, and refers to the MFN rate, and does not account for alternative rates that may be provided by regional agreements. Date for export taxes have not yet been researched.

Retail price margins are estimated as equal to the producer price in the base period for pricing of 2014-16, in the base US market. It is then scaled according to a logistics function which lowers the margin depending on the distance of per capita income in the given country and that of the United States, such that for example the margin for Ethiopia is 25% below that of the United States. The margin is indexed over time using the gross domestic price deflator, as a measure of the wage component of the margin. This estimation is broadly consistent with methods of the Aglink-Cosimo model and should also be subject to review. Data for consumer net subsidies and taxes (that is for fertiliser nutrients to consumers of fertilisers) have yet to be researched. This will be necessary for future policy simulations.

Other data

All other data derive from the current database supporting the Aglink Cosimo model, including crop prices, crop area was well as macro information for GDP, GDP price index, and population.

Parameter considerations

Initial choices for key parameters and elasticities are noted under model specification. These are templates which are used for each country/region of the Aglink-Cosimo model. There is a lack of parameter information on virtually all aspects of the proposed module, and they will critically determine the performance and functioning of the module and will require considerable consultation.

Parameters with respect to the impact of fertiliser application on crop yields have been based on Rosas (2011[7]). However, these have been adjusted for each country/region depending on application rates relative to representative countries depending on the crop. The base parameters are noted in Table 4.2 below, and parameters for each country/region lie in a range with high application rates lowering the marginal impact on yield, and where low application rates have a higher application rate. This adjustment follows a logistics formula that has a maximum value of the base rate to a minimum value of one third of the base rate.[12] For example, the marginal elasticity of nitrogen application on maize yield in the United States is 0.13, but it is 0.39 in Nigeria. Using the same formula, the demand parameters in the application rate equation is -0.067 in the United States and -0.193 in Nigeria. Tests will be required to assess parameters in more detail, and they may be refined with further research and discussion. These parameters are key to the demand side of the model, and in particular its linkage with the Aglink-Cosimo model.

Initial parameters chosen for the supply side of the model reflect the view that production capacity takes considerable time to come on stream. Hence at capacity, supply elasticity is very low, but below capacity it may be much higher. The long run capacity elasticity is set at 1, but the mean lag is about eight years.

The only parameters of the current model which have been estimated are the constant term in each equation and the coefficient of the trend variable. For the trend coefficients, these were estimated over the previous ten years, and since these estimates may be unstable, they were restricted to a range between -0.01 and 0.01. Once these values were fixed, all parameterized equations were re-estimated for the based period of the three most recent years as a means of calibration.

[12] The logistics formula used is $Ec=B-(B-B/3)*2/(1+exp(max(1,QCHA_{usa}/QCHA_{c}))^{0.5} - 1))$ for period 2016-18;

Table 4.2. Elasticity of yield to fertiliser application, base rates

	N	P	K
Wheat	0.40	0.06	0.06
Maize	0.40	0.17	0.07
Other coarse grains	0.40	0.15	0.15
Soybean	0.07	0.26	0.26
Other oilseeds	0.20	0.2	0.05
Rice	0.25	0.05	0.05
Sugar cane	0.12	0.12	0.12
Sugar beet	0.25	0.34	0.34

Note: Adjustments have been made. Wheat has been adjusted to 0.4 as the reported value of 0.17 appeared inconsistent within the paper. This needs to be validated.
Source: Basis for values is Rosas (2011[7]).

Policy

Many countries use fertiliser policies for a variety of reasons. Importantly, fertiliser inputs are often subsidised with direct payments to farmers, subsidies to fertiliser producer or to importers. Some countries apply export limits or taxes for different reasons including assuring domestic availability. Fertiliser has also been viewed as a strategic good, with destination/origin trade limitations for political purposes. At this point, the module only includes applied MFN import taxes, and further policy specification is a challenge for future work. An important exception is a simplified specification of the significant policy structure in India.

India fertiliser policy

The Government of India operates a complex fertiliser subsidy program for its agricultural producers. Subsidies are very large and vary within a given year according to the two different growing seasons, and according to movements in fertiliser prices. Compensation may also be offered for their transportation. A maximum retail price (MRP) established for nitrogen/urea at Rs 5360/tonne and retailers may apply for subsidy to cover costs of their sale. Under the Nutrient Based Subsidy (NBS) scheme which applies for compound nitrogen, phosphorus and potassium fertilisers, retailers may apply for a subsidy covering 100% of their purchase costs, either on the domestic or import market. Subsidies for nitrogen, phosphorus and potassium fertilisers in April 2022 were Rs 91960/t, Rs 72740/t and Rs 25310/t respectively.[13]

Indian fertiliser subsidies are extremely large relative to consumer prices – particularly so in the base period for this analysis. The fertiliser model was adjusted and re-calibrated with the following equations in order to implement the scenario:

IND_FTN_CP..E =
(IND_FTN_CP..MAR+IND_FTN_PP)*(1+IND_FTN_CP..TAX..REL/100)+IND_FTN_CP..TAX..ADD,

IND_FTN_CP..T = 5378*IND_ME_GDPD/1.8271,

IND_FTN_CP=MIN(IND_FTN_CP..E , IND_FTN_CP..T);

IND_FTP_CP..TAX..ADD'N=(-1)*IND_FTP_PP;

IND_FTK_CP..TAX..ADD'N=(-1)*IND_FTK_PP

For this implementation, an estimated consumer price for nitrogen was set to the model template, with a target price set and indexed at the 2022 nitrogen base for 2022 (RS 242/kg) of Rs 5378/t, adjusted to a nutrient equivalent basis. Then the selection of consumer price is set at the minimum of these two. For phosphorus and potassium, the *TAX..ADD* variable in the consumer price equations was set at the negative of producer prices, again on a nutrient equivalent basis.

[13] See https://fertiliserindia.com/nutrient-based-subsidy-nbs-rates-for-phosphatic-potassic-pk-fertilizers-for-the-year-2022-23/;

Concluding remarks

The module presented demonstrates properties that meet expectations – at least for its first experiments. It has been presented at a seminar involving experts. Building a consensus on specification, parameters and data is a critical activity for future work. The list below provides a set of priorities that have been identified for attention.

Data

Market balances for FAOstat data require further assessment. Importantly, updating balances and techniques of doing so need attention. Access to IFA's database and expert knowledge could be important if not critical. For trade, the detailed access to databases needs more formal procedures to assure accuracy in determining nutrient equivalents. Construction of price margins should be assessed. Finally, collection of policy data is important for future model use. Data research is needed not only on subsidies, export taxes and bans, but also how to interpret them into the model context.

Parameters

Templated parameters are a first step, but they should be reviewed and adjusted with experience and as comments are obtained from fertiliser experts. Such review should be by item, including impacts on yields, use elasticities with respect to prices, production elasticities, etc.

Model specifications

In the current model, the implementation of production capacity constraints has been set aside but is a feature of fertiliser supply and should be included in the module. The specification of nutrient demand should be reviewed, as currently nutrient demands are independent from each other. There is no substitution nor complementarity among nutrients. Crop specific "fertiliser formulae" could be assessed as an alternative specification. Specification of marginal yield impacts which change with higher application rates could make the responses of the model more meaningful for more scenarios where application rates increase significantly.

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