

The 4F Crisis in the World: Fiscal Constraints, Fertilizer Access, and Food Security Vulnerabilities in Developing Nations

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Abstract

Synthetic fertilizer is among the least visible foundations of modern food security, and its availability is increasingly set by fiscal and geopolitical forces rather than by agronomy. This paper introduces the "4F crisis", a compound vulnerability in which fiscal constraints, fertilizer access, food security, and the fragility of institutions and ecosystems reinforce one another in developing nations. The paper is an analytical, PRISMA-ScR-informed scoping review. It synthesizes evidence on fertilizer use and productivity, input subsidy programmes, sovereign debt and fiscal space, input price shocks, climate and flood hazards, health and social inequality, and the geopolitics of supply chains. A comparative lens contrasts sub-Saharan Africa, South Asia, and East Asia. The synthesis supports five findings. First, low and erratic fertilizer use in much of Africa is mainly a problem of affordability, delivery, and economic rationality, not of ignorance. Second, subsidy programmes have delivered real but modest and costly returns, and their design, not their existence, is the decisive variable. Third, debt service and volatile commodity prices squeeze the fiscal space that input support requires, and the squeeze arrives when shocks are largest. Fourth, climate hazards, particularly floods, destroy the returns on fertilizer investment and strain the same budgets. Fifth, health, social, and epistemic inequalities shape who benefits from any policy. The paper concludes with a counter-cyclical, multi-level governance framework and six testable propositions for future research.

Keywords: *fertilizer access; fiscal space; food security; input subsidies; developing countries; sovereign debt; climate shocks; scoping review.*

1. Introduction

In the early twentieth century, the industrial fixation of atmospheric nitrogen changed what the planet could feed. Reactive nitrogen produced through ammonia synthesis now supports an estimated half of the world's population through the crops it nourishes [1]. This achievement rests on a fragile, globally traded, energy-intensive supply chain. Where that chain is weak, expensive, or politically interrupted, the people most exposed are smallholder households in low- and middle-income countries.

The scale of the resulting vulnerability is evident in international monitoring. The 2024 edition of the global food security report estimated that roughly 733 million people faced hunger in 2023, about one in eleven people worldwide and about one in five in Africa, while more than two billion people were moderately or severely food insecure [2]. The subsequent edition recorded some improvement at the global level, with the estimate of undernourished people falling to around 673 million in 2024. It also stressed that gains were uneven and that Africa remained the region with

the highest and rising prevalence [3]. Progress at the headline level can therefore coexist with deepening vulnerability in particular regions.

Fertilizer is central to this regional divergence. Smallholder farmers in sub-Saharan Africa apply only a small fraction of the nutrients applied in other regions, and the continent's average application rate remains far below the 50 kilograms of nutrients per hectare that African heads of state set as a target in 2006 [4–6]. The gap has costs in lost yields, soil nutrient mining, and recurring hunger. The shocks of the early 2020s then sharpened the problem. The war in Ukraine disrupted exports of fertilizer and fertilizer inputs from the Black Sea region and Eastern Europe, pushed prices to multi-year highs, and exposed how concentrated the global supply of some nutrients is [7]. Many governments tried to cushion farmers just as higher global interest rates and heavy debt service reduced their budgets. By one estimate, some 3.3 billion people live in countries that spend more on interest payments than on either health or education [8].

Natural hazards add a third layer. Asia, home to most of the world's rice farmers and a growing share of its urban poor, experiences recurrent and intensifying floods driven by climate change, urbanization, and socio-economic exposure [9,10]. Each flood destroys standing crops and the fertilizer applied to them, and it draws on public finances that might otherwise have funded input support. Meanwhile, the strategic rivalry between major economies has begun to reshape global supply chains, trade routes, and the assumptions on which developing countries built their import strategies [11].

These pressures are usually studied separately. Agronomists examine nutrient response, economists examine subsidy design, macro-economists examine debt, climate scientists examine hazards, and political scientists examine trade blocs. Each body of work illuminates one face of the problem and misses how the faces interact. This paper argues that these pressures form a system, here called the **4F crisis**. Its four elements are *fiscal constraints*, which limit what states can spend; *fertilizer access*, which determines whether farmers can obtain and afford nutrients; *food security*, the outcome measured in calories, diets, and nutritional status; and a fourth "F" for *fragility*, which captures climatic, institutional, health-related, and geopolitical weakness that amplifies the other three. The name is analytical rather than official, and the paper treats it as a heuristic whose value will be judged by how well it organizes evidence and generates testable claims.

The paper addresses four research questions:

- What does the existing literature establish about the causal relationships among fiscal capacity, fertilizer access, and food security in developing countries?
- What do related reviews and empirical studies find about the effectiveness and limits of the principal policy instruments?
- How do comparative data from sub-Saharan Africa, South Asia, and East Asia illuminate the conditions under which fertilizer support succeeds or fails?
- What integrated governance framework follows from the evidence, and what remains unknown?

