Farmer's risks and economic use of fertilizer in Africa South of the Sahara

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Executive Summary

Introduction

Since 2006, when the Africa Fertilizer Summit was held in Nigeria, the African fertilizer sector has changed dramatically. During the past decade, Africa is the only continent that has witnessed increased fertilizer consumption (at over 8% per annum). Despite this progress, fertilizer use has remained well below the 50 kg/ha target. Fertilizer affordability (cost) and accessibility remains a major factor impeding use by farmers in ASoS countries. Governments have embarked on fertilizer subsidy programmes in various forms, with mixed results. Another challenge that has limited the impact of fertilizer is predominance of blanket fertiliser recommendations that fail to address the need for adapting fertilizer application to the need of specific crops, soil and agro-ecological conditions. Moreover, recent evidence shows that crops, particularly maize, tend to respond poorly to fertilizers in soils with low carbon content, high acidity, and other unfavorable soil characteristics.

The African Union Commission has recognized the importance of building soil health in conjunction with promotion of fertilizer markets and use in order to address the current need to increasing crop productivity, while sustaining soil health and other natural resources in the long-term. The convening of the 2023 Fertilizer and Soil Health Summit has the goal of developing and operationalizing an Africa Fertilizer and Soil Health Action Plan that aims to build a more dynamic fertilizer market and build research and extension capacity for sustainable crop production and soil health management. Against this background a consortium comprised of the African Network of Agricultural Policy Research Institutes (ANAPRI), the International Fertilizer Development Center (IFDC) and the Alliance for African Partnerships (AAP) received funding support to conduct research and prepare technical background documents and policy briefs for clarifying the context, challenges and opportunities, and priority investments and interventions in support of preparations for the Summit. The background documents are also guiding the priorities of the Action Plan that will be taken by governments, the private sector, and development partners to increase the availability, accessibility and affordability of fertilizer and other complementary inputs, and enhance the adoption of management practices that make fertilizer use more profitable for smallholder farmers.

Methodology

This study used systematic literature review and meta-analysis to gain insights into the status of crop fertilizer response at the country level in selected countries in ASoS. Instead of doing fresh econometric analysis on fertilizer use and profitability, the study focused on systematically reviewing the extensive literature on crop response to fertilizers for 10 countries represented by ANAPRI in the region.

The systematic literature review gathered country-specific data including: type and amount of fertilizer used, crops covered, yield response rate per kg of nitrogen fertilizer used, farm gate prices of outputs and fertilizer prices. Value Cost Ratios (VCR) are computed as a measure of fertilizer use profitability from each identified study. The meta-analysis was done to answer the question, "How do local edaphic, climatic, cropping systems and crop management factors affect yield responses to – and hence profitability of -- fertilizers across Africa South of the Sahara?"

Study Findings

Systematic Review Results

The result from the systematic review are summarised below:

- Crop yield response rates (mainly reported for maize) show wide variations across the different country studies reviewed. Yield responses vary widely across geographic locations, soil types, soil carbon, and soil pH Moreover, yield response to fertilizers also vary according to agronomic practices such as intercropping, effective weed management, crop rotations, and organic fertilizer applications. The wide variations in observed crop yield response to fertilizers underscores the importance of both farmer management and soil quality (which is influenced over time by farmer management).
- Crop yield response estimates tend to differ substantially depending on whether they are derived from experiment stations, on-farm trials, or on-farm based on farmers' own management practices. Studies using data from research experiments indicate the highest response rates (average 24.45 kg per kg of Nitrogen). On-farm researcher managed studies show a lower average response of 20.82 kg per kg of Nitrogen while on-farm (farmer managed) had the least response of 10.29 kg per kg of Nitrogen. On-farm yield response to N is twice as high, on average, for researcher-managed trials compared to farmer-managed conditions. The differences between these crop response rates highlight both the serious practical difficulties that prevent many smallholder farmers from adopting effective agronomic management, as well as the tremendous potential of improved farmer

management to raise crop yield response rates, the profitability of using fertilizers, and hence the effective demand for fertilizers by farmers.

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- Average Nitrogen application rates per hectare are much higher for studies conducted at research stations as well as on-farm (researcher managed) conditions. Smallholder managed maize farms receive the least amount of nitrogen per hectare.
- The highest average VCR was from experiment stations (6.84) followed by on-farm (researcher managed) (4.82) and the least was from on-farm (farmer managed) (1.68). The differences between on-farm researcher-managed vs. farmer-managed VCRs indicate the importance of farm management, which can be improved through well-functioning farm extension systems.

  There are wide variations in VCRs. Several factors condition the profitability of fertiliser use including those discussed under crop yield response. In addition, the ratio of output prices and nitrogen prices as well as input and output market policies constitute other important determinants of VCR.
- Of great concern is the low profitability of on-farm (farmer managed) for which VCR estimates average less than 2, which is below the threshold for farmers to adopt and continue investing in fertiliser use.
- Some of the factors contributing to the low profitability of fertiliser use on smallholder farms included: inadequate knowledge of soil health; inability to practice good agronomic management due to smallholder resource constraints; limited soil testing facilities; inadequate support for improving farm-level nutrient management; blanket fertiliser recommendations; high fertiliser prices; poor implementation of subsidy programmes, including late delivery of fertiliser; Inadequate fertiliser testing facilities; and non-existent dedicated soil health and fertiliser policies. A comprehensive and successful fertilizer promotion strategy will need to contain actions to address and overcome these varied constraints. Doing so will require that African governments allocate substantially greater funding for agricultural research, development and extension systems. This can be achieved either by increasing annual public budget allocations to agriculture or by reallocating funds between activities within the overall allocation to agriculture.

Meta-Analysis Results

The results of the meta-analysis show that:

- Fertilizers containing a combination of nutrients had larger effects than nitrogen (N) fertilizer alone. In particular, the combination of N and

Phosphorous (P) with other nutrients (NP+), most often Sulphur (S) or Zink (Zn), increased yields by 55% compared to 21% or 17% increases in yields with Nitrogen (N) alone or Nitrogen (N) and Phosphorous (P) only, respectively.

- Nitrogen application rates had relatively small effects on yield increases. The yield increases achieved with high N fertilizer rates (> 80 kg/ha) were similar to medium (20-80 kg/ha) and low (< 20 kg/ha) fertilizer N application rates.
- Fertilizer application was most effective for cereal crops (e.g. maize, rice, wheat, sorghum), which produced yield an average yield increase of 55%, compared with 8% for legumes (e.g. common beans, soybeans). The yield of vegetables and other crops (e.g. potatoes, cassava, and melon) were not significantly increased by fertilizer application.
- Location of the experiment, on-farm or on-station, had large effects on yields in response to fertilizer addition. Under on-farm conditions, fertilizers increased yields by 12%, while at experiment stations fertilizers increased yields by 33% highlighting the importance of farmer management,

Conclusions:

The study findings confirm that there is high correlation between crop yield response rate and fertilizer profitability and that yield response rate is conditioned by several factors, which include soil PH, soil types, soil organic matter, among other factors. Thus, farm management practices that improve soil health could be crucial for improving yield response rates and ultimately the profitability of fertilizer use. The findings also highlight that left on their own to manage their crop, smallholder farmers' fertilizer use was less profitable compared to researcher managed crops. This suggests that farmers would require significant extension support towards using fertilizer more profitably. Fertilizer application is unprofitable in the contexts where output–to–fertilizer price ratios are lower and in production zones with low crop response rates. Fertilizer application tends to be unprofitable for most smallholder farmers in contexts where output-to-fertilizer price ratios are relatively low (e.g., in relatively remote areas) and where soil, rainfall and/or management conditions result in low crop response rates.

Recommendations:

The findings in this study calls for serious actions from a broad range of stakeholders including national governments, National Agricultural Research Institutes and extension services, African Universities, CGIAR centers, private sector, Donors and cooperating partners. Against this background, the recommendations articulated below revolve around strengthening the National Agricultural Research Systems (NARS) with associated concrete actions (see Jayne et al 2023), policies and investments that will help contribute to creating an effective system that will work towards helping to increase crop productivity through increased fertilizer use efficiency and profitability. The recommendations focused on the how to achieve the desired outcomes. These recommendations should be considered during the development of the fertilizer and soil health summit action plan:

i) **Increase investments in soil health improvements that will increase on-farm fertilizer use efficiency and profitability**. The actions to achieve this should include:

- NARS should elevate soil health as a component of their programs given its importance in supporting resilience, adaptation to climate change, greater yield response from the use of inorganic fertilizers, and sustainable agricultural intensification.
- *Provide incentives to farmers to grow cover crops:* Soil organic matter can increase the uptake of fertiliser by crops. However, farmers seek to maximise short-term profitability and yet soil health requires long-term investment, as it is a public good. To that effect, Governments in Africa should ensure that adequate resources are provided to incentivise farmers to investment in soil management practices.
- *Integration of grain legumes in cereal-based systems* could help increase Nitrogen supply and build the organic matter in soil. However, millions of smallholder farmers are land constrained to increase the area under legumes or incorporate cover crops. Therefore, it is prudent to consider providing market incentivises to smallholder farmers to grow legumes, thus re-purpose part of the maize subsidies towards growing of grain legumes to increase organic matter content of African Soils.
- *Invest in reliable and low-cost soil testing technologies:* This includes investment in soil testing technologies and soil mapping to generate site-specific fertilizer, crop and soil management recommendations that adapted to local production conditions. For example, about 10% of soils in ASoS are acidic and require liming. Soil acidity affects nutrient uptake by the plant and reduces crop response to fertilizer.

- *Mechanisation for soil improvement operations:* Mechanisation improves fertiliser efficiency because it improves timeliness in operations and ensures that farmers have the right plant population that can optimise fertiliser efficiency.

- *Digitalisation:* Investing in digital technologies and ICT applications improving soil health and fertiliser management. These include application that can utilise remote sensing technologies to diagnose nutrient deficiencies and guide farmers on site-specific nutrient requirements.
- *Developing a soil management system for Africa:* This includes a soil information system and a dashboard to track progress in agricultural performance as well as strengthening education and training. Other areas include building human and institutional capital for soil science, economics of soil degradation and soil management.

ii) ***Increased Support to National Agricultural Research Systems and Extension Services:*** This is a precondition for sustainably raising fertilizer use in ways that raise agricultural productivity and food systems resilience. To date, there has been substantial investment in the international CGIAR system, but this international R&D system has under-performed because technology adoption requires interfacing with strong national R&D systems to scale out and adapt new technologies to specific local conditions.

One of the most crucial steps to improving the performance of NARS is for national governments to increase their funding and commitment to supporting their own NARS, particularly operational funds, to monitoring performance, and to demand greater accountability for results. Doing so would also help most African countries comply with their own commitments under the CAADP Maputo Declaration. Proposals for consideration include the following:

- Empower the national systems to compellingly define their own vision and priorities, consistent with broader national development strategies in a national R&D&E strategic plan, if not already done.
- Increase overall public disbursements to agriculture and raise the share of public agricultural expenditures going to organizations in the NARES. They must provide stable and sustainable levels of funding to secure a strategic program of effective research activities that yields increased agricultural productivity. Rather than relying too much on donor contributions and development bank loans to fund critical areas of research, governments need to determine their own long-term national priorities and design relevant, focused, and coherent agricultural R&D programs accordingly.
- Ensure that budget lines to organizations in the NARES are fully disbursed each year. Stads et al (2021) found that in many cases, governments did not fully disburse approved budgets to their NARES.

- In some cases, national policy objectives would be more effectively achieved by increasing funding support for higher-value and nutrient dense commodities, e.g., fruits, vegetables, and animal products. Including these issues for consideration in NARES priority setting activities would in some cases entail restructuring in how R&D&E efforts are currently organized to expand well beyond a small number of staple crops and industrial cash crops.
- Identify and support initiatives to strengthen the quality of education in agricultural universities, training colleges and Technical and Vocational Education and Training (TVET) organizations and facilitate the employment of graduates.
- Implement accountability frameworks to encourage greater impact from public funds allocated to the NARES.
- Explore opportunities to leverage the formidable R&D systems of the private sector. The private sector is currently the least developed source of sustainable financing for agricultural R&D in Africa. Cultivating private funding requires that national governments provide a favourable enabling policy environment through accountability, tax incentives, protection of intellectual property rights, and regulatory reforms to encourage the spill-in of international technology.
- The success of the new 1-CGIAR strategy rests with developing closer partnerships with NARS. The CGIAR can enhance the effectiveness of their own programs, as well as those of the NARS, by renewing and intensifying its efforts to strengthen the capacities of its regional and national partners, regional centers of excellence, African agricultural universities, and public extension systems. In most Asian countries, the capacities of their NARS were low several decades ago but are now comparable to those of the CGIAR organizations working in Asia. This has served both the Asian NARS and the CGIAR well because their roles are synergistic. Because the CGIAR's impact in Africa similarly depends on well-functioning local partners, the CGIAR can, and should, intensify its capacity strengthening efforts, focusing both on organizational and well as individual capacity development.

Donor organizations that primarily fund the CGIAR can support this proposed intensification of CGIAR capacity development activities by encouraging grants and programs that (i) involve NARS partners from the inception of grant design; (ii) have joint-directors and principal investigators from both CGIAR and NARS organizations; (iii) allocate substantive portions of grant budgets to the NARS; and (iv) have well-specified performance metrics and accountability for both CGIAR and NARS partners.

- Increased Investments in National Extension Systems: A key barrier to be overcome is low extension agent to-farmer ratios. Extension models that should be considered for broader replication, including the village-based extension services in Ethiopia (see Dorosh and Minten, 2020 for details) and the Farm Input Promotions (FIPS) program of advisory services and local access to inputs in Kenya, Tanzania, and Uganda. Whichever approach is utilized, two features have been identified as particularly important for performance: (i) an extension system that enables bi-directional learning between research units and farmers to encourage adaptation in ways that fit farmers resources (Cook et al., 2021; Davis et al., 2021); and (ii) close integration of extension workers and researchers into an integrated R&D&E system (Antwi-Agyei and Stringer, 2021), i.e., breaking down the divisions between R&D and extension systems, to ensure that the advisory services received by farmers are founded on established research evidence (Davis et al., 2021).

