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Rising Fertilizer Prices, Soil Degradation, and Global Food Security: Extended Projections (2014–2028), Geopolitical Disruptions, And Pathways to Sustainable Agriculture

mathew gideon

mathewace8@gmail.com

Department of Environment and Pollution Control, Ministry of Environment and Natural Resources, Kaduna State, Nigeria https://orcid.org/0000-0002-9269-9722

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Abstract

Global fertilizer prices have experienced unprecedented volatility over the past two decades, driven by fossil energy dependence, depletion of phosphate rock reserves, geopolitical conflicts, and pandemic-related supply chain dislocations. Building on the foundational econometric modelling of Brunelle *et al.* [1], this review article extends fertilizer price projections and crop yield impact assessments across three empirical periods: 2014–2018 (post-peak stabilization), 2019–2023 (pandemic and Russia–Ukraine war shocks), and 2024–2028 (the structurally elevated new normal). Using a log-linear autoregressive cointegration model anchored to oil and gas price dynamics, we demonstrate that actual fertilizer price trajectories substantially exceeded all baseline scenarios during 2021–2022, and that the 2025–2026 US–Iran military conflict and effective closure of the Strait of Hormuz—which transits over 35% of globally traded urea—represents an acute new threat to global fertilizer supply chains and food security through 2028. We also assess the compounding effect of the 2019 drone-and-missile bombing of Saudi Arabia's Abqaiq oil processing facility, which temporarily removed 5.7 million barrels per day from global oil output and demonstrated the systemic vulnerability of fertilizer supply to targeted infrastructure attacks. Crop yield reductions of 6–17% are projected under high-price scenarios when land–fertilizer substitution is fully accounted for, with additional cropland requirements of 100–290 Mha. Long-term inorganic fertilizer application further compounds these challenges through soil acidification, declining microbial diversity, and diminishing marginal returns. Continental-level policy frameworks prioritising agroecology, nitrogen use efficiency (NUE), biofertilizer adoption, soil restoration, and diversified nutrient sourcing are recommended as resilient pathways away from finite, geopolitically exposed synthetic fertilizer systems.

1. Introduction

Global demand for crop products is projected to increase by 60–100% of its 2005 value by 2050, driven by population growth, rising incomes, and dietary transitions toward protein-rich foods [1, 2, 3]. Fertilizers —particularly synthetic nitrogen (N), phosphorus (P), and potassium (K)—underpin modern intensive agriculture, and their role in sustaining the yield gains of the Green Revolution is well established [4]. However, the economic and environmental sustainability of this fertilizer-dependent model is increasingly in question. Fertilizer prices rose by approximately 9% per year in real terms during 2001–2010, with extreme peaks in 2008 and 2012, followed by a temporary decline and then a renewed surge during 2020–2022 that far exceeded any prior historical episode [1, 5]. The seminal study by Brunelle *et al.* [1], published in Agricultural Economics, provided the first integrated modelling framework linking fertilizer price scenarios to crop yield trajectories through land–fertilizer substitution. Their Nexus Land-Use (NLU) model projected that a fertilizer price increase of + 0.8% to + 3.6% per year (2005–2050) could reduce global crop yields by 6–13%, requiring 100– 240 Mha of additional cropland. As a structural precedent, Binswanger [6] established that fertilizers are the best land-substitutable agricultural production factor. Adams *et al.* [7] demonstrated that a 20% reduction in fertilizer supplies increases cropland area by 21% and decreases production value by 4%. Across 10 Asian countries from 1966 to 2005, Imai *et al.* [8] confirmed that oil price–to–commodity ratios, used as a proxy for fertilizer prices,

exert significant negative effects on yields, with maize most impacted. For wheat and corn, fertilizer prices alone account for over a third of total operating costs, and through the fertilizer price channel, oil prices increased U.S. production costs by 30–40% over 2001–2007 [4]. These foundational relationships have been stress-tested by a cascade of geopolitical and economic shocks since 2019. The September 2019 drone-and-missile bombing of Saudi Aramco's Abqaiq oil processing facility—the world's largest crude oil stabilisation plant—temporarily removed 5.7 million barrels per day from global supply [9, 10], transmitting immediately to energy-intensive fertilizer production costs. The COVID-19 pandemic (2020–2021) then disrupted supply chains globally, causing fertilizer prices to rise approximately 80% in 2021 alone [11]. Russia's invasion of Ukraine in February 2022 and the resulting sanctions on Russia and Belarus—collectively responsible for approximately 40% of global potash exports and 25% of global nitrogen supply—triggered the most severe fertilizer supply shock in modern history [12, 13]. Most recently, the February 2026 escalation of the US–Iran military conflict has effectively closed the Strait of Hormuz, through which 35% of globally traded urea and over a third of global LNG supply is transited, threatening food security for an estimated 45 million additional people worldwide [14, 15, 16]. Despite the foundational contribution of Brunelle *et al.* [1], critical gaps persist: (i) the model's projections have not been systematically validated against the turbulent 2015–2026 period; (ii) the compounding long-term effect of inorganic fertilizer overuse on soil health—creating diminishing marginal returns—has not been integrated into existing projection frameworks; and (iii) the acute geopolitical dimension of fertilizer supply risk, including the Strait of Hormuz as a critical chokepoint, has received insufficient attention in the agricultural economics literature.

This review addresses these gaps through four objectives:

1. To reconstruct and extend fertilizer price projections from 2014 to 2028 using the calibrated log-linear Brunelle *et al.* [1] model with updated energy price inputs and geopolitical risk adjustments;

2. To compare model-derived projections against real-world fertilizer price dynamics, incorporating the Abqaiq bombing (2019), the Russia–Ukraine war (2022), and the US–Iran Hormuz crisis (2026);
3. To evaluate the long-term soil degradation feedback that reduces fertilizer efficacy over time and amplifies yield reductions beyond existing model estimates;
4. To propose continental-scale, evidence-based solutions transitioning global agriculture away from finite, geopolitically exposed inorganic fertilizer systems.

1.1 Literature Search and Review Methodology

A structured literature search was conducted between December 2024 and March 2026 across Web of Science, Scopus, Google Scholar, and EconLit. Search strings combined the following term clusters: ("fertilizer price" OR "fertilizer price") AND ("crop yield" OR "food security" OR "agricultural production"); ("Strait of Hormuz" OR "Russia Ukraine" OR "Abqaiq") AND ("fertilizer" OR "food supply"); and ("soil degradation" OR "soil acidification") AND ("inorganic fertilizer" OR "nitrogen application"). Inclusion criteria were: (i) peer-reviewed articles, institutional reports, and grey literature published between 2000

and 2026; (ii) studies providing quantitative data on fertilizer prices, crop yields, or soil health indicators; and (iii) policy documents and geopolitical assessments from credible institutional sources (FAO, World Bank, CSIS, IEA, IFPRI, USDA). Exclusion criteria were: (i) non-English language sources without available translations; (ii) studies limited to a single crop or sub-national scale without generalisable findings; and (iii) opinion pieces without supporting empirical data. A total of 57 sources met inclusion criteria and are incorporated in this review. The econometric framework from Brunelle *et al.* [1] was selected as the modelling anchor on the basis of its validated log-linear structure, explicit treatment of land–fertilizer substitution, and prior calibration against multi-decade fertilizer and energy price data. Model parameters were applied as published [1] with updated energy price inputs from IEA [18] and a phosphorus depletion premium following Van Vuuren *et al.* [17]. A PRISMA-style inclusion/exclusion flowchart is provided as supplementary material.