The contribution is threefold. It consolidates evidence from agronomy, development economics, climate studies, public health, and political economy within a transparent scoping protocol. It offers a comparative analysis rather than a single-region account. And it advances a set of propositions that future researchers can test and cite.

2. Conceptual Framework: Understanding the 4F System

2.1 Food security as entitlement, availability, and stability

Any account of fertilizer and hunger must begin with a caution. Hunger is not simply a shortage of food. Sen's entitlement approach showed that famines can occur amid adequate aggregate supply when particular groups lose the means to command food through production, trade, labour, or transfers [12]. Contemporary measurement debates reinforce this point by distinguishing availability, access, utilization, and stability, and by warning that single indicators can obscure the lived experience of food insecurity [13]. Fertilizer matters because it affects availability, through yields and production, and access, through farm income and food prices. A smallholder who cannot afford fertilizer faces both a production problem and an entitlement problem. Fertilizer policy should therefore be judged not only by tonnes distributed but by changes in household food entitlements and dietary quality.

2.2 The productivity logic of fertilizer

The agronomic case is well established. Global demand for crops is projected to rise substantially by mid-century, with demand roughly doubling in some scenarios, and meeting it without converting additional natural land requires sustainable intensification [14]. Research on the Green Revolution describes how improved varieties, irrigation, and fertilizer together shifted yield frontiers in Asia [15], and recent econometric work suggests that the diffusion of modern varieties raised incomes and accelerated structural transformation in adopting countries, with global per-capita output a notable fraction higher than it otherwise would have been [16]. Studies of yield gaps indicate that closing the distance between actual and attainable yields

through nutrient and water management could raise production of major cereals by around half in many regions [17,18]. The gap is concentrated in Africa and parts of South Asia, where nutrient deficiency is a binding constraint.

Three qualifications keep this logic honest. First, response depends on soil condition, water, variety, timing, and complementary practices, and the notion that fertilizer alone solves low yields has been challenged as one of several popular myths about soil fertility in Africa [19]. Second, nitrogen use efficiency is often low, in the vicinity of 40–50 percent globally, so that large shares of applied nutrients are lost to air and water, causing pollution and waste [20,21]. Third, managing nitrogen for sustainable development requires both raising use where it is deficient and curbing excess where it is overapplied [20]. A global analysis of agricultural support further shows that large public transfers to farmers, totalling hundreds of billions of dollars annually, are often poorly aligned with productivity and environmental goals [22].

The resulting picture is one of global imbalance: too little where yields are lowest, and too much, with ecological harm, where policy has rewarded volume over efficiency. Developing countries must therefore navigate a dual challenge, which the 4F framework treats as one problem with two ends.

2.3 Fiscal space as the hidden determinant

Fiscal space, meaning a government's capacity to spend without jeopardizing solvency or crowding out other priorities, connects macroeconomic conditions to household nutrition. When debt service rises or revenue falls, governments typically protect interest payments and civil-service wages first, and cut or delay discretionary agricultural support. Fertilizer subsidies are particularly vulnerable because they are costly, seasonal, and politically visible. Global climate and environmental agreements are meanwhile redefining which states hold bargaining power and which receive finance, thereby altering the fiscal and diplomatic room available to the Global South [23].

2.4 Fragility as the amplifier

The fourth F, fragility, captures the conditions that transform a manageable shock into a crisis. They include exposure to floods and droughts, weak logistics, fragile health systems, displaced populations, thin social protection, and weak institutional learning. A fragile context lowers the return on every dollar spent, because inputs are lost to disaster, delayed by poor roads, or diverted by weak governance. In the framework, fragility does not sit beside the other three Fs; it is the multiplier that links them.

2.4.1 The causal loop

The conceptual model can be stated as a loop. Fiscal constraint reduces public support for input markets. Reduced support, together with high world prices, lowers fertilizer access for smallholders. Lower access depresses yields and farm income, which raises food insecurity and reduces tax revenue and foreign-exchange earnings. Those fiscal consequences then tighten the constraint further. Climate hazards, health burdens, and geopolitical disruption intervene at every link. The loop is reinforcing and, once established, difficult to escape without external or counter-cyclical intervention.

3. Methodology

3.1 Design and reporting standard

This study is an analytical scoping review. The reporting follows the structure of the PRISMA 2020 statement for systematic reviews [24] and its extension for scoping reviews, PRISMA-ScR [25], because the aim is to map a heterogeneous and interdisciplinary evidence landscape rather than to pool effect sizes from homogeneous trials. Scoping designs are suited to emerging, fragmented topics, and methodological guidance for early-career researchers emphasizes transparent mapping of concepts, sources, and gaps [26,27]. The review is explicitly a PRISMA-ScR-*informed* rapid synthesis. It has no registered protocol and did not use a logged, replicable multi-database search. The limitations section returns to this.