  While the digital revolution shows enormous potential to reduce information asymmetries and raise farm productivity, anecdotal reports that some digital extension services provide farmers with advisory services that are not clearly appropriate for the specific locations of farmers or their resource levels (FAO and ITU, 2022), which can spoil farmers' trust in extension services overall. Increased integration between extension and local research institutes can strengthen advisory services' capacity to adapt digital innovations to local contexts. With advances in the ability to reach farmers in remote areas through digital platforms, public extension services could collaborate with content moderators on digital platforms to ensure greater oversight over the content targeted at smallholder farmers and safeguard farmer privacy. Governments and development partners can also play a key role in minimizing the growing "digital divide", so as not to leave behind underprivileged members of society who may lack access to information and communication technologies. Supplying extension agents with smart phones and reliable digital connectivity is an integral part of this strategy.

iii) ***Strengthening the role of African universities.*** *African Universities play a critical role in NARS, hence, their role needs to be strengthened. A number of proposals to enhance their capacity should be considered including the following:*

- Prioritizing the improvement of post-graduate training in faculties of agriculture, including sandwich programs at qualified universities including developed countries with ample experience in Africa. The University of Pretoria Collaborative Masters in Agricultural Economics and Extension provides a useful model for consideration; this program allowed MSc students to take courses both at their home university and at the University of Pretoria for a year, where international faculty and UP faculty taught and mentored them, guided their thesis work, and supported their efforts to be placed in suitable organizations on the African continent after graduation. External reviews considered the program highly effective in raising the supply of well-trained MSc agricultural economists generate and could be considered for other disciplines.
- The senior management of many African universities tend to regard their resources and budget limits as being exogenously determined by budget allocations from their central governments. But African universities could potentially expand their budgets by proactively competing for international donor resources. They could form partnerships with CGIAR organizations, international universities, and/or relevant organizations in the global south to prepare proposals for funding new activities or expanding the funding for existing activities.
- In addition, Universities may benefit from updating curricula, getting well-trained young professionals to enliven faculties of agriculture, invite greater engagement with the private sector to encourage mentorship and the training of skills actually demanded after graduation
- Explore and utilize partnerships with international, continental and regional organizations such as the CGIAR, international universities, Forum for Agricultural Research in Africa (FARA), West and Central African Council for Agricultural Research and Development (CORAF/WECARD), Association for strengthening agricultural research in Eastern and central Africa (ASARECA), Centre for Coordination of Agricultural Research and Development for Southern Africa (CCARDESA) and African Forum for Agricultural Advisory Services (AFAAS) when funds can be directed to national priorities.

iv) ***Enhanced role of African organizations in supporting* African NARS and regional agricultural R&D systems:** The strategies of most African development organizations (e.g. AfDB, AGRA, African Union, FARA; ECOWAS, SADC, ASARECA, CORAF, etc.) include promoting agricultural productivity, climate-resilience, food security, capacity development, and knowledge management within the agricultural sector of African countries. Therefore, support for the development of African NARS and regional agricultural R&D systems should be an important component of African development organizations' programs.

African development organizations such as AfDB and AGRA may consider instituting strategies and concrete programs for strengthening agricultural R&D&E systems in Africa, with specific guidance for (a) NARS and extension services, (b) African Universities, (c) African governments, (d) the CGIAR, (e) international development partners, foundations, and financial institutions, (e) other African regional and continental development organizations; and (f) international universities.

v) *Refining the role of International funding partners:* Donors especially those that can afford to take a long-term time horizon for impact, should see the necessity of long-term support to the NARS, extension, and agricultural universities with long-term commitments, moving away from grants that focus on low-hanging fruit with short-term impact. Donors must engage with governments to support priorities defined by nationally-led, not externally led, processes.

Issue of "work-arounds": Some international donors and foundations appear reluctant to directly fund public sector entities and are inclined to create parallel structures to the NARS that carry out activities that duplicate the mandates of the NARS. While donors may ensure greater accountability for their funding by creating their own partners working on the ground, the long-term impacts are unclear, as they may weaken or marginalize organizations in the NARS that are still mandated by African governments to carry out the public goods role of agricultural R&D&E in their countries. Resentment, lack of cooperation, and missed opportunities have often resulted when donors create and fund new organizations to carry out tasks also in the mandate of existing national entities. Besides setting up parallel structures and potential competition between the externally funded agents and government NARS, the long-term impacts may be minimal or even negative if wider gaps are created if or when the donor discontinues funding for the new agency.

Proposals for consideration:

1. Encourage donor grants targeted to CGIAR or international universities to include organizations in the NARS at the design stage, ensuring that NARS interests and priorities are reflected in proposal and budget development. Encourage grants with co-directors from NARS so that their interests are equally reflected. Donors could do more to promote grants being co-led by organizations in the CGIAR and the NARS, starting from project design, so that NARS or regional R&D&E systems are brought in from the beginning.
2. Donor and development bank funding should be consistent with priorities set by national governments. The instability of donor funding or abrupt change in aid disbursement can have deleterious effects on the development and effectiveness of NARS activities (see Stads et al., 2021)

vi) *Strengthening the role of private sector: S*ustainability and resilience are increasingly important objectives of in large private international companies. As mentioned before accountability is one of the most important factors influencing the degree of collaboration between the NARS and the private sector. Many multinational companies, mainly seed and fertilizer companies, are heavily involved in ASoS where they develop and test their products under field conditions. If they could be assured of accountability and transparency in the use of funds, there could be mutual benefit, and NARS could potentially receive much greater funding than they currently do. Private companies may therefore make this collaboration potential explicitly to NARS organizations with the hopes that it may promote improved financial accounting protocols.

vii) ***Significant reforms of national subsidy programmes are urgently needed**. **These reforms entail developing well planned and implemented smart subsidy*** programmes as well as addressing the perennial implementation bottlenecks such as fertilizer leakages to elites and government administrators, crowding out of commercial input disttributors who cannot compete for long in areas where heavily subsidized fertilizers are widely available to farmers, the erosion of market competition that often results when one or two firms are awarded contracts to distribute subsidized fertilizers while all other firms are adversely affected to the point that they cease operating in the country, long distances to fertilizer collection points, financing and procurement problems and, late fertilizer deliveries, among others. This should lead to holistic improvements in soil health by promoting good agronomic practices and develop ways for greater and more efficient use of fertiliser among smallholders.

viii) *There is vital* ***need for governments to enact and implement policies and interventions that reduce farm-gate prices of fertiliser and other key inputs: This includes:***

a) Investing in physical infrastructure such asports, rail, roads, and communications.
b) Streamlining of regulations that impose unnecessary costs on businesses.
c) Encourage competition and private investment in input marketing, including fertilizer & seed.

ix) ***Encourage competition and investment in crop marketing and Trade.*** *Even the best-designed fertilizer promotion programmes will be undermined if trade and domestic grain marketing policy is not transparent and rules-based on incentive to grow productivity.* ***There is need to implement the African Continental Free Trade Agreement.*** The prospect of a unified African market with more than a billion consumers and a combined GDP of more than U$2.5 trillion presents vast opportunities for agribusiness. To realize this potential, African countries should effectively implement the African Continental Free Trade Agreement (AfCFTA).

x) ***Strengthen of the role of the public sector in fertiliser quality control. The quality of fertilizer is key in improving crop response and profitability, and hence it is important to address challenges associated with fertilizer quality and product adulteration.*** This requires:

a) Strengthening the role of the public sector in quality control of fertilizer by adequately funding the relevant institutions and enhancing their capacities for regulation.
b) Tightening the rules and laws against counterfeit products and take measures to educate farmers through various media, e.g., radio and TV and the use of ICTs in quality fertilizer assessment.

xi) ***Reduce the reliance on fertiliser imports by many countries. It is imperative that Governments explore opportunities for local manufacturing of fertilisers or blending facilities.*** The major role of Governments would be to:

a) Create favourable conditions that encourage private sector to invest in fertilizer production in order to ensure sustainable access and affordability of fertilizer to smallholder farmers in the country.

b) Nigeria is already advanced in fertiliser manufacturing and would be the first to set up more plants in other African countries as well as export its surplus fertiliser output. Nonetheless, Nigeria is only focusing on Nitrogen production. There are ample opportunities for the production of Phosphorous and Potassium.

xii) ***There is need to enact land tenure security policies that encourage farmers to make long-term investments in soil fertility improvement.*** Research shows that farmers are more likely to investments in practices that enhance soil fertility if long-term land tenure is guaranteed. In particular, there is need to pay more attention to tenure policies that provide greater security of tenure for women farmers.

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List of Acronyms

AAP	Alliance for African Partnerships
AfCFTA	African Continental Free Trade Agreement
AfDB	African Development Bank
AGRA	Alliance for a Green Revolution in Africa
ANAPRI	Africa Network of Agricultural Policy Research Institutes
ATPI	Agricultural Trade Policy Institute
BFAP	Bureau For Food and Agricultural Policy
FISP	Farmer Input Support Programme
IAPRI	Indaba Agricultural Policy Research Institute
IFDC	International Fertilizer Development Center
NAIVS	National Agricultural Input Voucher Scheme
IRES	Institut de Recherches Economiques et Sociales,
NFSP	National Fertilizer Subsidy Program
PFI	Presidential Fertilizer Initiative
PiLAF	Innovation Lab for Policy Leadership in Agriculture & Food Security
PPP	Public-Private Partnership
ReNAPRI	Regional Network of Agricultural Policy Research Institutes
SOM	Soil Organic Matter
VCR	Value Cost Ratios

1. Introduction

Since 2006, when the Africa Fertilizer Summit was held in Nigeria, the African fertilizer sector has changed dramatically. During the past decade, Africa is the only continent that has witnessed increased fertilizer consumption (at over 8% per annum). There has been significant investments on the continent for value-added utilization of mineral deposits and natural gas, shifting the focus from short-term trader perspective to domestic production of fertilizers. This market shift is aligning public and private sector incentives, creating opportunities for public, private, and development stakeholders to address soil health constraints, fertilizer market development, and farm-level risk management.

Despite this progress, fertilizer use has remained well below the 50 kg/ha target. The high cost of fertiliser remains a major factor impeding its access and use by farmers in most countries in ASoS. To remedy the problem, many governments in Africa have embarked on various strategies to improve farmers' access to fertilizers and complementary inputs at reduced costs. Some of the strategies include various forms of input subsidy programs, various models of financing to fertilizer supply chain actors, and public investments to facilitate private sector-led development of supply chains for fertilizers and complementary inputs. By 2019, two-thirds of African countries were implementing some form of fertilizer subsidy programs (both targeted and non-targeted) accounting for approximately 40% of fertilizer consumption of ASoS (Ariga et al., 2019).

These strategies have produced varying results. Notably, there has been some appreciable increase in fertilizer use in countries implementing subsidy programmes and complementary strategies (Druilhe & Barreiro-Hurlé, 2012; Sanchez et al., 2009). However, a major drawback of subsidy programmes is that the fertilizers result in a less than anticipated increase in national food production because of generally low yield response to fertilizer application under smallholder farm management conditions, substantial amounts of fertilizers to be allocated to farmers are frequently diverted to elites and government officials, commercial fertilizer sales often decline in areas where subsidized fertilizer is distributed because farmers that might have purchased fertilizer no longer feel a need to buy it after obtaining subsidized fertilizer; this means that national fertilizer often does not increase according to the quantity of fertilizers distributed through subsidy programs; and finally subsidy programs often cause input distributors to cease operating in the country when they are not able to distribute subsidized fertilizers or sell sufficient product commercially in areas where subsidized fertilizers are distributed (Jayne et al., 2018). In addition, subsidy programmes are often faced by high operational inefficiencies affecting the sustainability of such programs from the fiscal point of view. The possible low response to fertilizer application as a result of this will likely frustrate efforts to increase fertilizer consumption. Furthermore, recent evidence shows that crops (particularly maize) respond poorly to fertilisers in poor soils. Furthermore, recent evidence shows that crops (particularly maize) respond poorly to fertilisers in soils with low active soil carbon and low soil pH (Kihara et al., 2016; Burke et al., 2022). A study by Chamberlin et al. (2021) indicates that there is low carbon in the soils analysed in their study sample and suggests that raising active carbon stocks in smallholder systems may be a strategic priority in many areas for incentivizing greater use of inorganic fertilizer.

The African Union Commission has recognized the importance of building soil health in conjunction with developing viable fertilizer markets to better support farmers and address concerns about agricultural sustainability and resilience in the face of climate change. The convening of the 2023 Fertilizer and Soil Health Summit by the African Union Commission has the goal of endorsing the Africa Fertilizer and Soil Health Action Plan that outlines the priority actions developing a more dynamic fertilizer market, while addressing low and declining soil health. The action plan will also guide technological, information and capacity development investments necessary for improving fertilizer use efficacy and profitability. The Action Plan will be a solution-based road map to 2030 that will detail how to address major inhibitors to agricultural productivity growth and will include a set of quantifiable metrics to track progress over time, as the agricultural and food systems are changing rapidly.

It is against this background that a consortium comprised of the Africa Network of Agricultural Policy Research Institutes (ANAPRI), the International Fertilizer Development Center (IFDC) and the Alliance for African Partnerships (AAP) received funding support to conduct research and prepare technical background documents and policy briefs to support the development of the Africa Fertilizer and Soil Health Action Plan. As part of the background technical studies, this report focuses on "Farmer's risks and economic use of fertilizer in Africa South of the Sahara (ASoS)". The main objective was to determine the economic status of fertiliser use in ASoS, focusing on the profitability of fertiliser use on smallholder farms. In particular, the study sought to address the following questions: What is the profit margin of fertilizer use in smallholder crop production in ASoS? To what extent does fertilizer profitability vary according to farmer conditions? What are the main factors contributing to increased fertilizer response rates and farm profitability?, and what are the concrete solutions and actions needed to be taken by African governments to raise response rates to make fertilizer use profitable for smallholder farmers?