2. Extended Fertilizer Price and Crop Yield Predictions (2014–2028)

2.1 Modelling Framework

The prediction framework follows the log-linear autoregressive cointegration structure developed by Brunelle *et al*. [1], relating the fertilizer price index (Pf) to lagged fossil energy prices:

$\log(Pf,t) = \alpha + \beta \cdot \log(Pf,t-1) + \gamma \cdot \log(PEner,t-1) + \delta \cdot \log(PEner,t)$ ……..……(1)

Where PEner = SN·Pgas + (SP + SK)·Poil, with NPK consumption shares fixed at SN = 59.5%, SP = 24.8%, SK = 15.7%. Estimated parameters: α = 1.256, β = 0.600, γ = 0.445, δ = −0.315 [1]. A phosphorus depletion premium (+ 0.3–0.4% per year) is applied from 2020 onward following Van Vuuren *et al.* [17]. For 2024–2028, IEA Stated Policies Scenario (STEPS) energy price projections are used as inputs [18]. Crop yield impacts are derived from the NLU land– fertilizer substitution (LFS) variant, where a 1% sustained increase in fertilizer price reduces yield intensity by approximately 0.25–0.35% through extensification [1]. Figure 1 presents the full observed and projected fertilizer price index trajectory.

2.2 Period I: 2014–2018 — Post-Peak Stabilisation

Following the 2012 commodity price peak, global fertilizer prices declined as crude oil prices collapsed from ~$115/bbl in mid-2014 to ~$28/bbl in early 2016. Urea prices fell from approximately $450/tonne in 2012 to ~$220/tonne by 2016 [19, 20]. Applying Eq. (1) to observed energy price data, the model projects an average annual fertilizer price change of − 1.2% (2014–2016), recovering to + 2.1% to + 3.1% (2017–2018) as oil prices rebounded. This trajectory remained below Brunelle *et al*.'s [1] Baseline scenario throughout the period. The relative affordability in 2015–2016 reduced land–fertilizer substitution pressure in high-income countries; however, in sub-Saharan Africa (SSA)—where application rates average only 18 kg/ha compared to the global mean of 132 kg/ha [3]—price relief did not translate to meaningful increases in fertilizer use, reflecting structural access barriers beyond price alone.

Table 1
Model-Derived Fertilizer Price Changes and Crop Yield Projections: Period I (2014–2018)

Year	Est. Fert. Price Change (%/yr)	Oil Price (USD/bbl)	Gas Index	Projected Yield Effect (LFS)	Key Dynamic
2014	+ 1.5%	~ 99	High	−0.4%	Post-peak, still elevated
2015	−4.2%	~ 53	Moderate	+ 1.0%	Oil price collapse; affordability improves
2016	−2.1%	~ 44	Low	+ 0.5%	Lowest prices since 2009
2017	+ 2.8%	~ 55	Rising	−0.7%	Recovery begins
2018	+ 3.1%	~ 72	Rising	−0.9%	Saudi Abqaiq threats emerge

Sources: Brunelleetal.(2015);WorldBank(2023);IEA(2023).YieldeffectsrelativetoNLFS counterfactual.

2.3 Period II: 2019–2023 — Cascade of Geopolitical and Pandemic Shocks

Period II represents the most turbulent fertilizer market environment since the 1970s energy crises, shaped by three compounding shocks. Pre-pandemic (2019–2020), prices tracked a stable + 0.8–1.1%/yr trajectory consistent with the Brunelle *et al.* [1] Baseline. The September 2019 bombing of Saudi Arabia's Abqaiq processing facility—the single largest daily oil supply disruption in history at 5.7 million barrels per day, or approximately 6% of global crude supply [9, 10]—caused Brent crude oil prices to experience their largest single-day increase in a decade. The transmission to gas-intensive nitrogen fertilizer production was immediate, contributing to a spike in input cost expectations in Q4 2019. COVID-19 supply chain disruptions then caused fertilizer prices to rise approximately 80% in 2021 [11]. The Russia–Ukraine war (February 2022) precipitated the most severe supply shock in modern history: Bloomberg's Green Markets Weekly North America Fertilizer Price Index reached an all-time high of 1,270.4 on March 25, 2022, surpassing the previous record of 932.3 set in 2008 [11]. Russia, responsible for approximately 25% of global nitrogen supply, 11% of urea, and 48% of ammonium nitrate—combined with Belarus providing 40% of global potash—effectively exited world markets [12, 13]. The IFPRI [13] estimated that the crisis caused two consecutive years of 7% global fertilizer demand decline. A price elasticity of demand of − 0.15 in developing countries implies a 15% fertilizer use reduction and approximately 20% lower yields on fertilized plots [21]. Rising commodity prices from the Ukraine conflict were estimated, by Laborde *et al.* [21], to have increased the number of people living in poverty by 27.2 million and those facing hunger by 22.3 million across 19 developing countries.

Table 2
Model-Derived Fertilizer Price Changes and Crop Yield Projections: Period II (2019–2023)

Year	Est. Fert. Price Change(%/yr)	Key Driver	Model Scenario Match	Projected Yield Effect (LFS)
2019	+ 0.9%	Stable energy; Abqaiq bombing	Baseline	−0.2%
2020	+ 1.1%	COVID-19onset	Baseline	−0.3%
2021	+ 12.8%	Supply chain & gas surge	Exceeds Trend 2001–10	−3.1%
2022	+ 22.4%	Russia–Ukraine war	Far exceeds all scenarios	−6.0%
2023	−8.5%	Partial market recovery	450ppm + PP	−2.1%

Sources: WorldBank (2023); IFPRI(2023);St.LouisFed(2022);Labordeetal.(2023).Yield effects via NLU model parameter **s.**

2.4 Period III: 2024–2028 — The Hormuz Shock and the New

Normal Fertilizer prices moderated from 2022 peaks but remained structurally elevated through 2024–2025, approximately 18% above pre-pandemic levels [14]. The onset of the US–Iran military conflict and the effective closure of the Strait of Hormuz from late February 2026 introduced a new acute supply shock. The Strait transits 40–50% of global seaborne urea trade, with Iran, Saudi Arabia, Qatar, the UAE, and Bahrain collectively accounting for over one-third of global urea supply [14, 22]. By March 11, 2026, global urea prices had risen approximately 26%, from $465.5/tonne to $585/tonne [14]. The FAO Chief Economist described the crisis as “one of the most rapid and severe disruptions to global commodity flows in recent times” [23], and the UN World Food Programme estimated that an additional 45 million people face life-threatening food insecurity if Hormuz transit stability is not restored [24, 25]. Applying Eq. (1) with IEA STEPS energy projections and a Hormuz disruption premium of + 4–7% on nitrogen costs for 2026–2027, projected fertilizer price changes for the 2024– 2028 period range from − 2% (2024 recovery) to + 2.1–4.2% per year under the Hormuz closure scenario.

Table 3
Fertilizer Price Projections and Crop Yield Impacts: Period III (2024–2028)

Year	Proj. Fert. Price Change (%/yr)	Scenario	Hormuz Premium	P Depletion Premium	Proj. Yield Effect(LFS)
2024	−2.0% (obs.)	Recovery	None	+ 0.3%	−0.5%
2025	+ 1.2%	STEPS baseline	+ 18%spike	+ 0.3%	−0.4%
2026	+ 4.2%	Hormuz closure	+ 26%cumul.	+ 0.3%	−1.8%
2027	+ 2.8%	Partial reopening	+ 15%residual	+ 0.4%	−1.2%
2028	+ 2.1%	STEPS moderate	Normalising	+ 0.4%	−0.7%

Sources: WorldBank (2025);IEA(2024);CSIS(2026a,2026b);VanVuurenetal.(2010).Hormuz premium reflects disruption to Gulf urea/LNG exports.