3.2 Eligibility criteria

Sources were eligible when they met one or more of these conditions: (a) they provided empirical evidence or systematic review evidence on fertilizer use, input subsidies, or yield response in developing regions; (b) they provided evidence on fiscal capacity, debt, or price shocks relevant to agricultural input support; (c) they documented climate, hydrological, health, or social vulnerabilities that condition food-system outcomes in the Global South; or (d) they supplied conceptual, legal, or geopolitical analysis bearing on how states allocate resources and secure supply chains. Sources on topics unrelated to these themes were excluded regardless of quality.

3.3 Information sources and selection process

Two streams of records fed the review. The first was a supplied corpus of 117 bibliographic records. Two entries lacked complete bibliographic details and were set aside, leaving 115 for title-level and abstract-level screening. Of these, 86 were judged outside the thematic scope and excluded, and 29 were retained for synthesis. The second stream consisted of 28 established peer-reviewed and institutional sources on fertilizer economics, agronomy, subsidy evaluation, debt, and food security measurement, identified by citation chaining from foundational literature. In total, 57 sources were included. The selection can be summarized in prose as follows: 117 records identified, 2 removed for incomplete details, 115 screened, 86 excluded, 29 retained from the supplied corpus, 28 added through citation chaining, and 57 included in the qualitative synthesis.

3.4 Data charting and synthesis

For each included source, the following were charted: region and country focus, type of evidence, the 4F dimension addressed, principal result, and limitations. A narrative thematic synthesis then grouped results into seven themes: fertilizer access and productivity; subsidy programmes; fiscal and debt constraints; price shocks; climate and flood hazards; health and social inequality; and geopolitical and epistemic dimensions. Where sources disagreed, the disagreement was preserved rather than averaged away.

3.5 Research ethics and originality

The review used only published and public sources, and so required no ethical approval. Ethical practice in social science research, including accurate attribution, transparency about limitations, and avoidance of selective reporting, guided the conduct of the work [28]. The text was composed through original synthesis, with sources paraphrased and attributed, consistent with established guidance on producing plagiarism-free scholarship and on the role of detection tools in maintaining integrity [29,30].

4. Results: Related Reviews and Their Findings

This section reports the principal outputs of the related literature, organized by theme. It prioritizes what each study or review found, what it concluded, and where it was limited.

4.1 Fertilizer access and productivity

Reviews of fertilizer use in African agriculture established the baseline decades ago. A World Bank study concluded that low use was explained less by farmer reluctance than by high delivered prices, thin and poorly competitive input markets, weak credit, and unreliable output prices, and it recommended attention to the entire value chain rather than to subsidy alone [5]. A later synthesis of "striking facts" about input use in sub-Saharan Africa confirmed that application rates remain very low, that improved seed and fertilizer are used by a minority of plots, and that low profitability, not only low awareness, explains the pattern [4]. These findings are consistent. They imply that raising adoption requires altering the economic environment of the farmer.

Agronomic reviews add nuance. The popular claim that African soils simply need more fertilizer has been qualified by evidence that response varies widely with soil organic matter, micronutrient status, and management, and that fertilizer applied to degraded soils may deliver poor returns without complementary organic and soil-health practices [19]. Cross-regional modelling similarly shows that nutrient and water management can close substantial yield gaps but that the achievable gains depend on local constraints [18]. Taken together, these results suggest that access to fertilizer is a necessary but

not sufficient condition for productivity, and that integrated soil fertility management matters.

Evidence on how a changing climate interacts with these constraints comes from a synthesis of climate impacts on food security, which concluded that yields in low-latitude regions face disproportionate risk and that adaptation, including input access and risk management, is therefore a precondition for stable food supplies [31]. For the 4F framework, this reinforces the claim that fragility conditions the return on fertilizer.

4.2 Subsidy programmes: results and trade-offs

The most extensively evaluated instrument is the input subsidy. A review of second-generation programmes in Africa, built on earlier syntheses, found a mixed record [32]. Programmes raised input use and in many cases output in the short run, and they enjoyed strong political support. However, the incremental yield per kilogram of nutrient realized by farmers was frequently lower than trial-based expectations, the programmes were expensive and absorbed large shares of agricultural budgets, targeting was imperfect, and administrative delays reduced benefits [32,33]. An earlier review reached compatible conclusions, noting that the cost-effectiveness of subsidies depends on responsiveness, targeting, and the degree to which subsidized fertilizer displaces rather than adds to commercial purchases [34].

The displacement effect has been measured directly. A study of Malawi using a double-hurdle model of fertilizer demand found that subsidized fertilizer partially crowded out commercial purchases, so that each subsidized kilogram increased total use by less than a kilogram [35]. A programme-level assessment of Malawi's subsidy described considerable early achievements in national maize output and food availability alongside high fiscal cost, rising administrative burdens, and concerns over sustainability [36]. These two studies illustrate a general pattern: well-run subsidies can deliver tangible production gains, but the net effect is smaller than headline distribution figures suggest, and the fiscal exposure is large.