2. Progress in terms of fertilizer use

2.1 Trends in fertilizer use

Fertiliser use has increased in most of the focus countries, although it remains below the Abuja declaration recommendation of 50 kg/Ha. Figure 1 shows fertiliser consumption per hectare for the focus countries for this study a decade before the Abuja declaration (1996-2006) and the period after the Abuja declaration (2007-2020). The data shows that fertiliser use has increased in all the countries except for Zimbabwe. The countries that experienced the largest increase are Ghana, Kenya and Zambia. Only Zambia and South Africa currently have reached the target set by the Abuja declaration. Notably, South Africa was already above the 50 kg/Ha fertiliser consumption target before the Abuja declaration. Although Ethiopia was not part of the study, we made comparisons with the study countries due to its leading status in fertiliser consumption in the past 2 decades. Between 1996-2006, Ethiopia's fertiliser consumption was 13.5 kg/Ha, which increased to 26.6 kg/Ha (about double). Despite doubling in consumption, Ethiopia's fertiliser consumption is still lower than the 50 kg/Ha (Abuja declaration) and lower than most of the countries in this study.

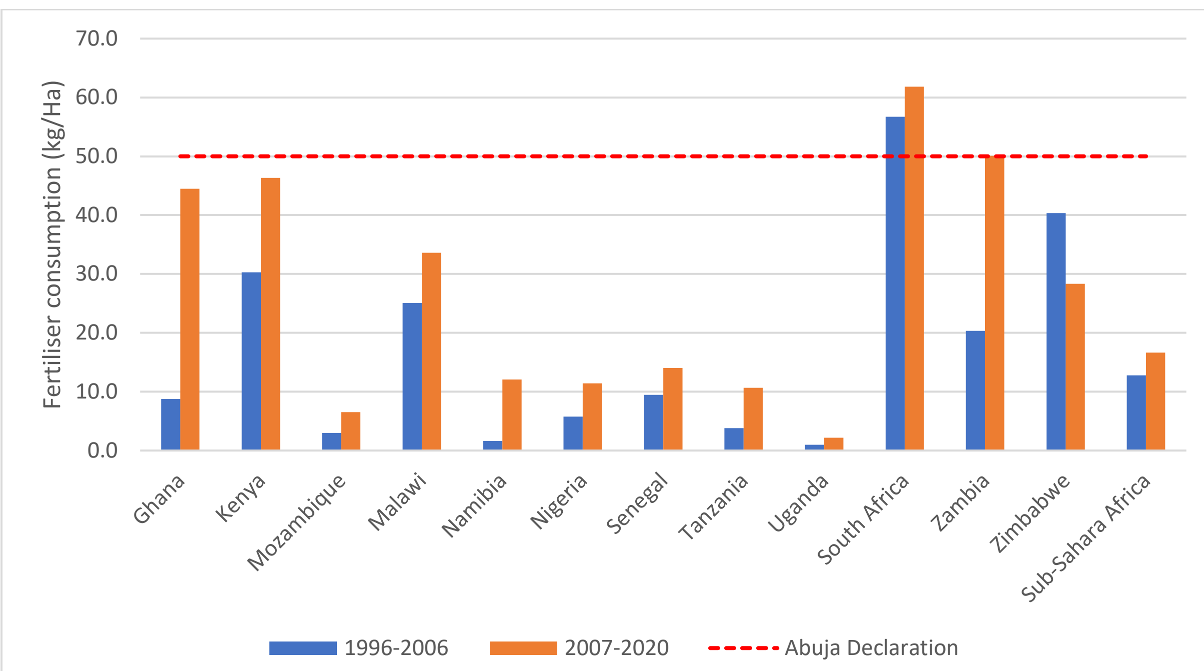


Figure 1: Trends in inorganic fertiliser consumption

Source: World Bank

Figure 2 shows average fertiliser consumption for the ASoS region as well as sub-regions i.e., Southern, East and West Africa. During the periods under review, Southern Africa has had the highest fertiliser consumption and also experienced a large increase in consumption. East and West Africa show similar patterns, with East Africa showing slightly higher fertiliser consumption for during the periods. Generally, ASoS region has continued to fall behind the 50 kg/Ha average fertiliser consumption agreed upon during the Malabo declaration.

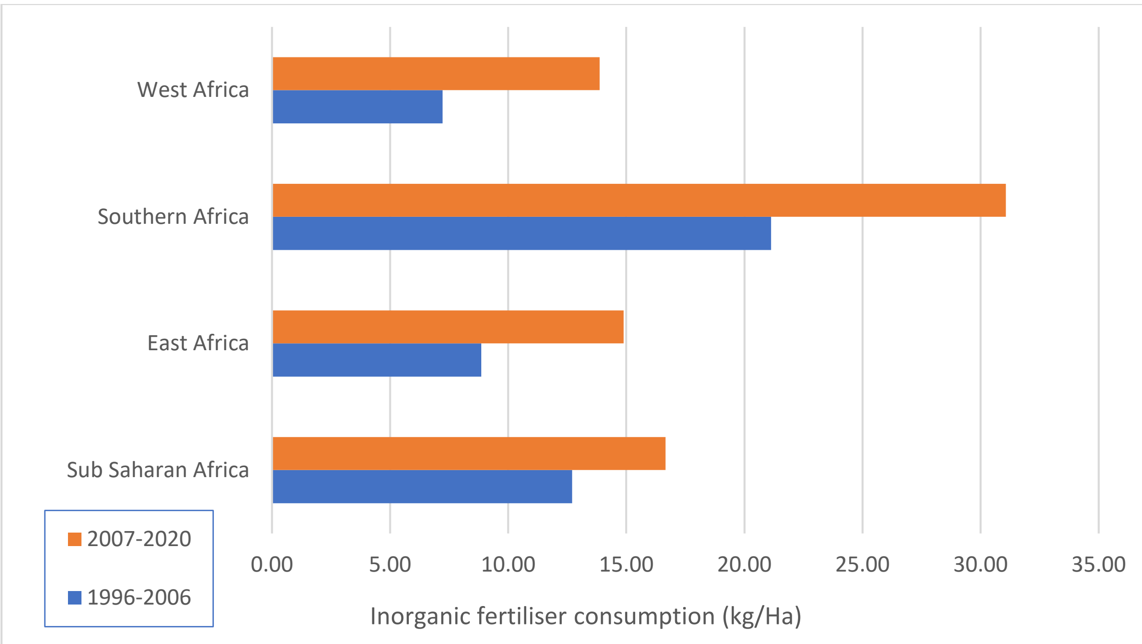


Figure 2: Trends in inorganic fertiliser consumption by region

Source: World Bank

Some nuances in terms of fertiliser use across countries are worth mentioning. In most countries, smallholder farmers account for the largest share of total fertiliser consumption. In Zimbabwe, 76% of fertiliser is consumed by small scale commercial farms[16]. In Mozambique, 96% of the fertiliser imported in the country goes directly to estates or concessions that produce tobacco, sugar and soybean. However, part of this fertiliser could have reached smallholder farmers via contract farming arrangements (AGRA, 2018).

Regional differences within countries, also brings in another interesting dimension of fertiliser use. According to the 2019/2020 Integrated Household Survey report in

[16] This is a classification of farmers in Zimbabwe who cultivate 20-50 hectares of land.

Malawi, 62% of urban-based farmers used fertiliser compared to 49% of the rural farmers (National Statistical Office (NSO), 2020). Similar trends have been observed in previous surveys. In Kenya, fertiliser consumption is significantly higher in regions with higher agricultural potential (72 kg/hectare) compared to regions with low potential (18 kg/acre)[17] (Tegemeo Institute, Various Years).

Maize accounts for most of the fertiliser consumption across the countries with 70% and 90% of fertiliser used for maize production in Malawi and Zimbabwe, respectively (Mangisoni et al., 2021; Mapfumo and Giller, 2001:12). Maize is a strategic crop in most countries and has a higher nitrogen response rate compared to other crops (Byerlee and Eicher, 1997:33). Rice is another important food crop taking up a large share of fertiliser consumption in countries such as Tanzania and Mozambique, while wheat also uses a significant amount of fertiliser in South Africa and Zambia.

In Senegal, less than half of cereal producers (37%) use fertilizers with 41.5% of them applying it in maize, 23.43% in millet and 3.8% in sorghum. Similar to Malawi, the largest share of households that use fertiliser are based in the urban regions of the country (Dakar and Saint-Louis) and also have a higher rate of use compared to the rest of the region (PAPA, 2017).

To summarize, ASoS as a region has experienced a major increase in fertiliser use between 2000 and 2022. Countries such as Ethiopia, Ghana, Kenya, and Nigeria are driving this increase for the region as a whole. Fertilizer use remains very low for many other African countries. In countries such as Ghana and Zambia, subsidy programs have contributed to a major increase in fertiliser use, but other countries implementing national input subsidy programs, such as Nigeria and Tanzania, have barely reached more than 10 kg of fertilizer per hectare. And despite ASoS overall increase in fertiliser use intensity, from 7 kgs/ha in 1990 to roughly 20 kgs/ha in 2021 – cereal crop yields continue to rise slowly, at roughly 1% per year, and the gap between cereal yields in Africa vs. the rest of the world only continues to widen over time (Figure 1).

[17] The reported fertiliser consumption rates for high and low potential regions are equivalent to 178kg/Ha and 44kg/Ha respectively.

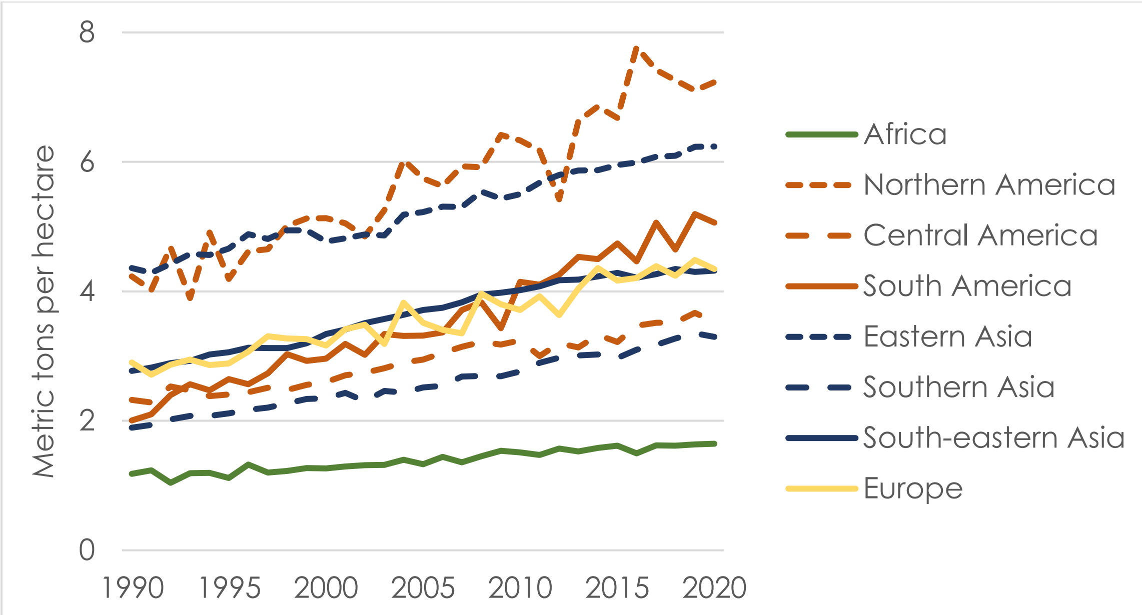


Figure 3: Cereal yields by region (metric tons per hectare), 1990 to 2020

Source: FAOSTAT (last accessed May 2022).

2.2 Programs and instruments used encourage fertilizer use

African countries have utilized a number of programmes and instruments to encourage fertiliser consumption. These include subsidy programmes, fertiliser supply initiatives to reduce the costs and local fertiliser blending and manufacturing.

2.2.1 Fertiliser subsidy programmes

Most countries have had a history of interventionist policies when it comes to fertiliser policies, which saw the establishment of various subsidy programmes. However, most of these programmes were dismantled during the implementation of Structural Adjustment Programmes (SAP) in the early 1990s. The period following the Abuja declaration has witnessed the resumption of subsidy programmes as well as other accompanying measures to encourage fertiliser use targeting smallholder farmers.

Subsidy programmes include the national fertilizer subsidy program (NFSP) in Kenya established in 2008, the Farmer Input Support Programme (FISP) and the Farm Input Subsidy Program (FISP) established in 2002 and 2005 by Zambia and Malawi, respectively. These subsidy programmes mostly support maize production. In Tanzania, the National Agricultural Input Voucher Scheme (NAIVS) was established in 2008 to support maize and rice production. In Senegal, the fertilizer subsidy component of the PRACAS program allowed for the partial subsidy of 50,000 to 80,000 tons of fertilizer, all types of fertilizers combined. In addition, a strategy was also put in place to improve access to fertilizer by encouraging the establishment of sales points during the product marketing period (Seck, 2017).