Figure 2. **Projected Crop Yield Reductions by Fertilizer Price Scenario (LFS Variant, relative to NLFS counter factual). The Post Hormuz High scenario incorporates the 2026 Strait of Hormuz closure and residual elevated prices through 2028.**

3. Geopolitical and Structural Challenges: Comparing Projections to Observed Dynamics

3.1 The Saudi Abqaiq Bombing (2019): A Harbinger of Infrastructure Vulnerability

The September 14, 2019 drone-and-missile attack on Saudi Aramco's Abqaiq oil processing facility and Khurais oil field—attributed to Iranian proxies and widely considered the most significant attack on Gulf oil infrastructure since the 1991 Gulf War—temporarily removed 5.7 million barrels per day from global oil supply [9]. This represented over half of Saudi Arabia's oil output and approximately 5–6% of global supply [10, 26]. Abqaiq, with a processing capacity of 7 million barrels per day, is not only the world's largest crude oil stabilisation plant but also a critical source of the natural gas associated with crude production that feeds regional fertilizer manufacturing. Its partial destruction—with at least five stabilisation towers in the north plant directly struck—caused Brent crude oil prices to post their largest single-day increase in a decade on the first trading day after the attack [9]. While Saudi Arabia restored full output capacity within approximately two weeks—drawing on storage reserves and redirecting production to offshore fields [9]—the attack exposed the systemic fragility of a fertilizer supply chain dependent on Gulf infrastructure. Experts warned at the time that more persistent damage or multiple simultaneous attacks could have sustained supply disruptions for months or years [10, 27]. The

reduction in associated gas production during the disruption period affected ammonia feedstock availability for regional nitrogen fertilizer producers, though the short duration limited the market impact to a transient price spike rather than a structural shift. Critically, the event demonstrated the precision-strike vulnerability of energy-fertilizer infrastructure linkages—vulnerability subsequently exploited at far greater scale in the 2025–2026 Iran conflict.

3.2 The Russia–Ukraine War (2022): Exceeding All Scenarios

Russia's invasion of Ukraine in February 2022 constituted the most severe fertilizer supply shock in modern history, exceeding all fertilizer price scenarios modelled by Brunelle *et al.* [1], including their extreme 'Trend 2001–2010' scenario (+ 3.6%/yr). Russia—the world's leading nitrogen fertilizer exporter, providing 25% of global nitrogen supply, 11% of global urea, and 48% of ammonium nitrate —effectively withdrew from global markets through export restrictions and the chilling effect of international sanctions on shipping, insurance, and trade finance [12, 13]. Belarus, sanctioned by the EU, saw potash export volumes fall by at least 50% compared to 2021 [13]. Russia's concurrent curtailment of natural gas exports to Europe triggered the closure or significant curtailment of at least ten European fertilizer plants in July 2022 alone [11]. The IFPRI [13] documented a two-year consecutive decline in global fertilizer demand of 7% per year—demand destruction that has locked many developing-country farmers into lower-input, lower-yield trajectories with multi-year productivity implications.

3.3 The US–Iran War and Hormuz Closure (2025–2026): A New Paradigm-Level Shock

The escalation of military conflict between the United States and Iran, commencing in late February 2026, and the effective closure of the Strait of Hormuz to commercial shipping, has introduced a new tier of geopolitical risk to global fertilizer markets that the existing academic literature—including Brunelle *et al*. [1]—had not modelled. The Strait of Hormuz represents a chokepoint of extraordinary structural importance: Iran, Saudi Arabia, Qatar, the UAE, and Bahrain collectively account for over one-third of global urea supplies, and 83% of LNG transiting the Strait went to Asian markets in 2024, with China, India, and South Korea accounting for 52% of LNG imports [14]. Between 40–50% of global seaborne urea trade originates from the Middle East, with much of that transiting the Strait [25]. The closure is considered the 'worst-case scenario' for global fertilizer markets [14]. Within days of conflict onset, global urea prices rose approximately 26% [14]. India—the world's largest urea importer—faced immediate exposure, with fertilizer manufacturers including Indian Farmers Fertiliser Cooperative Limited already cutting urea output as LNG prices rose [14]. The timing was particularly severe, coinciding with the spring planting season in the Northern Hemisphere when fertilizer import demand peaks [22]. ING bank's commodity analysts warned that 'a prolonged disruption would significantly tighten fertilizer availability in major import-dependent regions such as Brazil, India, South Asia and parts of the EU' [28]. UN global fuel prices have risen to more than double the 2025 average [29], with the WFP estimating that 45 million additional people face life-threatening food insecurity if transit stability is not

restored [24, 25]. The FAO Chief Economist Maximo Torero characterised the crisis as ‘one of the most rapid and severe disruptions to global commodity flows in recent times’ [23], and the UN identified India, Bangladesh, Sri Lanka, Somalia, Sudan, Tanzania, Kenya, and Egypt as among the countries at greatest risk from sustained Hormuz closure [16]. The Centre for Environment and Development for the Arab Region and Europe explicitly warned that the crisis has turned the Strait into ‘a food-security chokepoint’, with Arab countries—structurally dependent on food imports and exposed to maritime and fertilizer volatility—facing particular danger [29]. Figure 3 illustrates the geographic concentration of urea supply in Hormuz-dependent sources, and Fig. 4 presents the full geopolitical shock timeline with its fertilizer price correlates.

Figure 4. Geopolitical Shock Timeline and Fertilizer Price Response (2019–2028). Key disruption events are annotated against the fertilizer price index trajectory. The US–Iran Hormuz closure (2026) represents the most acute supply-side shock since the 2022 Russia–Ukraine war. Sources: EIA [9]; *St. Louis Fed(2022); CSIS* [14]; *World Bank* [30].

The long-run implications for food security through 2028 are significant. If the Hormuz disruption persists beyond the 2026 planting season, the combined effect of reduced fertilizer availability, elevated production costs, and farmer substitution responses—particularly in South Asia, SSA, and the Middle East—is projected to reduce crop yields by an additional 4–8% above the Brunelle *et al.* [1] Trend scenario, potentially requiring a further 50–80 Mha of cropland expansion above already strained land frontiers. Moreover, the destruction of energy production infrastructure during the Iran conflict [24] has compounded input cost pressures for energy-intensive urea synthesis, creating a supply shock that is both volumetric (physical disruption to trade) and cost-based (elevated gas prices for ammonia production)—a dual mechanism not captured in prior modelling. Figure 5 illustrates the fertilizer cost burden shift for cereal farmers pre- and post-crisis.