Beyond Africa, South Asia offers the largest-scale experience. India's fertilizer subsidy is among the biggest single items of agricultural expenditure, and in the fiscal year 2022–23 it rose to roughly two and a half trillion rupees as global prices surged, a figure that illustrates how external shocks transmit directly into the national budget [37]. A global assessment of agricultural subsidies has argued more broadly that untargeted, coupled support often encourages excessive input use, with associated environmental costs, and that repurposing support toward public goods can improve outcomes [22]. The South Asian lesson is therefore double-edged. Broad, price-based support protects farmers against volatility but invites overuse and fiscal strain, whereas narrow, targeted support is cheaper but harder to administer.

Taken together, the subsidy literature supports a conclusion that is less ideological than policy debates suggest. Subsidies are neither a failure nor a panacea. They work best when they are smart in design, meaning targeted at credible smallholders, delivered through competitive markets rather than state monopolies, accompanied by extension and complementary investments, and fiscally bounded [32,34].

4.3 Fiscal constraints, debt, and the legal-institutional environment

The fiscal side of the 4F system has received less attention in agronomic reviews. A global debt report documented that developing countries face high and rising interest costs, that billions of people live in countries where interest outlays exceed spending on health or education, and that the burden has intensified since 2020 [8]. In that environment, a fertilizer subsidy competes not only with other agricultural spending but with essential services. For the many countries that must also service external debt in foreign currency, the cost of imported fertilizer is aggravated by exchange-rate depreciation, which raises the local-currency price of every imported tonne.

Legal and policy scholarship offers a complementary view. An analysis of health legislation argued that durable national systems depend on enabling legal frameworks that stabilize financing, define responsibilities, and

protect entitlements, rather than on ad hoc programme funding [37]. Although written about health, the argument transfers to agricultural input systems, where programmes created by annual budget decisions are easily curtailed when revenue falls. The sociology of law similarly emphasizes that law is both an instrument of social control and a framework through which societies allocate resources and legitimacy [38]. Applied to the 4F crisis, these perspectives suggest that statutory or rules-based commitments, such as medium-term funding frameworks, can protect input support from short-term fiscal pressure.

4.4 Price shocks and global supply disruption

Reviews of the Russia–Ukraine conflict characterize it as a multi-channel shock to food systems. It disrupted exports of grain and oilseeds, raised energy and fertilizer prices, and strained trade and logistics, with outsized effects on import-dependent low-income countries [7]. Because natural gas is the principal feedstock and energy source for nitrogen fertilizer, and because a few exporters supply large shares of potash and phosphate, the shock spread through energy and input markets as well as through food trade. Evidence on the welfare effects of food price changes indicates that, in the short run, higher prices reduce the real incomes of the many poor households that are net buyers of food, even though some farm households gain as sellers, and that the distribution of gains and losses depends on each household's market position [38].

Strategic competition between major powers compounds such shocks. Analysis of decoupling and the new geopolitical competition argues that efforts to re-route or secure supply chains for strategic goods reshape trade patterns and raise costs, and that developing countries are often price-takers within these realignments [11]. For fertilizer, where production and trade are concentrated, this implies a structural risk of volatility that no domestic policy can eliminate.

4.5 Climate, floods, and ecological fragility

The hazard dimension is documented in a cluster of studies on floods in Asia. A comprehensive analysis of flood causes in Asian countries identified a combination of climatic change, rapid urbanization, deforestation, inadequate drainage,

and socio-economic vulnerability as drivers, and stressed that exposure is as important as hazard [9]. A companion assessment of flood dynamics and management documented the economic, social, and environmental impacts and the uneven quality of flood governance across countries [39]. A further study analysing flood disasters and their socioeconomic impacts across Asia, with attention to risk, vulnerability, and adaptation, concluded that the poorest households bear a disproportionate share of losses and recover slowest [10]. Another review traced the health consequences, including direct injuries, waterborne disease, interruptions to care, and the economic burden on health systems whose infrastructure is itself vulnerable to flooding [40].

These findings matter for fertilizer for three reasons. First, a flood that destroys a crop destroys the fertilizer applied to it, which turns an input investment into a loss and increases the perceived riskiness of future investment. Second, the fiscal costs of relief and reconstruction divert public funds from agricultural support. Third, repeated losses push households toward distress sales of assets and away from input-intensive strategies.

The human mobility consequences extend the picture. Work on climate-induced migration in South Asia described new displacement frontiers and growing urban fragility as people leave environmentally stressed rural areas [41]. Rural out-migration changes labour availability, the age structure of farming, and the demand for inputs, while placing strain on urban food systems. Evidence on urban sprawl indicates that expansion into surrounding land degrades local ecosystems and removes productive and buffering land, which further weakens food and flood resilience [42].

Psychosocial studies add that climate anxiety and youth activism are now salient across cultures, which signals changing expectations of governments and potentially changing political support for ecologically sensitive agricultural policy [43]. Contributions on women's role in environmental protection argue that women's knowledge and labour are central to conservation and resource management, yet are often under-recognized in policy design [44]. Because women farmers in many developing regions have less access to inputs and credit than men, this

evidence points to an equity dimension of fertilizer access that headline adoption statistics conceal.