The main success of these programmes has been the increase in fertiliser use in the countries where they have been implemented. These has been accompanied by the increase in the aggregate production for the targeted crops. Notably, yields have often stagnated, an indication of inefficient use of fertilisers. Fertiliser subsidy programmes have been marred by implementation challenges such as fertilizer leakages to non-targeted farmers; sub-optimal types of fertilisers distributed through subsidy programmes; long distances to fertilizer collection points; financing and procurement problems; and late fertilizer deliveries that lead to delayed farm operations (Jayne et al., 2018)

2.2.2 Fertiliser Supply Initiatives

Given that most countries import the bulk of their fertiliser requirements, improving fertiliser supply chains is at the centre of most of the countries' fertiliser strategies as means to improve access to fertiliser in a timely manner. While the private sector plays the leading role in importing and distributing fertilisers, governments have set up initiatives in partnership with private sectors to distribute fertilisers to farmers. Fertiliser bulk procurement initiatives have been tried in Kenya and Tanzania as a measure to reduce the cost of procuring fertilisers in partnership with the private sector. These have produced mixed results, and eventually the initiatives were mostly abandoned. Other measures include policy reforms to encourage private sector investment and new entry into fertiliser distribution (e.g., waivers on duties and other import requirements), improvements in road infrastructure to reduce fertiliser costs, and the regulation of fertiliser quality, among others.

2.2.3 Fertiliser blending and Manufacturing

National governments have recognised the need to invest in local manufacturing of fertilisers to guarantee steady supply and reduce the cost. In Nigeria, the Presidential Fertilizer Initiative (PFI) which kicked off in December 2016 is one of the approaches aimed at supporting the domestic blending of NPK fertilizer and eventually reducing the challenges faced by Nigerian farmers. According to PFI (2021), the PFI has since 2017 resuscitated and established 52 local blending plants across 19 states in the country. The Indorama Eleme Fertilizer project co-funded by the African Development Bank (AfDB) is a success story of public-private partnership (PPP) which aims at promoting increased fertilizer production in Nigeria. The completion and exploitation of the fertilizer plant in 2016 helped turn Nigeria from a net fertilizer importer to a self-sufficient producer and now a net exporter of fertilizer recording 700,000 metric tons of urea to Africa and global markets in 2017 (AfDB, 2019).

In Kenya, there has been an increase in fertilizer blending with 4 companies currently providing fertilizer blends for different crops, most of which are geared toward meeting balanced crop-specific nutrient demands. This includes specialty fertilizer blends for crops such as tea, coffee, potatoes, sugar cane and maize, that are tailored for different regions and soils.

2.3 Fertilizer and soil health management

The long-term application of chemical fertilizers has both positive and negative impacts on soil and the environment (Mkonda, 2018). Despite its increased productivity role, it can also cause health soil hazardous such as soil erosion. The long term application of fertilizer leads to increasing soil pH due to acidification. Similarly, the continuous application of fertilizer affects various physical properties of soil, either directly or indirectly. They tend to alter soil aggregate stability, water retention capacity, infiltration rate, porosity, hydraulic conductivity and bulk density thus causing soil erosion which may threat the crop yield and eventually discourages the use of fertilizer.

While inorganic fertilizers are extremely important for increased productivity, there have been efforts to increase use of organic and other bio-organic fertilisers. Organic fertilizers are particularly important in improving soil fertility, increasing nutrient holding capacity and nutrient use efficiency by the crops. In Malawi, for example, the Department of Land Resources Conservation in the Ministry of Natural Resources is mandated to promote integrated soil fertility management practices, and advocates the use of both organic and inorganic sources of nutrients. Other partners such as The World Agroforestry Center (ICRAF) have extensively promoted Soil Fertility Management (SFM) techniques such as the integration of leguminous plants with maize and planting nitrogen-fixing trees that maintain or improve soil health (Krah et al., 2019). In Senegal, a new map of soil fertility has been made available; researchers are currently working on new recommendations appropriate to the different soil types. This requires government support through funding for agricultural research and development (R&D) and well-functioning extension systems to establish bi-directional learning by farmers and agricultural scientists.

3. Data and methodology

This study was conducted in 10 African countries[18]. This report generates conclusions and key messages from the country level systematic review of literature and meta-analysis as described below.

The methodology of this work was updated after receiving input from experts who attended the Bill and Melinda Gates Foundation founded convening held in Nairobi, Kenya from 20 to 23 June 2022. In particular, the breakout session on *Fertilizer and Farm Economics* at the convening and the general feedback from participants helped to sharpen the methodology of the study. Instead of doing fresh econometric analysis on fertilizer use and profitability, it was recommended that the report generates conclusions and key messages from the country level systematic review of literature and meta-analysis.

3.1 Systematic Review

A template for the systematic review was developed and was used to compare fertilizer use response and farm profitability in 10 ANAPRI Centers (see template in Annex 1). Results from the 10 countries allowed for cross country comparison of fertilizer use and profitability across three different experimentation conditions (I) field trials at research stations (ii) on-farm trials/ researcher managed; and 3) on-farm/farmer managed.

[18] Zimbabwe, Zambia, Namibia, Mozambique, Nigeria, Senegal , Tanzania, Malawi, Uganda, Kenya. South Africa was excluded because the data collected could not be compared with the other countries

Figure 4: ANAPRI study countries

Source: ANAPRI

Literature included in the systematic review included peer reviewed journal articles, working/discussion papers, thesis/dissertations, government reports and other grey literature sources. The systematic literature review gathered country-specific parameters including: type of fertiliser used, crops covered, yield response rate per kg of nitrogen fertiliser used, farm gate prices of outputs and fertilizer. Value Cost Ratios (VCR) were computed as a measure of fertiliser use and profitability from each identified study (See Box 1).

The study also compares VCRs taking into account soil health factors affecting crop response to nitrogen. In particular, the systematic review included studies that contain parameter information from fertilizer response rates from interactions with such factors as soil carbon, soil PH, soil texture and soil type. The study was limited to crop response to Nitrogen rather than other nutrients such as Phosphorous and potassium, which may also be present in compound fertilisers such as DAP or Compound D.

3.2 Meta-Analysis

Fertilizer profitability and fertilizer efficacy are dependent on several key factors that include soil fertility status, climate and weather variability, and farmer management practices. In many crop production systems in ASoS, yield responses are suboptimal and lower than expected. This is mainly due to widespread soil degradation that affects crop yield response to fertilizers.

In this study, the meta-analysis asked the following research question:

- How do local climate and soil factors affect yield responses to fertilizer across ASoS?

The main hypotheses tested were:

i) Yield response to fertilizer will be determined by co-variation of climate, soil texture, pH, and SOM.
ii) Yield response to fertilizer will be greater at research stations compared to on farm locations
iii) Yield responses to nitrogen fertilizer will be greater when coupled with other nutrients such as phosphorus, sulphur and potassium.
iv) Yield response to fertilizer will be greater with high value crops versus cereals.

Box 1: Technical note on Computation of Value Cost Ratios

Value Cost Ratio (VCR) is computed as a proxy of farm-level profitability of fertiliser used. The VCR is defined as:

$$VCR = \frac{Value\ of\ increased\ crop\ output}{cost\ of\ fertiliser\ applied}$$

$$= \frac{Crop\ Price * Additional\ Crop\ production}{Fertiliser\ price * Fertiliser\ applied}$$

$$= \frac{P_y}{P_x} * \frac{\partial_y}{\partial_x} \qquad (1)$$

Where: y is crop output (e.g., maize) and x is a vector inputs including inorganic fertilisers; $\frac{\partial_y}{\partial_x}$ is the additional crop produced per unit of fertilizer used or the marginal product of fertilizer use. Marginal product of fertiliser measures the yield response of fertiliser if we use yield instead of total output (y). Assessing the profitability of fertiliser requires that we introduce prices, thus P_y and P_x are farm gate prices of the output and fertiliser respectively. Thus, the VCR is equivalent to the price ratio of the output and fertiliser prices $\frac{P_y}{P_x}$ multiplied by the marginal product of fertiliser use $\frac{\partial_y}{\partial_x}$.

The underlying production function (i.e. the amount of output y that can be produced from inputs x allows us to estimate the yield response of fertiliser (or N).

Assuming a linear relationship between output yield and fertiliser use a linear production function can be estimated as:

$$Y_{it} = \alpha_{oi} + \beta X_{it} + \gamma \boldsymbol{Z}_{it} + \mu \qquad (2)$$

Where Y_i is output yield per unit of area planted, X_i is fertiliser (kilograms of Nitrogen (N)) applied per unit of area, $\boldsymbol{Z}_i$ is a vector of management practices, household, plot, agroecological and other control variables for output yield. α_{oi} is the yield that can be achieved in the absence of fertiliser. $\alpha_{oi} = \alpha_o$ in the case of cross sectional data but measures individual effects in the case of panel data. The parameter β measures the yield response of fertiliser (N) or $\frac{\partial_y}{\partial_x}$. We can obtain the elasticity of fertiliser response if we convert Y_i and to natural logarithm and obtain the coefficient. This measures the percentage increase in the output for a 1% increase in fertiliser use.

Different functional forms of the production function my entail non-linearity in the parameters. Examples include quadratic, Cobb-Douglas, Trans log, Transcendental, Constant Elasticity of Substitution (CEC) etc. Non-linearity in the parameters affects the interpretation of coefficients and elasticities. However, some functional forms such as Cobb-Douglas can easily be transformed to linear models by applying natural logarithms. In non-linear models yield response to N is evaluated at the mean or median or is also reported as a range. Interaction terms can be introduced in the model to study the differential impacts of fertilizer use by various soil health factors or farm management practices.

4. Results of the systematic review

4.1 Fertilizer use response and profitability

4.2.1 Crop yield response rate to Nitrogen

The crop yield response to nitrogen were computed as averages (means) from the different studies reviewed during the systematic review. For each of the reviewed study countries, we disaggregated the crop yield response by the three categories of data sources i.e., research experiment (managed by researcher); on-farm experiment (researcher managed); and on-farm (farmer-managed). Although we reviewed different crops, we only present results for maize in order to make comparisons. From the studies reviewed, data on the other crops is more scanty compared to maize. Table 1 is a summary of the crop yield response rates.

Our results indicate that maize crop yield response was highest from research carried out at experiment stations (24.45 kg per kg of Nitrogen), followed by on-farm (researcher managed) (20.82 kg per kg of Nitrogen) and was least for on-farm (farmer managed) (10.29 kg per kg of Nitrogen). We also computed national averages for crop yield response in order to make cross-country comparisons. From those comparisons, we found that Tanzania[19] had the highest crop yield response rate of kg per kg of Nitrogen for researcher managed plots 33.3 kg per kg of nitrogen and 9.97 kg per kg of Nitrogen for farmer managed. While Senegal had the lowest yield response rate of 8.40 kg per kg of Nitrogen for on-farm experiments (no data for farmer manged plots was available for comparison) The average national maize yields have also been presented in table 1.

[19] Although Zimbabwe had the same average yield response rate, we note that there was no data for Zimbabwe on "on-farm-farmer managed" crop yield response, hence in reality, Zimbabwe's average response rate might be lower than what is presented in table 1.

Table 1: Summary of maize crop yield response to Nitrogen by country

Country*	Crop yield response to fertiliser (N) in Kg per kg of nitrogen used			Average yield response(Kg/Kg of N)	Average Yield (Kg/Ha)
	Experiment station	on-farm (researcher managed)	On-farm(farmer managed)		
Malawi	42.91	23.23	7.83	**24.66**	**2.10**
Tanzania	33.33	33.38	9.97	**25.56**	**1.60**
Zambia	29.5	20.3	8.90	***19.57***	**2.54**
Kenya	17.46	16.95	17.05	**17.15**	**1.73**
Mozambique	30.80	17.68	-	**24.24**	**0.71**
Nigeria	18.17	17.97	7.67	**14.60**	**1.59**
Senegal	8.40	-	-	**8.40**	**2.65**
Zimbabwe	24.05	27.04	-	**25.55**	**1.18**
Uganda	15.40	10.00	-	**12.70**	**2.77**
Average	**24.45**	**20.82**	**10.29**	**17.02**	**2.23**

Source: ANAPRI Systematic Review

*Note: There was no data from South Africa and Namibia

Despite the crop yield response rates averages we have reported, we note that there are several nuances that are masked. For example there were wide variations in yield responses reported by Sheahan et al. (2013) under farmer management ranging from 11 to 39 kg/kg of N[20] depending on geographic location within Kenya, while (Burke et al., 2022) documents yield responses ranging from -2.4 to 6.2 kg/kg of N depending on soil types (soil carbon) in Malawi. Furthermore, findings by (Xu et al., 2009) in Zambia suggest that yield response varied widely depending on whether the geographic area was "remote" or "accessible". Other conditioning factors such as soil pH, timely fertiliser application, intercropping, effective weed management, crop rotations, and organic fertilizer applications, use of mechanical/animal draught power have been found to significant effects on yield response (Burke et al., 2017; Xu et al., 2009; Jayne et al., 2018).

4.2.2 Fertiliser Profitability based on Value Cost (VCRs)

Table 2 shows the VCRs for the study countries disaggregated by the three categories of data sources. Essentially a VCR value greater than 1 means that the cost of fertiliser is recovered, while a VCR of 2 represents 100% return on the money invested in fertiliser and is enough to warrant investment in fertiliser. Previous

[20] Crop yield response measured by the Marginal Productivity (MP)

research suggests that a VCR of 2.0 or greater is generally required for farmers to profitably adopt fertiliser use (Kihara et al., 2016; Xu et al., 2009).

Similar to the findings on crop yield response, VCRs results indicate that the highest average VCR was from experiment stations (6.84) followed by on-farm (researcher managed)(4.82) and the least was from on-farm (farmer managed) (1.68) (Table 2). The differences between on-farm researcher-managed versus farmer-managed VCRs indicate the importance of farm management, which can be improved through well-functioning farm extension systems. As noted in the case of crop yield response, there are wide variations in VCRs. Some of the reviewed studies found much smaller VCRs under farmer management ranging from 0.3 to 1.2 in Zambia (see Burke et al., 2017). Similarly, Ricker-Gilbert & Jayne, (2012) found VCRs ranging from 0.6 to 1.6 in Malawi. Several factors condition the profitability of fertiliser use including those discussed under crop yield response. In addition, the ratio of output prices and nitrogen prices as well as associated input and output market policies affecting this ratio constitute other important determinants of VCR.