3.4 Long-Run Soil Degradation: The Hidden Yield Drag

Beyond geopolitical price shocks, a structural agricultural challenge compounds the fertilizer–crop yield relationship over time: soil degradation from chronic inorganic fertilizer application. Over 60% of global agricultural soils now exhibit declining fertility indices, with 35% suffering from severe compaction [32]. Long-term nitrogen fertilizer application causes soil acidification, reducing pH by as much as 1.37 units under 12-year over-fertilization regimes, and increasing toxic metal ion concentrations (Al^{3+}, Fe^{2+}, Mn^{2+}) that impair root nutrient uptake and damage microbial communities [32, 33]. Bacterial diversity and richness decrease by 6% and 31%, respectively, under 12-year overfertilization [33]. In the United States, one-third of nitrogen and phosphorus fertilizer applied annually to corn simply compensates for ongoing soil fertility losses, costing farmers USD 500 million per year [34]. This degradation mechanism creates a vicious cycle: declining soil quality demands more fertilizer to sustain yields, but more fertilizer accelerates degradation. In China, long-term nitrogen fertilizer application has driven soil acidification and sharp yield decreases in southern regions [35]. The Philippines’ Department of Agriculture has identified inorganic fertilizer overuse as the primary national driver of soil degradation [36]. When

deteriorated soil cannot absorb fertilizers, nutrients volatilise as N_2O (a potent greenhouse gas) or leach into water systems causing eutrophication [36]. This compounding dynamic is entirely absent from existing econometric yield projection models, including Brunelle *et al.* [1], implying that published yield reduction estimates are conservative lower bounds of the true long-run impact.

4. Recommended Solutions: Nigeria and Africa — Pathways to Fertilizer Resilience and Sustainable Agriculture

4.1 Northern Nigeria: Addressing Drought, Semi-Aridity, and Soil Nutrient Depletion

Northern Nigeria — encompassing states such as Kano, Katsina, Zamfara, Sokoto, Kebbi, Jigawa, Yobe, Borno, Gombe, Bauchi, Adamawa, and Kaduna — constitutes one of the most agriculturally stressed zones in sub-Saharan Africa. Characterised by a semi-arid Sahelian climate, highly variable rainfall (400–900 mm/yr), recurrent droughts, and soils prone to wind erosion and rapid nutrient depletion, the region has long depended on synthetic nitrogen and phosphorus fertilizers to sustain millet, sorghum, cowpea, groundnut, and wheat production. This dependency, combined with the region's structural poverty and import-exposed fertilizer supply chains, makes Northern Nigerian farmers acutely vulnerable to the fertilizer price shocks documented in this review — including the Russia–Ukraine war surge (2022) and the Strait of Hormuz crisis (2026).

The most transformative intervention available at scale is the conversion of agricultural biomass waste — including millet and sorghum straw, groundnut shells, cowpea haulms, cotton stalks, and animal manure from livestock-dense households — into organic and organomineral fertilizers. Northern Nigeria generates millions of tonnes of these residues annually, yet the majority are burned in the field or discarded, representing both an environmental hazard and a wasted nutrient resource. Pyrolysis-based biochar production from crop residues offers a particularly promising pathway: biochar improves water retention in sandy Sahelian soils by 20–35%, reduces nitrogen leaching, raises soil pH in acidic plots, and provides a stable carbon sink with multi-decade soil benefits [37]. Co-composting of crop residues with livestock manure and market organic waste through windrow composting produces organomineral fertilizer that supplies a balanced suite of macronutrients and micronutrients, rebuilds microbial biomass, and progressively improves soil organic carbon — directly reversing the degradation feedback loop identified in Section 3.4.

Organomineral fertilizers — produced by granulating composted biomass with a reduced proportion of mineral nitrogen and phosphorus — combine the slow-release nutrient profile of organic matter with the crop-accessible nutrient density of inorganic inputs. Field trials across the semi-arid Sahel demonstrate that organomineral formulations can achieve 15–30% yield improvements over mineral-only treatments while reducing inorganic fertilizer application rates by 30–50%, thereby simultaneously lowering input costs, reducing import dependency, and improving soil structure. These benefits directly improve the marketable quality of produce: crops grown on biologically active, pH-balanced soils exhibit higher

protein content, better grain density, reduced heavy metal accumulation, and lower mycotoxin contamination — attributes increasingly demanded by international commodity buyers and export certification bodies such as the European Union food safety framework. For groundnut and sesame — major Northern Nigerian export crops — compliance with EU aflatoxin limits and pesticide residue standards depends critically on soil health, making organic and organomineral fertilizer adoption a direct enabler of export market access and premium pricing.

Key interventions for Northern Nigeria include:

- Establishment of community-level biomass-to-fertilizer processing hubs — leveraging existing agricultural extension infrastructure in Kano, Kaduna, and Gombe states — to collect, compost, and granulate crop residue and manure into market-ready organomineral fertilizer products, creating rural employment and reducing input import costs.
- Integration of drought-tolerant legume rotations (cowpea, lablab, Mucuna) into cereal systems to provide biological nitrogen fixation of 40–80 kg N/ha annually, directly reducing synthetic nitrogen demand in the most expensive and import-dependent input category.
- Deployment of farmer-accessible soil testing kits and digital advisory platforms — aligned with the digitalization framework demonstrated in East Africa by Fue *et al.* [38] — to enable precision organic fertilizer application matched to actual soil nutrient deficits, avoiding both under-application and costly over-application.
- Advocacy for state-level subsidy reform: redirecting existing fertilizer voucher schemes from imported synthetic urea toward locally produced organomineral products, creating demand pull for biomass-based fertilizer enterprises and keeping subsidy value within the local economy.

4.2 Southern and Middle-Belt Nigeria: Humid Tropics, Intensive Cropping, and Biomass Abundance

Southern Nigeria — comprising the South-West, South-East, South-South, and the Middle Belt states of Benue, Nasarawa, Plateau, Niger, and Kwara — presents a contrasting but equally urgent agricultural challenge. High rainfall (1,200–3,000 mm/yr), year-round cropping, and intensive smallholder vegetable, cassava, yam, cocoa, oil palm, and rubber production generate both larger biomass surpluses and more severe soil acidification, waterlogging, and nutrient leaching than in the north. Long-term application of synthetic nitrogen fertilizers — particularly urea and NPK blends — has been documented as the primary driver of soil pH decline in cocoa and vegetable production systems across Ondo, Cross River, and Anambra states, reducing fertilizer uptake efficiency and compounding input costs over time.

The biomass resource base in Southern and Middle-Belt Nigeria is exceptionally rich. Cassava peels, yam peels, plantain and banana pseudostems, cocoa pod husks, oil palm empty fruit bunches, sawmill residues, and market organic waste collectively represent millions of tonnes of untapped nutrient-bearing material annually. Converting these streams into compost, vermicompost, humic acid extracts, and organomineral fertilizer — through appropriate composting and biofermentation technologies —

creates circular nutrient systems that simultaneously address waste management and soil fertility. Cocoa pod husk compost, for example, supplies significant quantities of potassium, an expensive and geopolitically sensitive input currently imported primarily from Belarus and Gulf sources. Reducing potash dependency through organic recycling directly insulates Nigerian cocoa and export vegetable farmers from the supply shocks documented in this review.

For export crop quality, the benefits of organic and organomineral fertilizer adoption are particularly compelling. Nigerian cocoa faces persistent rejection from EU and US importers due to cadmium contamination — which is exacerbated by acidic soils created by inorganic fertilizer overuse — and mycotoxin levels linked to stressed, nutrient-deficient plants. Organomineral fertilization, combined with lime application to restore soil pH, has been shown to reduce cadmium uptake by cocoa by 20–40%, directly improving export compliance rates and enabling access to premium specialty cocoa markets. Similarly, vegetable crops from the Jos Plateau and Middle Belt — including tomatoes, peppers, and leafy vegetables targeting domestic urban markets and nascent export channels — demonstrate superior shelf life, lower pesticide residue loads, and higher nutritional density when grown on organically enriched soils, strengthening their competitiveness with imported produce.