4.6 Health, social inequality, and organizational learning

Population health conditions the labour and nutrition outcomes on which food security ultimately depends. A comprehensive analysis of disease burden in India documented a dual burden of communicable and non-communicable disease and large regional variation [45], and an analysis of disease patterns and epidemiological transitions during 2020–2025 emphasized the pressures this transition places on public health systems [46]. Illness reduces farm labour, diverts household income to medical costs, and worsens nutritional outcomes, thereby coupling health fragility to food security.

Socio-legal studies of regional disparities show how structural inequality persists despite formal rights. A study of health disparities in Punjab, a state often regarded as agriculturally advanced, identified structural inequities, legislative gaps, and pathways toward equity [47]. A parallel study of educational disparities in India reached analogous conclusions about unequal access and implementation gaps [48]. The relevance to fertilizer is indirect but real. Education and extension shape how well farmers use inputs, and health shapes whether households can farm effectively, so unequal social provision produces unequal returns on identical input support. A study of digital health equity found that access to and outcomes from telemedicine vary across socioeconomic groups [49], a finding that serves as a cautionary analogue for digital agricultural advisory services, which risk reaching better-resourced farmers first.

Conflict and displacement represent the extreme end of fragility. A systematic review and meta-analysis on trauma-related mental health among refugees and internally displaced persons in Africa documented high prevalence of adverse outcomes during conflict and crisis [50]. In such settings, input markets collapse, humanitarian food assistance replaces production, and the preconditions for fertilizer-led recovery are absent. The 4F loop is at its most severe here.

Finally, an analysis of crisis leadership in healthcare highlighted that organizations often fail to convert crisis experience into durable learning [51]. The point carries over to agricultural and fiscal institutions: many countries have lived through repeated fertilizer price spikes, and the evidence suggests that policy responses are frequently improvised afresh rather than guided by institutionalized contingency plans.

4.7 Geopolitical, technological, and epistemic perspectives

Bilateral dependence is a geopolitical concern in its own right. An analysis of India–China relations discussed the interplay of opportunity and challenge in a relationship that includes substantial trade in industrial and agricultural inputs [52]. For countries that rely on a small number of suppliers of fertilizer or fertilizer intermediates, trade tensions or export controls can quickly become food-security risks. Work on cyber-diplomacy argues that states increasingly use digital means as instruments of conflict, which widens the range of threats to critical infrastructure, including logistics and commodity-market systems [53]. A study of digital surveillance and sovereignty in the Global South warns that technological dependence can reduce policy autonomy, an issue that applies to data-intensive agriculture, where platform ownership and data governance may shift control away from farmers and national institutions [54].

Epistemic questions matter as well. Scholarship on decolonizing sociology argues that Indigenous knowledge systems have been marginalized in the production of social theory [55], and the same critique can be applied to agronomy, where farmer knowledge, traditional soil management, and local seed systems are often treated as backward rather than as sources of adaptive capacity. Evidence on consumer behaviour in organic food markets indicates growing demand for organically produced food and a willingness to pay a premium among some segments [56]. This suggests a possible, though bounded, market pathway for reducing reliance on imported synthetic inputs in specific value chains, particularly high-value export or urban niches, without implying that organic methods can replace mineral fertilizer for staple production in nutrient-depleted regions.

5. Comparative Analysis

5.1 Why compare regions

A comparative approach is needed because the headline claim that developing countries lack fertilizer hides large differences in their fertilizer systems. Three archetypes are useful: sub-Saharan Africa, where use is low and fragmented; South Asia, where use is high, heavily subsidized, and increasingly imbalanced; and East Asia, where intensification occurred earlier and now confronts efficiency and environmental limits.

5.2 Sub-Saharan Africa: low use, high cost, thin markets

In much of sub-Saharan Africa, average application rates are a small fraction of the world average and well below the continental target [4–6]. Delivered prices are high because of long inland transport distances, small and irregular order volumes, port inefficiency, and limited competition among importers and distributors [5]. Farmers' profit from fertilizer is also reduced by volatile or low output prices and by poor yield response on degraded soils [4,19]. Subsidy programmes have tried to overcome these barriers, and in countries such as Malawi they produced visible production gains alongside heavy fiscal commitments and partial crowding out of commercial demand [32,35,36]. Fiscal exposure is intensified by debt-service pressure and by the exposure of imported inputs to currency depreciation [8].

The comparative lesson is that, in Africa, the binding constraint is usually not the absence of a subsidy but the high underlying cost of getting nutrients to farms and the low profitability of using them. Subsidies address the symptom, and market and infrastructure investments address the cause. The two are complements.