Comparing across countries, we find that the country with the highest VCR was Tanzania averaging 8.45 with 10.00 under researcher management and 2.36 under farmer management. Kenya had the lowest VCR of 1.71, with small difference between experiment station or (on-farm researcher managed), 2.01(1.42) compared to 1.26 respectively. . Also of great concern is the low profitability of on-farm (farmer managed) which is less than 2, which is below the threshold for farmers to adopt or invest in fertiliser use. On average, when left to manage their own fields under farmers' own conditions, the returns from using fertiliser do not warrant them to continue investing in fertiliser use.

Table 2: Fertiliser profitability (VCRs) for maize by country

Country	Value Cost Ratios (VCRs)			Average
	experiment station	on-farm (researcher management)	On-farm(farmer managed)	
Malawi	2.79	2.50	1.17	**2.15**
Tanzania	12.98	10.00	2.36	**8.45**
Zambia	9.33	1.58	1.44	**4.12**
Kenya	2.01	1.42	1.26	**1.56**
Mozambique	7.99	2.55	-	**5.27**
Nigeria	10.51	11.17	1.82	**7.83**
Senegal	7.48	7.48	-	**7.48**

Zimbabwe	3.93	3.79	-	**3.86**
Uganda	4.51	2.90	2	**3.14**
Average	**6.84**	**4.82**	**1.68**	**4.44**

Source: ANAPRI Systematic Literature Review
*Note: There was no data from South Africa and Namibia

Figure 4 summarises the Nitrogen application rates by the different study countries. The average nitrogen application was much higher for researcher managed experiments at experiment stations and on-farm i.e. 70.93 kg/Ha and 76.31 kg/Ha respectively, compared with 45.42 kg/Ha for on-farm (farmer managed). Once again this highlights the inadequate amounts of fertiliser that holder managed maize farms receive per hectare.

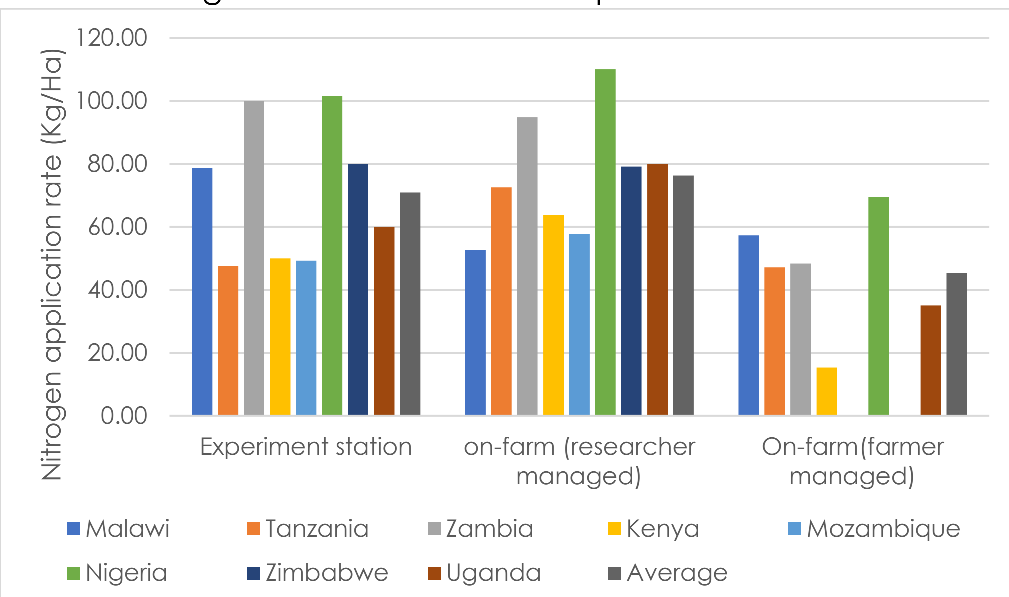


Figure 5: Average nitrogen application rate by country

Source: ANAPRI Systematic Literature Review

Given the low profitability from fertiliser use by smallholder farmers, we in turn discuss some of the possible contributing factors below:

i) Limited knowledge on soil health management

Farmers have limited knowledge on soil health management, hence soils may become acidic or have low level of organic matter, yet they may continually apply fertiliser and obtain poor yield response. Additionally, poorly drained and leached soils are characteristic of most smallholder farms. Soils often lack secondary nutrients and soil compaction occurs leading to surface sealing and hardpan formation. Inadequate soil health management by farmers means that crops cannot effectively utilise nutrients from fertiliser.

ii) Inadequate soil testing facilities

Farmers lack the requisite knowledge on soil health hence do not test their soils to enable them apply soil-specific fertilisers in line with the required nutrients for their soils. This also leads to poor returns on fertiliser use in that they may be applying fertilisers to acidic or leached soils. Limited soil testing facilities in the countries is yet another factor that affects decisions on soil health management by farmers.

iii) Blanket fertiliser recommendations

Most of the countries provide blanket recommendations and fail to consider the diversity of the soil types. Blanket recommendations cover entire regions, encompassing broad areas with considerable differences in soils and growing conditions. Failure to take into consideration the soil health aspects such as pH leads to low fertiliser response rates hence the low profitability. These uniform recommendations may not reflect nutrient deficiencies on an individual farmer's plot, hence limiting the effects of the fertilizers on crop yields.

iv) High fertiliser prices

Most countries depend on imported fertiliser except for Nigeria, which has invested significantly in local production facilities. This leaves countries susceptible to international price shocks such as Russia-Ukraine conflict, which leads to skyrocketing prices that are too high relative to output prices. Lack of access to credit facilities for smallholder farmers further compounds the problem as fertiliser prices are outside the reach of most small-scale farmers.

v) Poor implementation of subsidy programmes

Some countries, including Zambia, Zimbabwe, Malawi, Tanzania and Kenya have implemented input subsidies, which have included fertiliser. However, these subsidies have been characterised by poor targeting of beneficiaries, late delivery and inefficiencies leading to high cost of programmes and fiscal strain. Despite running such subsidies, fertiliser consumption in these countries remains well below the Abuja Declaration of 50 kg/ha.

vi) Inadequate fertiliser testing facilities

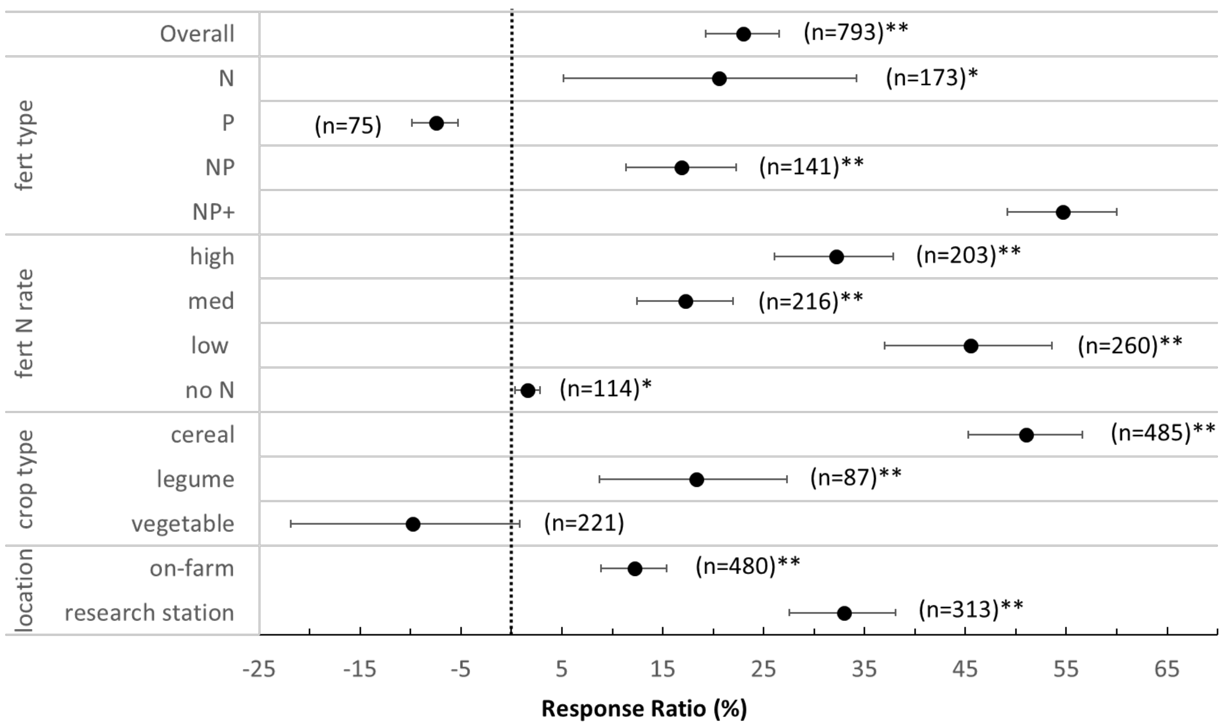
Fertiliser quality as well as perceptions of quality among farmers has an effect on its adoption and use. Due to the widespread counterfeit fertilisers reported by countries such as Tanzania, farmers may develop negative perceptions on the returns to fertiliser use, hence the limited use. Inadequate laboratories for testing fertiliser quality at border entry points or within countries further exacerbate the problem.

vii) Non-existent dedicated soil health and fertiliser policies

Most countries do not have dedicated soil health and fertiliser legislation, which leads to poor implementation of fertiliser legislation.

4.2 Results of the Meta-Analysis

Figure 4 shows the average crop yield responses (in percent change) with fertilizer application, overall and grouped by fertilizer formulation type, fertilizer (Nitrogen) application rate, main crop type, and research site location.



(** $p < 0.001$; * $p < 0.01$)

Figure 6: Average crop yield responses (in percent change) with fertilizer application

Source: ANAPRI Systematic Literature Review

In summary, the results of the meta-analysis show that:

i) Overall, fertilizer application of any type increased crop yields, on average, by 23%.

ii) Application of balanced fertilizer with multiple nutrients resulted in higher yields than N fertilizer alone. In particular, the combination of Nitrogen (N) and Phosphorous (P) with other nutrients (NP+), most often, but in some studies Sulphur (S) or Zinc (Zn), increased yields by 55% compared to 21% or 17% increases in yields with Nitrogen (N) alone or Nitrogen (N) and Phosphorous (P) only, respectively.
iii) Nitrogen addition rates had relatively small effects on yield increases with high N fertilizer rates (> 80 kg/ha) increasing yields similarly to medium (20-80 kg/ha) and low (< 20 kg/ha) fertilizer N application rates.
iv) Fertilizer application was most effective for cereal crops (e.g., maize, rice, wheat, sorghum) increasing yields by 55% compared to legumes (e.g. common beans and soybeans) which increased by 18%, or to vegetables and other crops (e.g. potatoes, cassava, melon) which were not significantly different from zero.
v) Location of the experiment, on-farm versus at a research station, had large effects on yields in response to fertilizer addition; in on-farm studies fertilizers increased yields 12% while at experiment stations fertilizers increased yields by 33%.

5.0 Conclusions and Recommendations

5.1 Conclusions

Despite highly variable trends on the increases in aggregate fertilizer consumption and application rates over the last two decades in most of the countries, fertilizer use and application rates remain remarkably low especially for smallholder farmers. Lower and variable application rates are often linked with lower and variable returns to fertilizer uses. Similar to most research findings, our systematic review and meta-analysis show that there is a strong correlation between crop yield response rate and fertiliser profitability but that crop yield response rate is conditioned by soil health factors, which include soil PH, soil types, soil organic matter, among others. Thus, improving soil amendment practices could be crucial for improving yield response rates and ultimately the profitability of fertiliser use.

Fertilizer application is unprofitable in the context where output–to–fertilizer price ratios are lower and in production zones with low crop response rates. Factors such as poor infrastructure and associated high transport and transaction costs worsens the unprofitability of fertilizer use as they impede access and raise transaction costs and thus prices. Our findings also indicate that current farmer management practices are sub-optimal, resulting in lower fertilizer profitability compared to researcher managed trials. This suggests that farmers would require significant support towards using fertiliser more profitably.

5.2 Recommendations:

The findings in this study calls for serious actions from a broad range of stakeholders including national governments, National Agricultural Research Institutes and extension services, African Universities, CGIAR centers, private sector, Donors and cooperating partners. The recommendations articulated below revolve around strengthening the National Agricultural Research Systems (NARS) with associated concrete actions (see Jayne et al 2023), policies and investments that will help contribute to creating an effective system that will work towards helping to increase crop productivity through increased fertilizer use efficiency and profitability. The recommendations focused on the how to achieve the desired outcomes.

i) **Increase investments in soil health improvements that will increase on-farm fertilizer use efficiency and profitability**. The actions to achieve this should include:

- NARS should *elevate soil health as a component of their programs* given its importance in supporting resilience, adaptation to climate change, greater yield response from the use of inorganic fertilizers, and sustainable agricultural intensification.
- *Provide incentives to farmers to grow cover crops:* Soil organic matter can increase the uptake of fertiliser by crops. However, farmers seek to maximise short-term profitability and yet soil health requires long-term investment, as it is a public good. To that effect, Governments in Africa should repurpose some of resources to fertilizer subsidy towards incentivising smallholder farmers to investment in soil management practices.
- *Integration of grain legumes in cereal-based systems* could help increase Nitrogen supply and build the organic matter in soil. However, millions of smallholder farmers are land constrained to increase the area under legumes or incorporate cover crops. Therefore, it is prudent to consider providing market incentivises to smallholder farmers to grow legumes, thus re-purpose part of the maize subsidies towards growing of grain legumes to increase organic matter content of African Soils.
- *Invest in reliable and low-cost soil testing technologies:* This includes investment in soil testing technologies and soil mapping to generate site-specific fertilizer, crop and soil management recommendations that adapted to local production conditions. For example, about 10% of soils in ASoS are acidic and require liming. Soil acidity affects nutrient uptake by the plant and reduces crop response to fertilizer.