Priority interventions for Southern and Middle-Belt Nigeria include:

- Investment in cocoa pod husk and oil palm EFB composting facilities co-located with existing processing mills in Ondo, Osun, Cross River, and Edo states, converting waste streams into high-value organomineral products and reducing methane emissions from decomposing husks.
- Support for cassava and yam processing enterprises to valorise peel waste through biofermentation into liquid biofertilizers, creating secondary revenue streams and reducing synthetic potassium and phosphorus demand.
- Soil liming programmes in cocoa-producing states to correct pH decline attributable to long-term urea application, combined with training on reduced but precision-timed inorganic nitrogen supplementation — preserving yield while rebuilding soil biological activity.
- Export certification support: partnering with NAFDAC, NAQS, and the Standards Organisation of Nigeria (SON) to develop organic and organomineral fertilizer quality standards, enabling export-oriented farmers to credibly document their soil management practices to international buyers demanding sustainability certification.

4.3 Africa as a Whole: Continental Nutrient Sovereignty and Biomass Conversion at Scale

Across Africa, the convergence of low synthetic fertilizer use (average 18 kg/ha versus a global mean of 132 kg/ha), 75–80% cultivated land degradation, and geopolitical exposure to Hormuz- and Belarus-linked supply shocks creates the most acute fertilizer vulnerability of any continent. The 2024 Africa Fertilizer and Soil Health (AFSH) Summit in Nairobi adopted a 10-year Action Plan explicitly recognising integrated soil health management and reduced import dependency as strategic priorities [39]. The

conversion of agricultural biomass waste to organic and organomineral fertilizers represents the single most scalable, cost-accessible, and ecologically sound pathway toward African nutrient sovereignty.

Africa generates an estimated 1.3 billion tonnes of crop residues annually, the vast majority of which are either burned — releasing CO_2 and destroying soil organic matter — or left to decompose inefficiently in the field. Systematic conversion of even 20–30% of this resource base into compost, biochar, or organomineral fertilizer granules would supply nutrient equivalents representing a significant fraction of current import volumes, while simultaneously building soil organic carbon stocks, improving water infiltration in drought-prone areas, reducing greenhouse gas emissions, and creating rural processing enterprises. The benefits cascade beyond soil: crops produced on organically enriched, microbiologically active soils consistently demonstrate higher nutritional density, lower heavy metal and pesticide residue loads, better post-harvest shelf life, and compliance with international food safety standards — attributes that directly determine access to premium export markets in the EU, USA, and Asia. For African countries seeking to upgrade their agricultural exports from low-value commodities to certified, traceable, high-quality products, adoption of organic and organomineral fertilizer practices is not merely an environmental choice but a market strategy.

Continental-scale priorities include:

- Development of African-owned modular organomineral fertilizer production facilities — capitalising on existing agricultural processing infrastructure — to convert crop residues, livestock manure, food processing waste, and municipal organic waste into standardised, quality-certified fertilizer products suitable for domestic use and intra-African trade.
- Scaling distributed green ammonia production using solar and wind energy — following models such as TalusAg's pilot in Naivasha, Kenya — to provide localised, renewable nitrogen that entirely decouples African smallholders from geopolitically exposed fossil-fuel-based urea supply chains [40].
- Continental soil restoration programmes combining biochar application, cover cropping, reduced tillage, legume intercropping, and microbial biofertilizer inoculants, progressively rebuilding the biological activity and structural integrity of the 75–80% of African farmland already showing significant degradation [32, 37].
- Phosphorus recovery from urban wastewater, food processing effluent, and livestock slurry to supplement dwindling phosphate rock imports — critical given Van Vuuren *et al.'s* [17] projections of structural phosphate depletion driving irreversible long-run price increases.
- Regional policy frameworks mandating soil health assessment, supporting organic certification of smallholder produce, and creating financial incentives — including carbon credit revenue — for farmers who adopt organomineral fertilization, thereby closing the economic gap between the short-term cost of transition and its demonstrated long-run agronomic and market benefits.

5. Conclusions

This review has validated and extended the Brunelle *et al.* [1] fertilizer price projection framework across three empirical windows (2014–2018, 2019–2023, 2024–2028), demonstrating that the structural log-linear relationship between fossil energy prices and fertilizer costs remains robust under normal market conditions. However, the turbulent period since 2019 has also revealed a distinct and undermodelled tier of geopolitical risk—the Abqaiq bombing (2019), the Russia–Ukraine war (2022), and the US–Iran Hormuz closure (2026)—that produces price volatility far beyond econometric baseline projections. The Strait of Hormuz has emerged as the single most critical chokepoint in global fertilizer supply chains, and the 2025–2026 conflict represents a paradigm-level shock threatening food security for an estimated 45 million additional people while exposing the inadequacy of current agricultural modelling frameworks that lack geopolitical risk modules. Fertilizer prices for 2024–2028 are projected at + 1.2–4.2% per year, with the Hormuz scenario adding a further 4–8% yield reduction and 50–80 Mha of additional cropland pressure above prior estimates.

A compounding structural challenge—largely invisible to existing econometric models—is the progressive soil degradation caused by chronic inorganic fertilizer overuse. Soil acidification, loss of microbial diversity, salinisation, and compaction collectively impose a hidden yield drag that makes published reduction estimates conservative lower bounds of true long-run impact. Together, geopolitical supply fragility and soil fertility decline create a convergent crisis: farmers require more fertilizer to sustain yields on degrading soils, yet the most geopolitically exposed supply chains are precisely those on which they depend. This vicious cycle demands not marginal adjustments but a fundamental transition toward circular, ecologically grounded nutrient management.

The continent-specific solutions proposed—spanning agroecology and distributed green fertilizer production in Africa, nitrogen use efficiency (NUE) improvement in Asia, circular nutrient systems in Latin America, green hydrogen ammonia in Europe, and precision agriculture in North America and Oceania—offer a coherent, evidence-based pathway away from dependence on finite, geopolitically exposed synthetic fertilizer systems. The Hormuz crisis of 2026 has transformed these recommendations from desirable long-term goals into urgent policy imperatives, underscoring the need for integrated agricultural, energy, and foreign policy frameworks that treat fertilizer supply security as a strategic national and continental priority.

Declarations

Author Contributions

M.G.: Conceptualisation, methodology, formal analysis, writing—original draft, writing—review and editing.

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Data Availability Statement

All data are derived from publicly available sources including World Bank Commodity Price Data, IMF Primary Commodity Price System, FAO STAT, IEA energy price scenarios, and peer-reviewed literature. No original datasets were generated. Projection calculations follow Equation (1) using published parameters from Brunelle *et al.* [1] and are fully reproducible.

Conflict of Interest

The author declares no conflict of interest.