5.3 South Asia: scale, subsidy, and imbalance

India and its neighbours illustrate the other end of the spectrum. Application rates are far higher, administered prices have long kept fertilizer cheap to farmers, and the budgetary cost is enormous and highly sensitive to world prices [37]. The benefits are visible in the yield gains associated with the Green Revolution, which is

credited with substantial and lasting economic effects [15,16]. The costs are visible in the fiscal strain during price spikes and in nutrient imbalance, since cheap, price-controlled nitrogen encourages overapplication relative to phosphorus, potassium, and micronutrients, with lower nutrient use efficiency and environmental damage [20,21]. South Asia is also among the regions most exposed to floods, so the climate and fiscal dimensions of the 4F loop converge there [9,10,39]. Climate-induced displacement and urban fragility add further stress [41].

The comparative lesson is that South Asia faces the opposite problem to Africa's. The challenge is to improve efficiency and fiscal sustainability without removing the protection that millions of small farmers rely on. Reforms that shift from price-based to direct, targeted, and balanced-nutrition support are conceptually attractive, but the political economy of subsidy reform is difficult and the transition risks hurting poorer farmers if mishandled [22].

5.4 East Asia: intensification and its ecological limits

In China and other East Asian economies, intensification came earlier, and application rates are among the highest in the world. Analysis of nitrogen management has shown that overapplication has produced large nitrogen losses and that substantial reductions in use are possible without yield loss when management improves [20]. Trends in nitrogen use efficiency show how efficiency fell during rapid intensification and then began to recover in places that adopted better practices and policies [21]. East Asia therefore represents a later stage of the trajectory in which fertilizer's marginal contribution to yield is small and its marginal environmental cost is large.

5.5 A cross-regional reading of the evidence

Placing the three archetypes side by side clarifies a non-obvious point: the same instrument, a fertilizer subsidy, has opposite appropriate roles in different contexts. Where use is low and nutrient deficiency is binding, as in much of Africa, the priority is to raise adoption profitably. Where use is high and imbalanced, as in parts of South Asia, the priority is to improve efficiency and rebalance nutrients. Where intensification is

mature, the priority is to reduce losses. The 4F framework therefore does not recommend one policy; it recommends matching policy to a country's position on the intensification trajectory and to its fiscal and fragility conditions.

Cross-regional comparison also reveals asymmetries in shock exposure. Importers with high debt and weak currencies, such as many African countries, experience price spikes as immediate access crises, because farmers simply cannot buy the input. Importers with large budgets and administered prices, such as India, transmit the same spike into the fiscal account, because the state absorbs the cost. The consequences differ, with lower yields in the first case and larger deficits in the second, but both flow from exposure to the same external shock [7,8,37].

5.6 Illustrative case: the risks of abrupt input policy change

Recent experience with abrupt shifts in national input policy offers a cautionary comparison. Sri Lanka's sudden restriction of chemical fertilizer imports in 2021, framed as a move toward organic farming and later reversed, is widely discussed as an example of how rapid policy change, in a context of foreign-exchange scarcity and without time for farmers or supply chains to adapt, can disrupt production. The episode is better understood as a failure of transition management than as evidence for or against organic methods as such. The market evidence on organic demand suggests that organic and sustainable production can be viable in particular value chains where consumers pay a premium [56], but it does not show that a national staple system can switch quickly. The case supports a general principle: reforms in input policy must be gradual, sequenced, and matched to farmers' capacity and market structures.

6. Analysis from Different Perspectives

Authentic analysis requires examining the problem through several disciplinary lenses and noting where they conflict.

6.1 The economic perspective

Economists tend to frame the problem as one of incentives and market failure. Fertilizer is under-used when the ratio of crop price to fertilizer price is unfavourable, when farmers face credit and liquidity constraints, and when risk makes investment unattractive [4,5]. The economic perspective values subsidies when they correct genuine market failures, such as underdeveloped input markets or credit constraints, but criticizes them when they displace commercial trade, reward overuse, or crowd out better public investments [32,34,35]. This perspective is strongest at quantifying trade-offs and weakest at capturing social and political dimensions, such as why governments continue costly programmes that appear inefficient.

6.2 The agronomic and ecological perspective

Agronomists emphasize that the productivity gain from fertilizer depends on soil, water, varieties, and management, and that over-reliance on mineral inputs can degrade soils and pollute waters [19,20]. For ecologists, the global nitrogen cycle has already been pushed beyond sustainable limits in some regions [1,20]. This perspective is a valuable corrective to the idea that more fertilizer is always better. Its risk is that, applied carelessly, it could discourage input use in precisely the regions where nutrient depletion is the problem. A balanced reading holds both claims: raise use where deficient, improve efficiency where excessive.

6.3 The fiscal and macroeconomic perspective

Public finance scholars highlight that the capacity to fund input support is determined by revenue, debt, and exchange-rate conditions rather than by agricultural need [8]. This perspective explains why countries that most need support are often least able to provide it, and why shocks are procyclical in the worst way: when world prices spike, import bills rise, currencies weaken, and borrowing costs climb at the same time. It supports calls for counter-cyclical financing mechanisms, such as contingent credit or international facilities that expand fiscal space during price spikes. Its limit is that it treats agricultural policy as a line item and may undervalue the long-term returns of investing in smallholder productivity.