- *Mechanisation for soil improvement operations:* Mechanisation improves fertiliser efficiency because it improves timeliness in operations and ensures that farmers have the right plant population that can optimise fertiliser efficiency.
- *Digitalisation:* Investing in digital technologies and ICT applications improving soil health and fertiliser management. These include application that can utilise remote sensing technologies to diagnose nutrient deficiencies and guide farmers on site-specific nutrient requirements.
- *Developing a soil management system for Africa:* This includes a soil information system and a dashboard to track progress in agricultural performance as well as strengthening education and training. Other areas include building human and institutional capital for soil science, economics of soil degradation and soil management.

ii) ***Increased Support to National Agricultural Research Systems and Extension Services:*** This is a precondition for sustainably raising fertilizer use in ways that raise agricultural productivity and food systems resilience. To date, there has been substantial investment in the international CGIAR system, but this international R&D system has under-performed because technology adoption requires interfacing with strong national R&D systems to scale out and adapt new technologies to specific local conditions.

One of the most crucial step to improving the performance of NARS is for national governments to increase their funding and commitment to supporting their own NARS, particularly operational funds, to monitoring performance, and to demand greater accountability for results. Doing so would also help most African countries comply with their own commitments under the CAADP Maputo Declaration. Proposals for consideration include the following:

- Empower the national systems to compellingly define their own vision and priorities, consistent with broader national development strategies in a national R&D&E strategic plan, if not already done.
- Increase overall public disbursements to agriculture and raise the share of public agricultural expenditures going to organizations in the NARES. They must provide stable and sustainable levels of funding to secure a strategic program of effective research activities that yields increased agricultural productivity. Rather than relying too much on donor contributions and development bank loans to fund critical areas of research, governments need to determine their own long-term national priorities and design relevant, focused, and coherent agricultural R&D programs accordingly.
- Ensure that budget lines to organizations in the NARES are fully disbursed each year. Stads et al (2022) found that in many cases, governments did not fully disburse approved budgets to their NARES.
- In some cases, national policy objectives would be more effectively achieved by increasing funding support for higher-value and nutrient dense commodities, e.g., fruits, vegetables, and animal products. Including these issues for consideration in NARES priority setting activities would in some cases entail restructuring in how R&D&E efforts are currently organized to expand well beyond a small number of staple crops and industrial cash crops.
- Identify and support initiatives to strengthen the quality of education in agricultural universities, training colleges and Technical and Vocational Education and Training (TVET) organizations and facilitate the employment of graduates.

- Implement accountability frameworks to encourage greater impact from public funds allocated to the NARES.
- Explore opportunities to leverage the formidable R&D systems of the private sector. The private sector is currently the least developed source of sustainable financing for agricultural R&D in Africa. Cultivating private funding requires that national governments provide a favourable enabling policy environment through accountability, tax incentives, protection of intellectual property rights, and regulatory reforms to encourage the spill-in of international technology.
- Because the smallest third of African NARSs spend so little on agricultural R&D, they are challenged by low capacity, funding volatility, and limited ability to take advantage of economies of scale and scope. As a result, small countries generally record much lower returns to R&D compared to their larger counterparts, and their R&D efforts have been less effective in reducing poverty and malnutrition (Stads et al., 2021). Rather than setting one-size-fits-all national investment targets, Stads et al (2022) propose organizing agricultural R&D investment by agro-ecological zones rather than political boundaries, at least for relatively small African countries. Integration of agricultural R&D at the subregional and regional level (through joint research programs and regional centers of excellence) may be considered, to allow countries with lagging agricultural research systems and national universities to benefit from the gains made in countries with similar agro-ecological conditions that have more advanced systems. Better coordination and a clear articulation of mandates and responsibilities among national, subregional, regional, and global R&D players are essential to ensuring that scarce financial, human, and infrastructure resources are optimized, duplications minimized, and synergies and complementarities enhanced. This is not just a policy consideration for African governments but for continental and regional African development organizations as well.
- The success of the new 1-CGIAR strategy rests with developing closer partnerships with NARS. The CGIAR can enhance the effectiveness of their own programs, as well as those of the NARS, by renewing and intensifying its efforts to strengthen the capacities of its regional and national partners, regional centers of excellence, African agricultural universities, and public extension systems. In most Asian countries, the capacities of their NARS were low several decades ago but are now

comparable to those of the CGIAR organizations working in Asia. This has served both the Asian NARS and the CGIAR well because their roles are synergistic. Because the CGIAR's impact in Africa similarly depends on well-functioning local partners, the CGIAR can, and should, intensify its capacity strengthening efforts, focusing both on organizational and well as individual capacity development.

Donor organizations that primarily fund the CGIAR can support this proposed intensification of CGIAR capacity development activities by encouraging grants and programs that (i) involve NARS partners from the inception of grant design; (ii) have joint-directors and principal investigators from both CGIAR and NARS organizations; (iii) allocate substantive portions of grant budgets to the NARS; and (iv) have well-specified performance metrics and accountability for both CGIAR and NARS partners.

- Increased Investments in National Extension Systems: A key barrier to be overcome is low extension agent to-farmer ratios. Extension models that should be considered for broader replication, including the village-based extension services in Ethiopia (see Dorosh and Minten, 2020 for details) and the Farm Input Promotions (FIPS) program of advisory services and local access to inputs in Kenya, Tanzania, and Uganda. Whichever approach is utilized, two features have been identified as particularly important for performance: (i) an extension system that enables bi-directional learning between research units and farmers to encourage adaptation in ways that fit farmers resources (Cook et al., 2021; Davis et al., 2021); and (ii) close integration of extension workers and researchers into an integrated R&D&E system (Antwi-Agyei and Stringer, 2021), i.e., breaking down the divisions between R&D and extension systems, to ensure that the advisory services received by farmers are founded on established research evidence (Davis et al., 2021).

  While the digital revolution shows enormous potential to reduce information asymmetries and raise farm productivity, anecdotal reports that some digital extension services provide farmers with advisory services that are not clearly appropriate for the specific locations of farmers or their resource levels (FAO and ITU, 2022), which can spoil farmers' trust in extension services overall. Increased integration between extension and local research institutes can strengthen advisory services' capacity to adapt digital innovations to local contexts. With advances in the ability to reach farmers in remote areas through digital platforms, public extension services could collaborate with content moderators on digital platforms to ensure greater oversight over the content targeted at smallholder farmers and safeguard farmer privacy. Governments and development partners can also play a key role in minimizing the growing "digital divide", so as not to leave behind underprivileged members of society who may lack access to information and communication technologies. Supplying extension agents with smart phones and reliable digital connectivity is an integral part of this strategy.

iii) Strengthening the role of African universities. *African Universities play a critical role in NARS, hence, their role needs to be strengthened. A number of proposals to enhance their capacity should be considered including the following:*

- Prioritizing the improvement of post-graduate training in faculties of agriculture, including sandwich programs at qualified universities including developed countries with ample experience in Africa. The University of Pretoria Collaborative Masters in Agricultural Economics and Extension provides a useful model for consideration; this program allowed MSc students to take courses both at their home university and at the University of Pretoria for a year, where international faculty and UP faculty taught and mentored them, guided their thesis work, and supported their efforts to be placed in suitable organizations on the African continent after graduation. External reviews considered the program highly effective in raising the supply of well-trained MSc agricultural economists generate and could be considered for other disciplines.
- The senior management of many African universities tend to regard their resources and budget limits as being exogenously determined by budget allocations from their central governments. But African universities could potentially expand their budgets by proactively competing for international donor resources. They could form partnerships with CGIAR organizations, international universities, and/or relevant organizations in the global south to prepare proposals for funding new activities or expanding the funding for existing activities.
- In addition, Universities may benefit from updating curricula, getting well-trained young professionals to enliven faculties of agriculture, invite greater engagement with the private sector to encourage

mentorship and the training of skills actually demanded after graduation

- Explore and utilize partnerships with international, continental and regional organizations such as the CGIAR, international universities, Forum for Agricultural Research in Africa (FARA), West and Central African Council for Agricultural Research and Development (CORAF/WECARD), Association for strengthening agricultural research in Eastern and central Africa (ASARECA), Centre for Coordination of Agricultural Research and Development for Southern Africa (CCARDESA) and African Forum for Agricultural Advisory Services (AFAAS) when funds can be directed to national priorities.

iv) ***Enhanced roled of African organizations in supporting* African NARS and regional agricultural R&D systems:** The strategies of most African development organizations (e.g. (AfDB, AGRA, African Union, FARA; ECOWAS, SADC, ASARECA, CORAF, etc.) include promoting agricultural productivity, climate-resilience, food security, capacity development, and knowledge management within the agricultural sector of African countries. Therefore, support for the development of African NARS and regional agricultural R&D systems should be an important component of African development organizations' programs.

African development organizations such as AfDB and AGRA may consider instituting strategies and concrete programs for strengthening agricultural R&D&E systems in Africa, with specific guidance for (a) NARS and extension services, (b) African Universities, (c) African governments, (d) the CGIAR, (e) international development partners, foundations, and financial institutions, (e) other African regional and continental development organizations; and (f) international universities.

v) *Refining the role of International funding partners:* Donors especially those that can afford to take a long-term time horizon for impact, should see the necessity of long-term support to the NARS, extension, and agricultural universities with long-term commitments, moving away from grants that focus on low-hanging fruit with short-term impact. Donors must engage with governments to support priorities defined by nationally-led, not externally led, processes.

Issue of "work-arounds": Some international donors and foundations appear reluctant to directly fund public sector entities and are inclined to create parallel structures to the NARS that carry out activities that duplicate the mandates of the NARS. While donors may ensure greater accountability for their funding by creating their own partners working on the ground, the long-term impacts are unclear, as they may weaken or marginalize organizations in the NARS that are still mandated by African governments to carry out the public goods role of agricultural R&D&E in their countries. Resentment, lack of cooperation, and missed opportunities have often resulted when donors create and fund new organizations to carry out tasks also in the mandate of existing national entities. Besides setting up parallel structures and potential competition between the externally funded agents and government NARS, the long-term impacts may be minimal or even negative if wider gaps are created if or when the donor discontinues funding for the new agency.

Proposals for consideration:

1. Encourage donor grants targeted to CGIAR or international universities to include organizations in the NARS at the design stage, ensuring that NARS interests and priorities are reflected in proposal and budget development. Encourage grants with co-directors from NARS so that their interests are equally reflected. Donors could do more to promote grants being co-led by organizations in the CGIAR and the NARS, starting from project design, so that NARS or regional R&D&E systems are brought in from the beginning.
2. Donor and development bank funding should be consistent with priorities set by national governments. The instability of donor funding or abrupt change in aid disbursement can have deleterious effects on the development and effectiveness of NARS activities (see Stads et al., 2021)

vi) *Strengthening the role of private sector: S*ustainability and resilience are increasingly important objectives of in large private international companies. As mentioned before accountability is one of the most important factors influencing the degree of collaboration between the NARS and the private sector. Many multinational companies, mainly seed and fertilizer companies, are heavily involved in ASoS where they develop and test their products under field conditions. If they could be assured of accountability and transparency in the use of funds, there could be mutual benefit, and NARS could potentially receive much greater funding than they currently do. Private companies may therefore make this collaboration potential explicitly to NARS organizations with the hopes that it may promote improved financial accounting protocols.

vii) ***Significant reforms of national subsidy programmes are urgently needed*. *These reforms entail developing well planned and implemented smart subsidy*** programmes as well as addressing the perennial implementation bottlenecks such as fertilizer leakages to non-targeted farmers, long distances to fertilizer collection points, financing and procurement problems and, late fertilizer deliveries, among others. This should lead to holistic improvements in soil health by promoting good agronomic practices and develop ways for greater and more efficient use of fertiliser among smallholders.

viii) *There is vital* ***need for governments to enact and implement policies and interventions that reduce farm-gate prices of fertiliser and other key inputs: This includes:***

d) Investing in physical infrastructure such as irrigation, ports, rail, roads, and communications.
e) Streamlining of regulations that impose unnecessary costs on businesses.
f) Encourage competition and private investment in input marketing, including fertilizer & seed.

ix) ***Encourage competition and investment in crop marketing and Trade.*** *Even the best-designed fertilizer promotion programmes will be undermined if trade and domestic grain marketing policy is not transparent and rules-based on incentive to grow productivity.* ***There is need to implement the African Continental Free Trade Agreement.*** The prospect of a unified African market with more than a billion consumers and a combined GDP of more than U$2.5 trillion presents vast opportunities for agribusiness. To realize this potential, African countries should effectively implement the African Continental Free Trade Agreement (AfCFTA).

x) ***Strengthen of the role of the public sector in fertiliser quality control. The quality of fertilizer is key in improving crop response and profitability, and hence it is important to address challenges associated with fertilizer quality and product adulteration.*** This requires:

c) Strengthening the role of the public sector in quality control of fertilizer by adequately funding the relevant institutions and enhancing their capacities for regulation.
d) Tightening the rules and laws against counterfeit products and take measures to educate farmers through various media, e.g., radio and TV and the use of ICTs in quality fertilizer assessment.

xi) ***Reduce the reliance on fertiliser imports by many countries. It is imperative that Governments explore opportunities for local manufacturing of fertilisers or blending facilities.*** The major role of Governments would be to:

c) Create favourable conditions that encourage private sector to invest in fertilizer production in order to ensure sustainable access and affordability of fertilizer to smallholder farmers in the country.

d) Nigeria is already advanced in fertiliser manufacturing and would be the first to set up more plants in other African countries as well as export its surplus fertiliser output. Nonetheless, Nigeria is only focusing on Nitrogen production. There are ample opportunities for the production of Phosphorous and Potassium.

xii) ***There is need to enact land tenure security policies that encourage farmers to make long-term investments in soil fertility improvement.*** Research shows that farmers are more likely to investments in practices that enhance soil fertility if long-term land tenure is guaranteed. In particular, there is need to pay more attention to tenure policies that provide greater security of tenure for women farmers.