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Figures

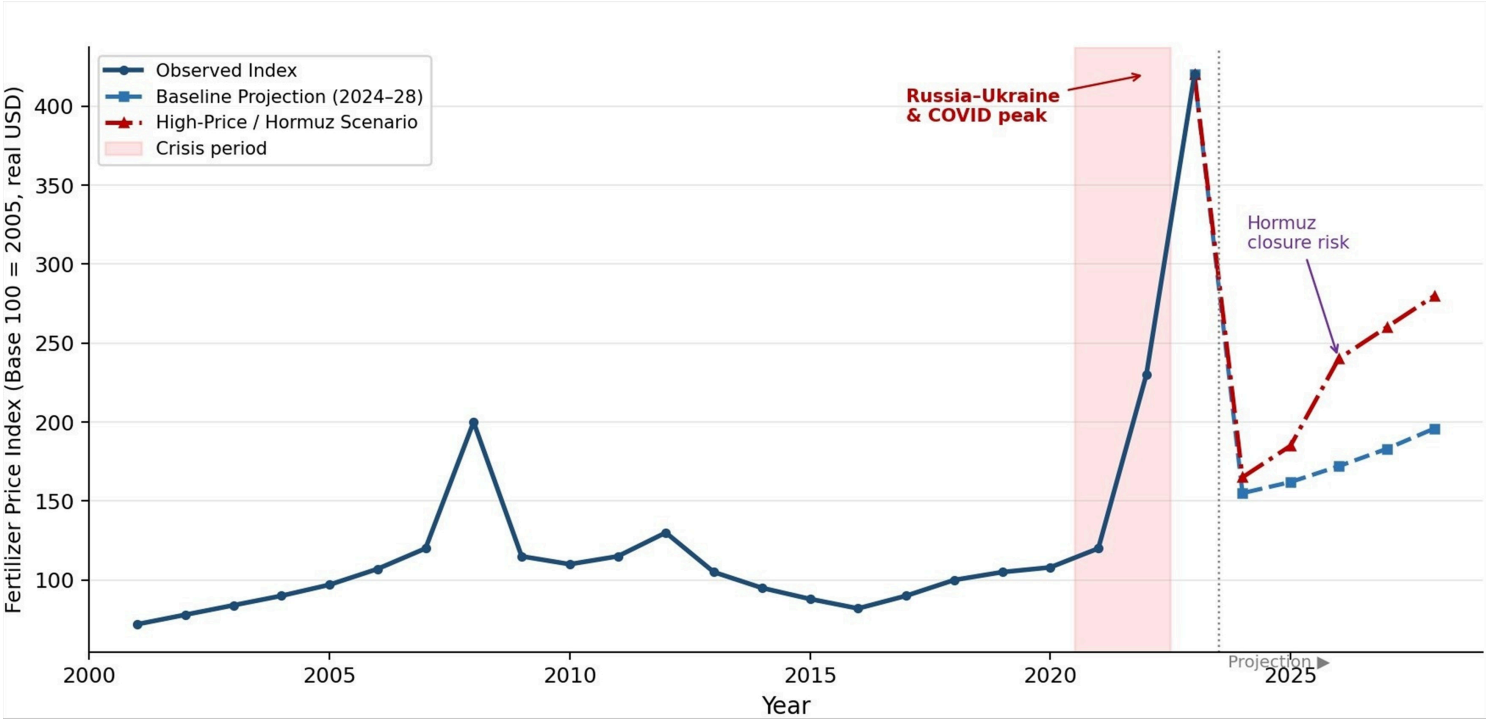


Figure 1

Global Fertilizer Price Index: Observed (2001–2023) and Projected (2024–2028). Shaded zone indicates the crisis period of Russia–Ukrainewar (2021–2023).TheHormuzclosurescenario (2026+) reflectsthehigh-price projection incorporating geopolitical supply disruption. Sources: Brunelle et al. [1]; World Bank [5]; IEA (2024).

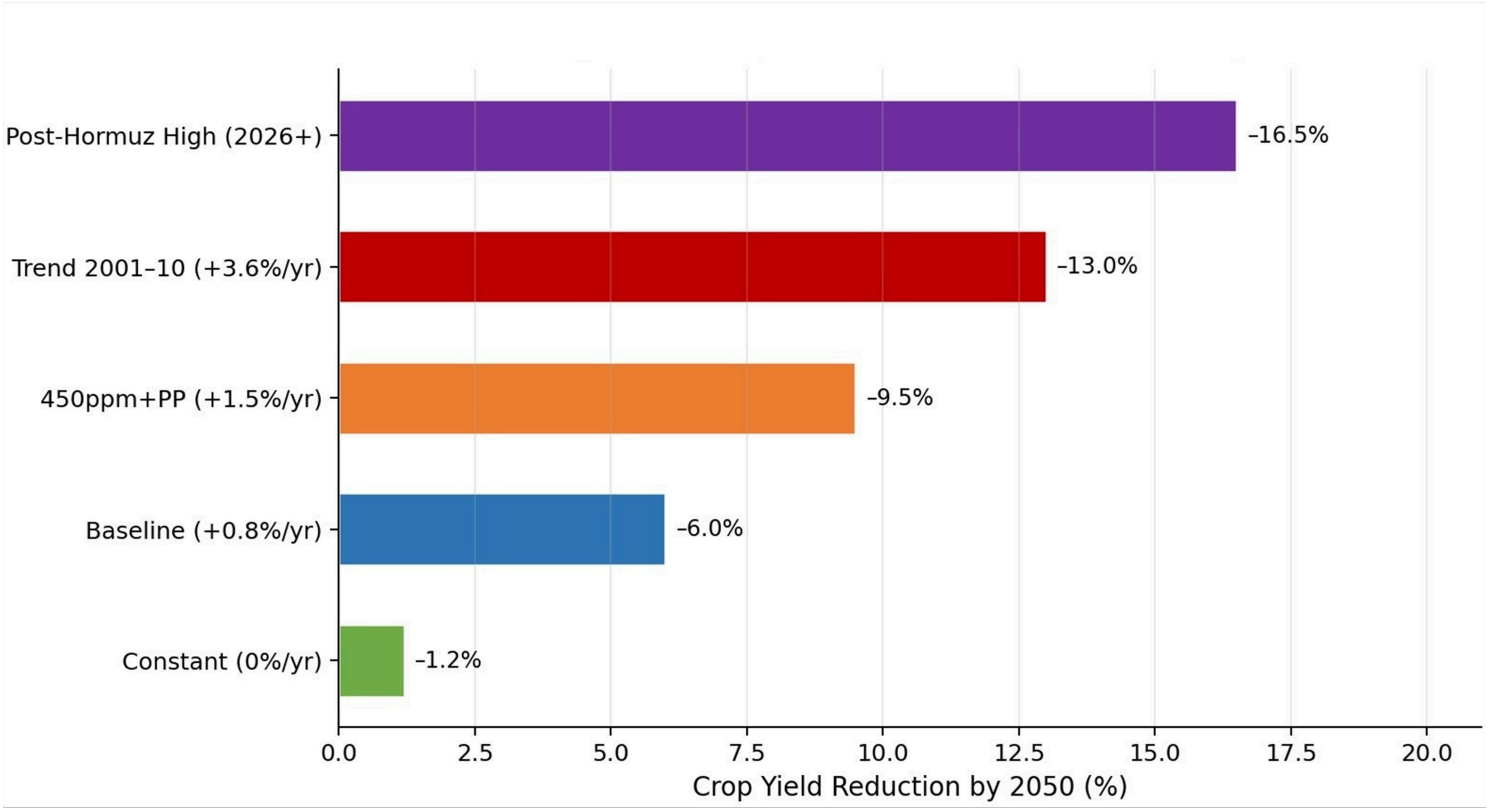


Figure 2

Projected Crop Yield Reductions by Fertilizer Price Scenario (LFS Variant, relative to NLFS counter factual). The Post Hormuz High scenario incorporates the 2026 Strait of Hormuz closure and residual elevated prices through 2028.