6.4 The political-economy and geopolitical perspective

Political economists observe that fertilizer subsidies persist partly because they are visible, deliverable to large constituencies, and politically rewarding, and that reform is difficult because of entrenched interests [22,32]. Geopolitical analysis adds that the concentration of production and trade in a handful of exporters makes fertilizer a strategic commodity, and that great-power competition and sanctions regimes can quickly convert commercial dependence into vulnerability [7,11,52]. States may respond with strategic stockpiles, diversification of suppliers, bilateral supply agreements, or domestic production, each with its own costs. Cyber threats to infrastructure and trade systems widen the geopolitical risk set [53]. A weakness of this perspective is that it can overemphasize state strategy at the expense of farmers' own decisions.

6.5 The social-equity and health perspective

Social scientists underline that the benefits of any input programme are filtered through unequal social structures. Educational and health disparities, gender inequality, and weak legal protection determine who can access, apply, and profit from inputs [44,47,48]. Evidence on digital health equity warns that technology-based delivery can reproduce socioeconomic gaps [49]. The same caution applies to digital extension and e-voucher systems for fertilizer. Health burdens and displacement further constrain household capacity [45,46,50]. This perspective is essential for judging whether a policy that raises average yields also improves the position of the poorest and most excluded households. It is less well suited to estimating national fiscal costs or agronomic response.

6.6 The decolonial and epistemic perspective

Critical scholars argue that development policy has often imported external models and discounted local knowledge [55]. In the fertilizer domain, this critique implies that technology transfer should be paired with respect for farmer innovation, local soil classification, and community seed systems, and that research agendas should be shaped with, not for, smallholders. Concerns about technological dependence and data sovereignty extend the

critique into the digital realm [54]. The perspective does not dispute the yield benefits of mineral fertilizer, but it challenges who defines problems, who owns data, and who captures the value in input and advisory markets. Its limitation is that it offers fewer operational prescriptions than economic or agronomic perspectives.

6.7 The institutional-learning perspective

Finally, scholarship on organizational learning stresses that crises generate valuable information that institutions often fail to retain [51]. Applied here, the repeated cycle of price spikes, emergency subsidies, and later retrenchment suggests weak institutional memory. Building standing contingency frameworks, early-warning systems, and independent evaluation of past responses is a governance reform that cuts across the other perspectives.

6.8 Points of convergence and conflict

Several points emerge when the perspectives are compared. They converge on the view that fertilizer access is shaped by cost and delivery, that subsidies must be well designed, and that shocks are transmitted through fiscal and trade channels. They conflict on the weight to place on efficiency versus access, on the role of the state versus markets, on organic and agroecological alternatives, and on whose knowledge counts. The 4F framework does not resolve these tensions; it makes them explicit and indicates that the correct balance depends on country context.

7. Discussion: Critical Synthesis and Policy Implications

7.1 The 4F crisis as a coupled system

The review supports the claim that fiscal constraints, fertilizer access, food security, and fragility interact as a coupled system. The evidence for each link is uneven but suggestive. Fertilizer's contribution to yield and food availability is strongly supported [1,14,17,18]. The influence of fiscal capacity on input support is demonstrated by the cost and cyclicity of subsidy programmes [32,36,37] and by the macro-fiscal context [8]. The influence of fragility on returns is supported by flood, health, and displacement studies [9,10,39–41,50]. What

is less well documented is the full feedback loop: how food-security deterioration feeds back into fiscal and political instability. That gap is a research priority.

7.2 Six propositions

To make the analysis citable and testable, the paper advances six propositions:

Proposition 1. Where fertilizer use is below agronomic and economic optimum, the dominant barrier is the delivered price relative to crop revenue, so interventions that reduce transaction costs and raise output-price stability will raise adoption more durably than input price subsidies alone.

Proposition 2. The returns to input subsidies decline as targeting, market competition, and complementary extension weaken, so identical budgets yield very different welfare gains across institutional contexts.

Proposition 3. Fiscal stress and fertilizer price spikes are positively correlated, because the same global conditions that raise energy and input prices also weaken currencies and raise borrowing costs in import-dependent economies, making input support procyclical unless counter-cyclical mechanisms exist.

Proposition 4. Climate hazards, particularly floods, lower the expected return on fertilizer investment and simultaneously raise public expenditure on relief, so that adaptation and risk-transfer investments raise the productivity of fertilizer policy.

Proposition 5. Social inequalities in education, health, gender, and digital access reduce the share of any input programme's benefits reaching the most vulnerable, so equity-targeted design will outperform universal design on food-security outcomes per unit of expenditure.

Proposition 6. Rules-based, legally anchored, medium-term commitments to input support are more resilient to fiscal shocks than annual discretionary allocations.

7.3 A counter-cyclical, multi-level governance framework

The synthesis suggests five mutually reinforcing policy domains.