The following are the recommendations of the study:

i) **Investing in soil health improvements that will increase the efficiency with which crops utilise fertiliser as well as farmers' profitability**. This includes the following actions:

a) *Incentivise farmers to grow cover crops:* SOM can increase the uptake of fertiliser by crops. However, farmers seek to maximise short-term profitability and yet soil health requires long-term investment, as it is a public good. Governments should incentivise Small-scale farmers to adopt soil management practices as they are land constrained. Because legumes are nitrogen-fixing in nature, they produce at lower yields compared to cereals. One way to raise fertiliser profitability is to re-purpose part of the maize subsidies towards legumes. Another way is to promote production of cover crops for livestock. With the right price incentives, farmers can grow cover crops such as cow pea and pigeon pea as feed for their livestock. Other innovative ways to promote cover crops could be through creation of market incentives to support start-ups on soil compost. Medium-scale farmers have more access to land and as such can be incentivised to grow cover crops on large areas. If for example medium scale farmers are incentivised to put half of their land under cover crops, this would increase total land under cover crops.

b) *Invest in low-cost soil testing infrastructure:* This includes investment in soil testing infrastructure to generate site-specific information and recommendations that fit local production conditions. This also requires improving farmers' access to low-cost fertilizer and soil testing services, sensitizing farmers on soil testing and introducing soil amendment practices and good agricultural practices such as incorporating carbon into soil, crop rotation etc. Soil testing can help in amending acidic soils which constitute around 10% of ASoS's soils.

c) *Mechanisation for soil improvement operations:* Mechanisation improves fertiliser efficiency because it improves timeliness in operations and ensures that farmers have the right plant population that can optimise fertiliser efficiency. Mechanisation can help to scale-up soil health improvement such as composting.

d) *Digitalisation:* Investing in applications that can be useful for improving soil health and fertiliser efficiency: These include applications that can utilise remote sensing technologies to guide farmers on the nutrient requirements specific to their soils.

e) *Developing a soil management system for Africa:* This includes a soil information system and a dashboard to track progress via metrics as strengthening education and training. Other areas include building human and institutional capital for soil science, economics of soil degradation and soil management.

ii) Supporting national adaptive Research & Development & Extension (R&D&E): This is a precondition for sustainably raising fertilizer use in ways that raise agricultural productivity and food systems resilience. To date, there has been substantial investment in the international CGIAR system, but this international R&D system has under-performed because international technology transfer requires interfacing with strong national adaptive R&D systems to scale out and adapt new technologies to specific local conditions. Therefore, there is need to:

a. Increase the funding that goes to agricultural R&D: Currently, less than one percent of agricultural spending goes to R&D. On average, Asian countries spend eight times more per farmer than African countries. Ethiopia, which tripled its funding to its national agricultural R&D system between 1990 and 2015 provides important lessons as its maize yields have also doubled in recent years. Ethiopia accounts for half of all extension workers in Africa south of the Sahara.

b. *Build strong local and regional African-led R&D&E systems*: Specifically, there is need to strengthen the capacity of national research capacity to conduct comprehensive research on fertilizer technologies, soil testing, and production of soil fertility and fertilizer maps for area and crop-specific fertilizer formulations. There is need to strengthen bi-directional learning between farmers and information providers including researchers and extension officers.

iii) **Government support in reducing farm-gate cost of fertiliser and other key inputs:** This includes
   a) Investing in physical infrastructure such as irrigation, ports, rail, roads, and communications.
   b) Streamlining of regulations that impose unnecessary costs on businesses.
   c) Encourage competition and private investment in input marketing-fertilizer & seed.

iv) **Encourage competition and investment in crop marketing.** The viability of intervention to increase fertilizer use will be limited without transparent and rules-based trade and domestic grain marketing policy the incentivise farmers to increase crop productivity.
   a) There is need to implement the African Continental Free Trade Agreement. The prospect of a unified African market with more than a billion consumers and a combined GDP of more than U$2.5 trillion presents vast opportunities for agribusiness. To realize this potential, African countries should effectively implement the African Continental Free Trade Agreement (AfCFTA). The additional state revenues from greater intra-Africa food trade can finance additional public investments to make their food systems more resilient and sustainable.

v) **Significant reforms of national subsidy programmes are urgently needed**. These reforms entail developing well-designed and structured smart subsidy programmes as well as addressing the perennial implementation bottlenecks such as fertilizer leakages to non-targeted farmers, long distances to fertilizer collection points, financing and procurement problems and late fertilizer deliveries, among others. This is supportive of holistic improvements in soil health by promoting good agronomic practices and develop ways for greater and more efficient use of fertiliser among smallholders.

vi) **Strengthen of the role of the public sector in fertiliser quality control:** The quality of fertilizer is key in improving crop response and profitability, and hence it is important to address challenges associated with fertilizer quality and product adulteration. This requires:
   a) Strengthening the role of the public sector in quality control of fertilizer by adequately funding the relevant institutions and enhancing their capacities for regulation.
   b) Tightening the rules and laws against counterfeiters and also take measures to educate farmers through various media, e.g., radio and

TV as well as increase the use of ICTs in authenticating the genuineness of fertilizers.

vii) **In view of the reliance on fertiliser imports by many countries it is imperative that Governments explore initiatives such as setting up local manufacturing of fertilisers or blending facilities.** The major role of Governments will be to:

a) Create favourable conditions that encourage private sector to invest in fertilizer production to ensure sustainable access and affordability of fertilizer to smallholder farmers in the country.
b) Nigeria is already advanced fertiliser manufacturing and could provide an investment model that can be taken up by other countries.

viii) **There is need to enact land tenure security policies that encourage farmers to make soil fertility-enhancing investments on their fields.** Research shows that farmers, including women are more likely to make investments for long-term soil health improvements if they have secure land tenure. Hence, there is need for land tenure policies that provide greater security of tenure for women farmers.

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Appendices

Appendix 1: Kenya Country Analysis

1 Country Context

1.1 The agricultural sector in Kenya

Kenya's agriculture sector is a key driver of Kenya's economy as exemplified in the high correlation between the country's economic growth and the rate of growth of the sector. It is estimated that a 1% increase in agriculture growth results in a corresponding 1.6% in Gross Domestic Product (GDP) growth (World Bank, 2019). Agriculture contributes about 33% of the GDP directly and another 27% of GDP indirectly through linkages with other sectors such as manufacturing, distribution and services. It accounts for about 60% of exports, with the largest contribution coming from crops production. In addition, it employs more than 40% of the total population and about 70% of the rural population (Government of Kenya, 2018).

Agriculture is dominated by smallholder rain-fed production farming systems of between 0.2 and 3 hectares, which account for 78% of total agricultural production and 70% of commercial production (World Bank, 2015). According to the Agricultural Sector Transformation and Growth Strategy (ASTGS), between 2012 and 2016, the main components of the sector, namely crop production, livestock and fisheries, accounted for 84%, 14% and 2% of agricultural growth, and grew at 25%, 8% and 6% per annum, respectively. Crop production comprises of food crops (cereals, pulses, roots & tubers), industrial crops, and horticulture. The livestock sub-sector in Kenya contributes less than 20% to agriculture GDP and about 4% to the national GDP. Livestock comprises of beef and dairy cattle, sheep and goats, camels, poultry and pigs. The dairy industry has the largest contribution to the value of livestock but the fastest-growing component is meat, which almost doubled in value in the period 2012-2014 (Government of Kenya, 2018). The fisheries and aquaculture sub-sector currently contributes about 2% to agricultural GDP, but has potential to grow since the Government's Big Four Agenda recognizes the importance of this sub-sector and it seeks to leverage emerging opportunities in the Blue Economy.

1.2 Kenya's progress in terms of fertilizer use

1.2.1 Trends in fertilizer use

Aggregate fertilizer consumption in Kenya has increased from 227,715 MT in 1990 to 604,704 MT in 2021 (Figure 1). The annual growth in consumption averaged 4.3% in the 1990-2006 period, when fertilizer trade was mainly controlled by the private sector. This declined marginally to 4.1% between 2007 and 2021, a period when the government intervened in the fertilizer market through subsidies (Kirimi et al., forthcoming).

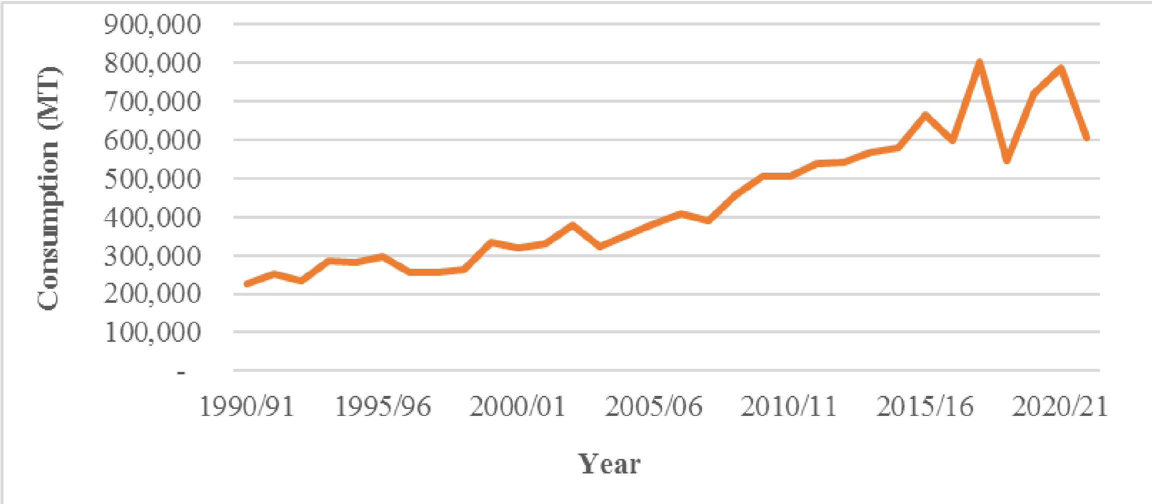

Figure 1: Trends in aggregate fertilizer consumption in Kenya
Source: Kirimi et al., forthcoming.

The increase in fertilizer consumption is reflected in the growth of imports from 228,215 MT in 1990/91 to 660,551 MT in 2021/22. This is because Kenya relies on imports for nearly all its fertilizer needs, with the single super phosphate (SSP), being the only fertilizer manufactured in the country, as a by-product in the manufacturing process of sulphuric acid. There has been an increase in fertilizer blending in the country, with 4 companies currently providing fertilizer blends for different crops, most of which are geared toward meeting balanced crop-specific nutrient demands.

Household access to fertilizer and fertilizer use have increased overtime. Data collected by Tegemeo Institute between 1997 and 2007 shows that the percentage of households that applied fertilizer on crops increased from 64% to 76%. This could be partly explained by better access to fertilizer since the same data shows a decline of 58% in average distance to a fertilizer retail shop (from 8.1 km to 3.4 km) within this time period. However, the intensity of fertilizer use decreased from an average of 72 kg/acre in 2000 to 63 kg/acre in 2007[21]. This decline, in spite of increasing fertilizer adoption rates could be an "indication of increasing awareness in the importance of using fertilizer but within a very constrained budget" (Mathenge et al., 2010).

Various fertilizer types contribute to the aggregate consumption and statistics for the 2010-2021 period show that the major ones are diammonium phosphate (DAP) and NPK that account for 34% and 22% of all fertilizer consumed, respectively, followed by CAN (18%) and urea (12%) (Kirimi et al., forthcoming). The use of fertilizer varies across different crops with maize ranking first in terms of the share of crops in the aggregate fertilizer consumption, followed by tea. Tea accounts for the second largest share of fertiliser consumption after maize.

[21] This is equivalent to 179 kg/Ha and 156 kg/Ha.

1.2.2 Comparisons of fertilizer use

According to data from Tegemeo Institute, the proportion of households that used fertilizer increased for both male and female headed households between 2000 and 2007. However, a higher proportion of male than female headed households used fertilizers (Table 1). Fertilizer use rate among households in the high agricultural potential areas were higher (above 90%) and they consistently increased between 2000 and 2007. Adoption also increased in the low potential areas, but fertilizer use remains much lower (below 40%) than in high potential areas. With regards to intensity of use, male headed households used fertilizer more intensively than female headed households across all the years, and this difference statistically significant. As expected, the intensity of fertilizer use was significantly higher in the high potential than in the low potential areas.

Table 1: Fertilizer adoption and intensity of use

	2000		2004		2007	
	% using	Intensity (kg/acre)	% using	Intensity (kg/acre)	% using	Intensity (kg/acre)
Gender of household head						
Male	71.2	74	75	67	79.3	66
Female	59.6	52	59.7	55	65.3	52
Overall	**69.8**	**72**	**71.9**	**65**	**76**	**63**
Agro-potential						
Low potential	25.9	20	30	13	38.3	18
High potential	90.6	79	91.8	73	93.9	72
Overall	**69.8**	**72**	**71.9**	**65**	**76**	**63**

Source: Tegemeo Institute data, 2000-2007

1.2.3 Programs and instruments to encourage fertilizer use

Patterns and trends in fertilizer use and supply in Kenya have been shaped by various policy and institutional interventions. Key among these is the structural adjustment programme of the early to mid-1990s, when the fertilizer sector was gradually liberalized. This was characterized by the elimination of fertilizer distribution restrictions, price controls, import duty and Value Added Tax (VAT). This opened the way for private trade in fertilizer that resulted in an increase in the number of private traders in the fertilizer industry.