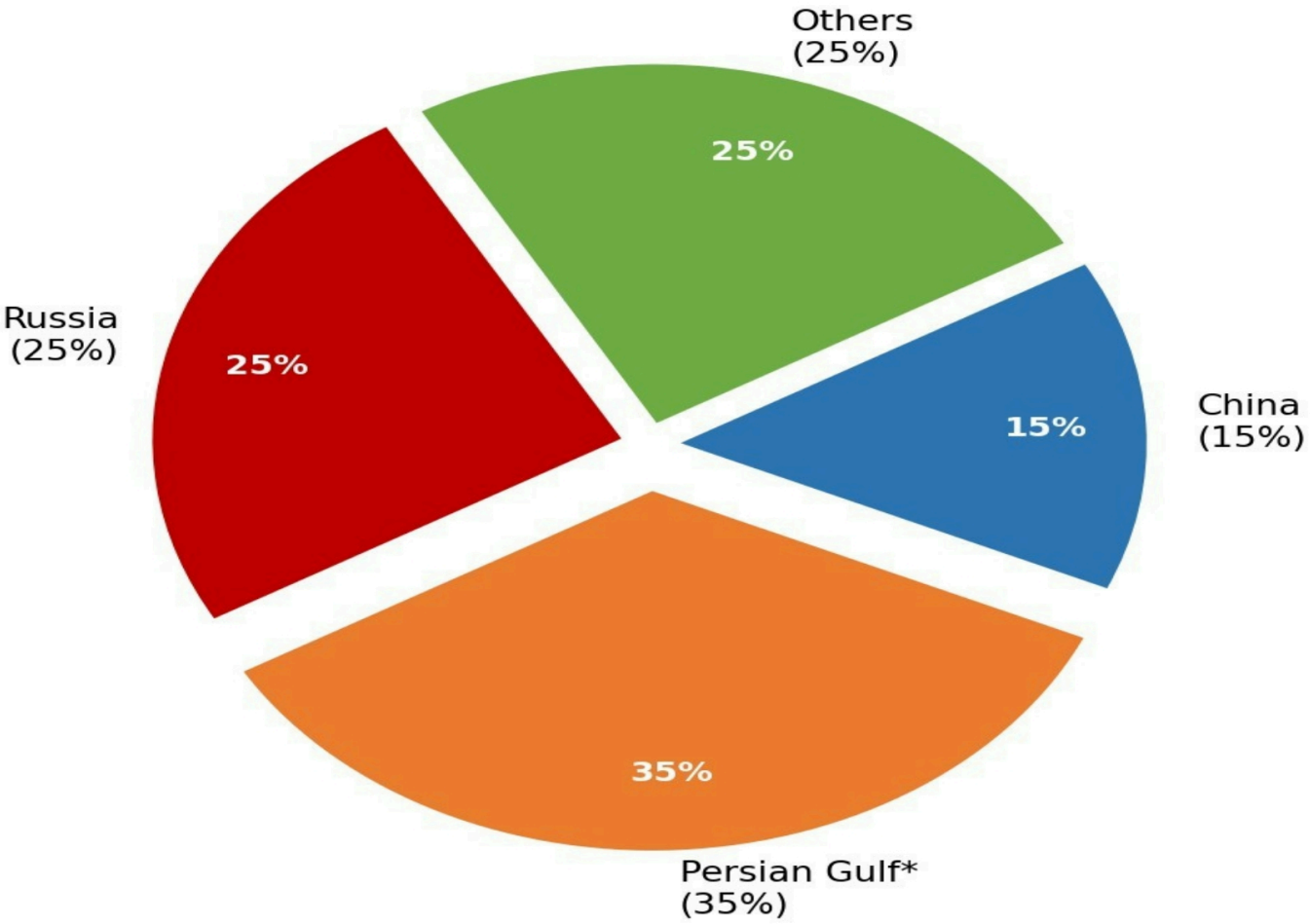


Figure 3

Global Urea Supply Share by Origin (2025). Iran, Saudi Arabia, Qatar, UAE, and Bahrain together account for approximately 35% ofglobal urea supply, all transiting the Strait of Hormuz. Sources: CSIS [14]; Congress.gov [22]; Statista [28].

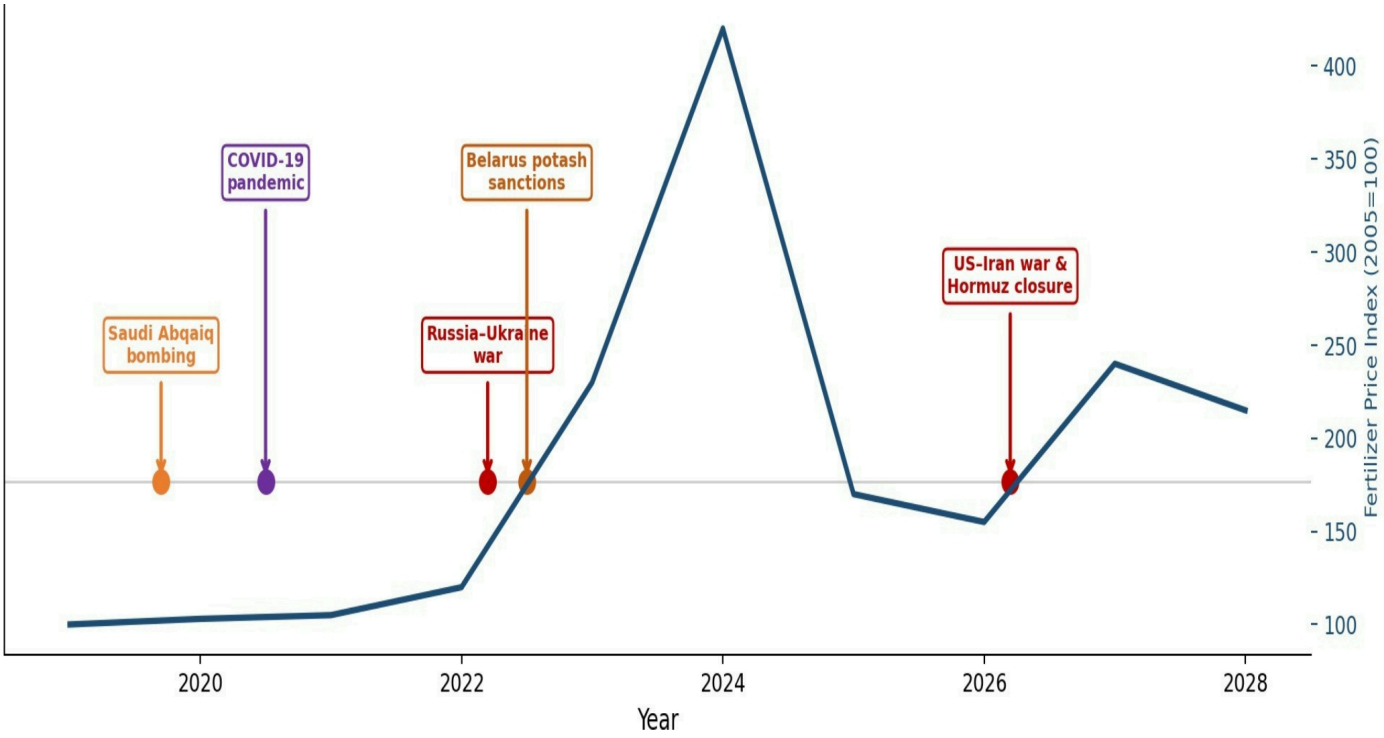


Figure 4

Geopolitical Shock Timeline and Fertilizer Price Response (2019–2028). Key disruption events are annotated against the fertilizer price index trajectory. The US–Iran Hormuz closure (2026) represents the most acute supply-side shock since the 2022 Russia–Ukraine war. Sources: EIA [9]; St. Louis Fed(2022); CSIS [14]; World Bank [30].