First, make the market work. Reduce the delivered cost of nutrients through regional procurement, port and corridor investment, blending near consumption centres, and competitive distribution. Evidence on African fertilizer markets indicates that structural cost reductions are the most sustainable route to adoption [4,5].

Second, design smart, bounded subsidies. Where subsidies are used, target credible smallholders, use market-based vouchers rather than state monopolies where feasible, pair them with extension and soil-health practices, and cap fiscal exposure [32,34,35]. Where subsidies are already large, as in South Asia, shift gradually toward direct support and nutrient balance, with safeguards for the poorest [22,37].

Third, increase nutrient efficiency. Promote efficiency through improved management, enhanced-efficiency products, and integrated soil fertility approaches. Reviews of fertilizer technology indicate that enhanced-efficiency formulations and better timing can raise nitrogen use efficiency, though their cost and suitability for smallholders need evaluation [57]. Efficiency lowers both environmental damage and import dependence [20,21].

Fourth, build fiscal and external resilience. Create counter-cyclical instruments that expand fiscal space when input prices spike, such as contingent financing, regional buffer stocks, and debt-treatment mechanisms that protect agricultural and social spending in crises [8]. Anchor commitments in legal or medium-term frameworks to resist short-term cutbacks [37,38].

Fifth, invest in adaptation and inclusion. Integrate flood and climate-risk management with input policy, strengthen health and social protection systems, and ensure that women and marginalized farmers can access inputs and information [9,10,39,40,44,47–49]. Climate agreements and global financing arrangements should be pursued as sources of fiscal space for developing countries [23].

7.4 International responsibility and coordination

National policies alone cannot address a problem driven by global energy markets, concentrated production, and interest-rate cycles. International cooperation matters in three ways. Regional trade and procurement arrangements reduce exposure to single suppliers. Development finance and debt-relief instruments can protect agricultural input budgets in crises. And transparent information on stocks, prices, and export restrictions can reduce panic-driven policy responses. Strategic rivalries complicate such cooperation by hardening supply-chain blocs [11,52], but the shared exposure to fertilizer and food-price volatility offers a basis for pragmatic collaboration.

7.5 What the review does not show

It would be overreach to claim that fertilizer access alone determines food security. Dietary diversity, women's education, health, water and sanitation, social protection, and conflict all matter, and many food-insecure households are not primarily farm producers. The review also does not show that subsidies are inherently superior or inferior to alternatives; it shows that outcomes depend on design and context. Nor does it demonstrate that agroecological or organic approaches could substitute for mineral fertilizer at national scale in nutrient-poor regions, though they may complement it and may be commercially viable in specific market niches [19,56].

8. Limitations

Four limitations should be acknowledged. First, the review is PRISMA-ScR-informed rather than a fully registered, database-searched systematic review. The supplied corpus was screened exhaustively, but the external stream was assembled through citation chaining, so the search is not fully replicable and may reflect selection bias. Second, scoping reviews do not appraise study quality formally, so the synthesis weighs sources by design and relevance rather than by risk-of-bias scores [24,25]. Third, the supplied corpus is thematically heterogeneous and includes several studies of limited direct relevance to fertilizer, so some arguments, particularly in the social and health domains, rely

on analogy and indirect linkage rather than direct evidence of fertilizer outcomes. Fourth, the 4F framework is a heuristic. It has not been tested through formal causal modelling, and its propositions require empirical validation using panel data on fertilizer prices, fiscal indicators, climate exposure, and nutrition outcomes.

9. Conclusion

The central claim of this paper is that fertilizer access in developing nations cannot be understood or fixed in isolation. It sits within a system in which fiscal constraints limit public support, global shocks transmit through trade and energy markets, climate hazards destroy investment returns, and social and institutional fragilities determine who benefits. The evidence reviewed shows that low fertilizer use in Africa reflects cost, market, and profitability barriers more than farmer ignorance. It also shows that subsidies can raise production but at high fiscal cost and with partial displacement of commercial demand, that South Asia's large-scale support brings both gains and imbalances, and that East Asia's intensification now faces ecological limits.

Comparison across regions suggests that the right policy depends on where a country stands on the intensification trajectory and on its fiscal and fragility conditions. In low-use settings, the priority is to make fertilizer profitable and available. In high-subsidy settings, it is to improve efficiency and fiscal sustainability. In mature systems, it is to reduce environmental loss. Across all settings, counter-cyclical financing, legally anchored commitments, climate adaptation, and equity-focused design raise the effectiveness of every dollar spent.

The six propositions offered here give researchers concrete hypotheses, and the 4F framework gives policymakers a shared vocabulary for coordinating agricultural, fiscal, climate, and social policy. As debt burdens, price volatility, and climate hazards intensify, the cost of treating these as separate problems will rise. A fertilizer policy that ignores fiscal space will be unsustainable, a fiscal policy that ignores food systems will be self-defeating, and a food-security strategy that ignores fragility will be fragile itself.

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