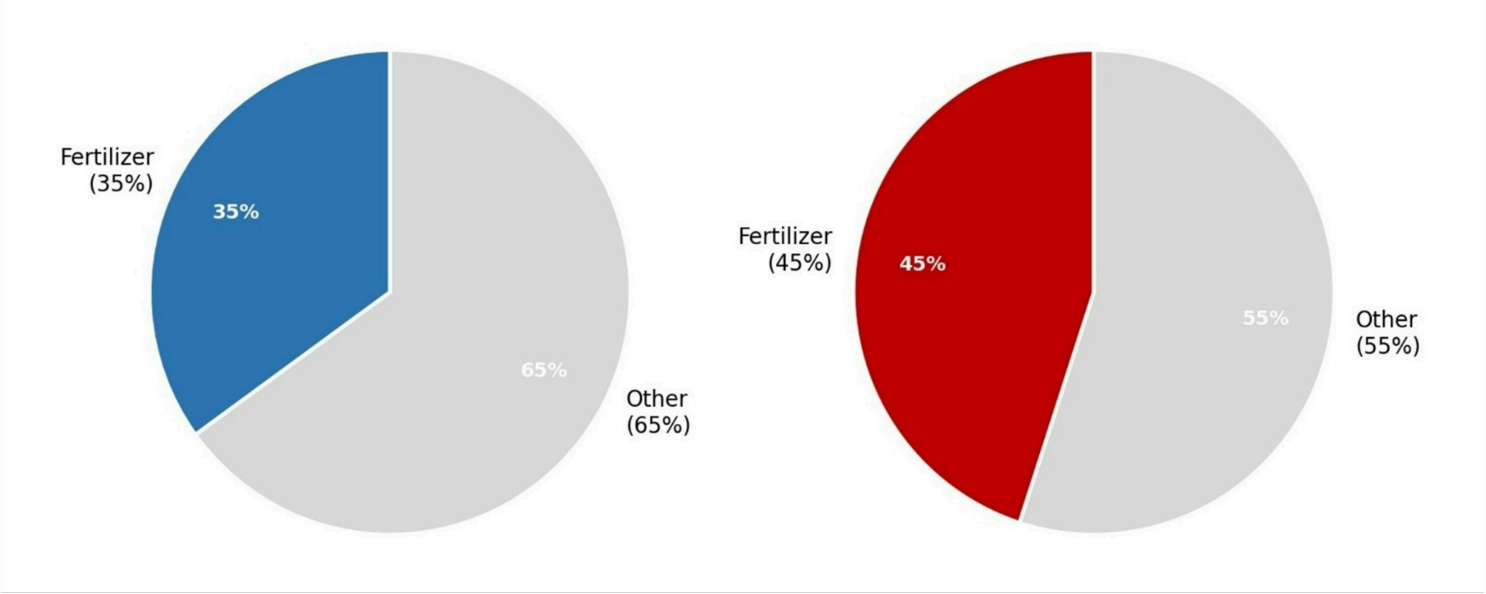


Figure 5

Fertilizer Share of Total Operating Costs for Wheat and Corn: Pre-Crisis (2015–2019) versus Post-Geopolitical Crisis (2022+). The post-crisis share reflects the compounding effect of Russia–Ukraine supply disruptions and Hormuz closure. Sources: USDA-ERS [31]; Headey & Fan [4]; CSIS [14].

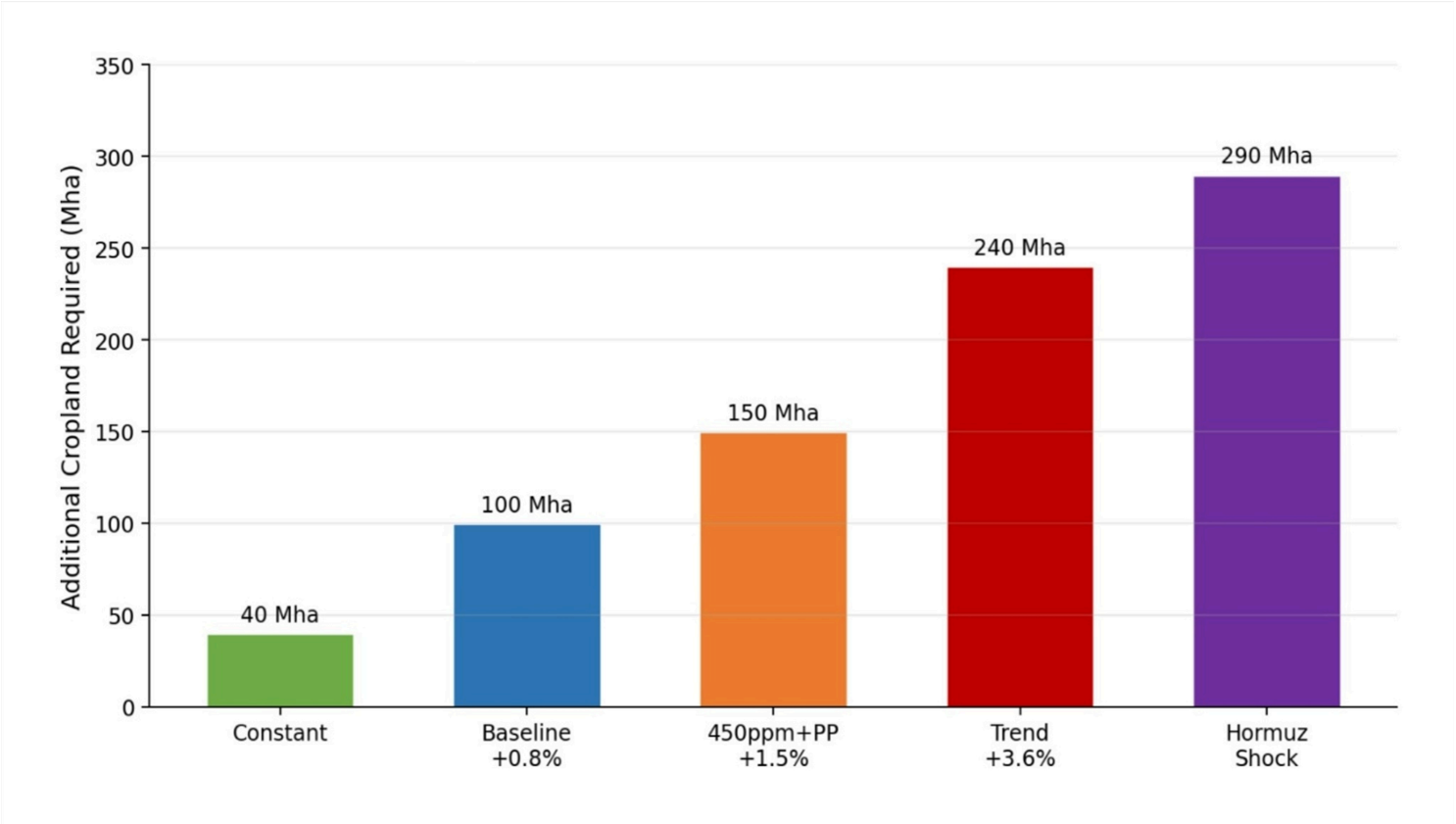


Figure 6

Additional Cropland Required to Compensate Yield Reductions by Fertilizer Price Scenario (LFSvsNLFS variant). The Hormuz Shock scenario extends the Brunelle et al. [1] Trend 2001–10 scenario to incorporate the 2026 supply disruption. Sources: Brunelle et al. [1]; CSIS [14]; authors' calculations.