In June 2008, the Kenya Vision 2030 (Government of Kenya, 2007) was launched with its flagship project being the development and implementation of a three-tiered fertilizer cost reduction programme. This comprised of bulk procurement of fertilizer, domestic fertilizer blending and packaging as well as the establishment of a fertilizer manufacturing plant for national/ regional fertilizer requirements. The plan for a manufacturing plant was put on hold after a feasibility study in 2012 indicated that the viability of the plant was hampered by inadequate raw materials and the substantive capital required, which would entail the government investing at least 30% of the required capital expenditure to incentivize a strategic investor in fertilizer manufacturing. Hence, Kenya has continued to rely on imports for most of its fertiliser requirements. A small but increasing number of specialty fertilizers are blended locally for crops such as tea, coffee, potatoes, sugar cane and maize. Companies processing fertilizer blends include Toyota Tsusho Fertilizers Africa (Baraka Fertilizers); Omya-ARM (formerly Athi River Mining) (Mavuno fertilizers); Yara; MEA; Minjingu Mines & Fertilizer Ltd; and Export Trading Group.

In the last 15 years, the government of Kenya used different forms of subsidy to promote the use of fertilizer and improve agricultural productivity. The National Accelerated Agricultural Input Access Programme (NAAIAP) was initiated in 2007 in response to the 2006 Abuja Declaration on fertilizer for the African Green Revolution. The NAAIAP was targeted to resource-poor farmers producing maize, who received a one-time fully subsidized input package (50 kg bag of basal fertilizer, 50 kg bag of top dressing fertilizer, and 10 kg of improved maize seed). The fertilizer subsidy was distributed through private agro-dealers and thus supported private sector trade in fertilizer. By 2015, the programme had distributed about 50,800 tons of fertilizer valued at KES 2.73 billion to about 533,000 smallholder farmers.

While NAAIAP was on-going, the government established the National Fertilizer Subsidy Program (NFSP) administered through the National Cereals and Produce Board (NCPB) in 2008. This was in response to the oil price shock that tripled fertilizer retail prices. Unlike the NAAIAP, this subsidy was not targeted, and its objective was to lower and stabilize local fertilizer prices to make fertilizers affordable to all farmers. The bulk procurement of fertilizers under the NFSP, is part of the three-tiered fertilizer cost reduction programme. By 2019, this subsidy programme had distributed 1.27 million MT of fertilizer at a cost of KES 28 billion.

The NAAIAP was terminated in 2017 and a more effective and efficient targeted e-subsidy programme was established under the National Value Chain Support Programme (NVSP), which started in 2019, in line with the ASTGS (2019-2029). The NVSP aims at supporting agricultural production and marketing through input-subsidized agriculture using the e-voucher input management system. It will be implemented in three phases targeting a total of 1.4 million registered high needs farmers as stipulated in flagship 2 of the ASTGS.

In the course of the last two years, the government has used subsidies to deal with increasing fertilizer prices and as part of reforms in the tea and coffee sectors. For instance, in October 2021, the President announced a new KES 26 billion economic stimulus program targeting key productive and service sectors of the economy that was to cost KES 26 billion. It was aimed at accelerating the pace of Kenya's economic growth and reinvigorating the economy, which was reeling from effects of the Covid-19 pandemic. Part of this stimulus package was KES 1 billion allocated in support of a fertilizer subsidy for tea farmers. Also, in February 2022, the government launched a KES 1 billion Coffee Farm Inputs Subsidy Program, which will enable coffee farmers to enjoy a 40 percent discount on farm inputs. The E-subsidy program being implemented by the New Kenya Planters Cooperative Union will benefit smallholder coffee farmers in cooperative societies and small estate coffee farmers.

In response to the large increase in the global fertilizer prices in 2022, the government allocated KES 5.7 billion for a fertilizer subsidy for the 2022 long and short rains seasons. This was aimed at stabilizing fertilizer prices for all farmers and was administered through the NCPB depots countrywide. Effective September 2022, the national government is rolling out the fertilizer subsidy, starting with counties undertaking planting during the short rains season of 2022.

In July 2022, Kenya secured KES 7.3 billion from the African Development Bank to extend fertilizer subsidy to support food security efforts amid rising cost of inputs and prevailing drought. The loan facility will see at least 650,000 cereal and oil seeds farmers across the country access subsidized fertilizer, certified seeds and agriculture extension over the next two years, beginning in the 2022 short rains season and into the 2022/2023 long rains season.

Following Kenya's 2010 Constitution, most of the agriculture functions were transferred to the county governments under the devolved system of government effective 2013. A number of county governments have been providing fertilizer subsidies to farmers as part of their strategy to support agriculture, which is the main economic activity in most of the counties.

2 Results of the Systematic Review

2.1 Fertilizer use and profitability

The 6 papers reviewed where mainly on maize, and where maize is intercropped with other crop, the other crops (mainly beans) were converted into maize yield equivalents. Data was mainly from household surveys that focused on maize yield response to Nitrogen. Our review indicates a large variation in the VCRs for maize as shown in Table 2. This varies from 0.01 to 18.5. There was less variation for the studies using household surveys, with the VCR ranging from 1.7 to 1.9. In the meta-analysis study by Ichami et al. (2019), the high VCR was attributed to the high agronomic nitrogen use efficiency in Kenya of 42 kg dry weight of maize per kg of Nitrogen compared to 18 kg dry weight of maize per kg of N for the rest of ASoS. The differences across the study years in the study by Keiji et al. (2020) are due to favourable weather conditions in 2018 compared to 2017.

Where the VCR is greater than 1, it implies that fertilizer use could be profitably expanded and hence farmer income would be increased with an increase in the rate of fertilizer application. Notwithstanding, there are hosts of factors conditioning yield response to fertiliser use such as soil acidity, low soil carbon and poor agronomic practices. However, data on factors conditioning yield response to N is scarce, particularly on farm management practices. The reviewed studies show that the profitability of N fertilizer use in maize is dependent on soil pH, soil types and texture, and soil organic carbon.

Table 2: Profitability of fertilizer use in maize production in Kenya

Study	Type of data used	VCR	Conditioning factors for fertilizer response
Vanlauwe et al. 2006	On farm/ researcher managed	Ranges from 0.05 to 0.10	
Tjernström et al. 2018	On farm/	1.9	pH

	farmer managed (RCT)		
Ichami et al. 2019	Meta-analysis On farm, both researcher and farmer managed	18.5	Soil type and texture
Sheahan et al. 2013	On farm/ farmer managed	1.7	Soil types
Keiji et al. 2020	On farm/ farmer managed	From 0.01 (in 2017) to 4.13 (in 2018)	
Marenya and Barrett. 2009	On farm/ farmer managed	1.76	Soil organic matter

Source: Authors compilation from various papers

2.2 Constraints and solutions in literature

A number of constraints to fertilizer yield response and profitability, and potential solutions have been identified. These are summarised below:

a) Variations in crop response to fertilizer application are primarily due to variation in soil and farm management (Jayne et al., 2018) and amount of soil organic matter (Marenya and Barrett. 2009).
b) Higher fertilizer rates may require other inputs and management practices to be profitable (Sheahan et al., 2013). However, farmers have limited of knowledge of such inputs and practices.
c) There is great variation in soil quality and properties within and between localities and ignoring this variability could lead to misleading recommendations for farmers not well-represented by regional averages (Tjernström et al., 2018).
d) Quality of fertilizer is key to fertilizer profitability. Returns to high-quality fertilizer were quite high but the presence of low-quality fertilizer in local input markets was associated with low returns Tjernström et al. (2018). Tjernström et al. (2017) noted that farmers need assurance that they are accessing fertilizers with accurately specified nutrient content, and if they have concerns about the quality of the fertilizer in the market, this will impact on their willingness to pay for it and consequently, their decision to purchase.

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Appendix 2: Malawi Country Analysis

1 Country Context

1.1 The Agricultural Sector in Malawi

The agriculture sector in Malawi remains the backbone of the economy (Malawi Government, 2021). In 2021, it accounted for 23.2% of the Gross Domestic Product (GDP) and 70% of the total export earnings. The crop and livestock sub-sectors contributed roughly 22.1% to the GDP, while tobacco was 51% of the total export earnings, followed by coffee (11%) and sugar (10%) (Malawi Government, 2021).

Traditionally, Malawi has a dual agriculture structure comprising smallholder and estate sub-sectors (Malawi Government, 2016). Approximately 80% of the population are smallholder farmers relying on rain-fed agriculture for their livelihoods (NPC, 2020). Maize, the main staple food, is the dominant crop grown by smallholder farmers.

Unsurprisingly, maize has been the focus of agricultural policies and public expenditure for decades (Malawi Government, 2018). Agriculture has consistently been allocated more than 10% of the national budget for nearly two decades, fulfilling the Comprehensive African Agricultural Development Programme (CAADP) target. However, a huge proportion of this funding is allocated to the Inputs Subsidy Program, which the government has been implementing since 2005. For instance, the share of the subsidy budget in the Ministry of Agriculture (MoA) budget in the 2005/06 season was 41%. This share increased to 88% in the 2006/07 season before falling to 51% in the 2018/19 season (Mazunda, 2013; Malawi Government, 2019). The subsidy program targets between 0.9 million and 4.3 million farm households with maize and grain legume production inputs. The 4.3 million farm households were reached during the 2020/21 season when the subsidy program became universal. The increase in the number of beneficiaries raised the MoA budget in the national budget to 19.9% in the 2020/21 season and 24.3% in the 2021/22 season (Malawi Government, 2020; Malawi Government 2021). The program has since been renamed as the Affordable Input Program (AIP).

This notwithstanding, agricultural productivity (and overall production) has remained relatively low due, among other factors, to high environmental degradation, increasing climatic risks, low technology adoption and mechanization, low access to farm inputs, and poor access to finance (NPC, 2020).

1.2 Malawi's progress in terms of fertilizer use

1.2.1 Trends in Fertilizer use

The general trend in fertilizer use has been positive since 2006 despite fluctuations. In the past two decades, fertilizer consumption has been above 25 kg/ha, and the average consumption has been 20 kg/ha since 1960. However, there is no consensus regarding the highest consumption rate for Malawi. Data from the World Bank suggest that Malawi achieved its highest consumption at a rate of 43 kg/ha in 2015 (see Figure1, below).

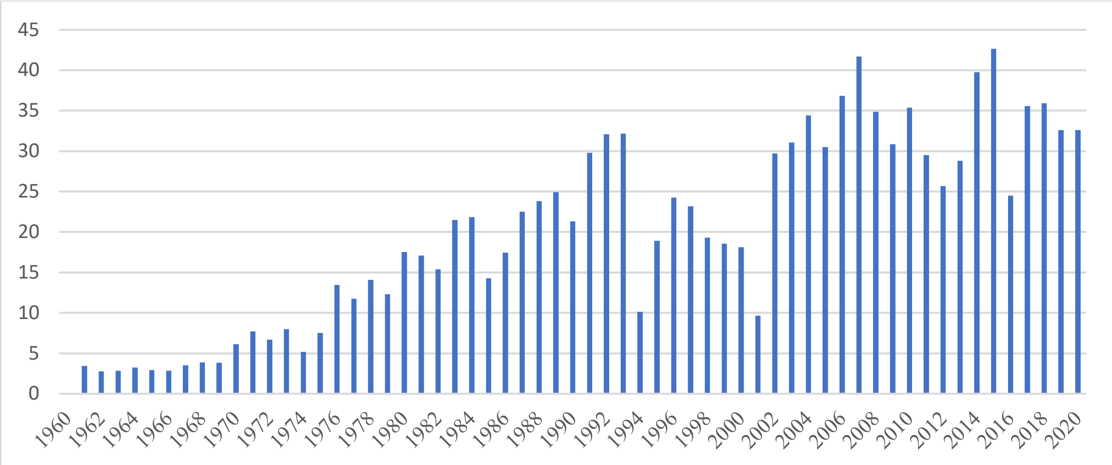

Figure 1. Fertilizer Consumption in Malawi (Kg/ha)
Source: World Bank – World Development Indicators

1.2.2 Comparisons of fertiliser use

The gender and regional comparisons of fertiliser use among farm households during the periods 2011/12, 2015/16, and 2019/20 are summarised in Table 1. The proportion of households using inorganic fertilizers increased from 11.2% in 2010 to 54.7% in 2016 and slightly dropped to 49.7% in 2019 (NSO, 2010; NSO, 2016; NSO 2019). Conversely, the proportion using organic fertilizers dropped from 61.3% in 2010 to 21.3% in 2019. Further analysis shows that urban households use slightly more inorganic fertilizer relative to rural households for all the survey years. This may reflect on higher accessibility by urban populations because of their higher incomes than rural populations. Further, the results show that male-headed households used slightly more inorganic fertilizers than their female counterparts.

Table 1: Proportion of Plots by fertilizer use for 2010/11, 2015/16 and 2019/2020

	2019/2020			2015/2016			2010/2011		
	Organic Fertilizer	Inorganic Fertilizers	No fertilizers	Organic Fertilizer	Inorganic Fertilizers	No fertilizers	Organic Fertilizer	Inorganic Fertilizers	No fertilizers
Malawi	21.3	49.7	42.6	19.2	54.7	37.6	61.3	11.5	27.2
Residence									
Urban	20.6	62.9	30.8	24	69.6	23.1	67.9	16	16.1
Rural	21.3	49	43.2	18.9	52.6	38.7	61	11.3	27.7
Region									
North	10.5	53.9	43.3	12.8	55.8	39.4	58.6	6.2	35.2
Central	18.2	48.1	45.9	18.1	53.8	39.8	59.7	14.6	25.7
Southern	27.7	50.2	39	21.9	55.4	34.8	64.3	9.8	25.9
Sex of HH									

Male	20.4	51.2	44.1	18.9	56.5	36.6	61.9	11.7	26.4
Female	23.4	46.2	41.9	19.9	50.1	40.3	59.8	10.9	29.3

Source: National Statistical Office, Integrated Household Survey Reports 2010/11, 2015/16, 2019/20

Maize, the main subsistence and food crop for Malawi consumes roughly 70% of the fertilizer supplied in Malawi, followed by cash crops, such as, tobacco (10%), tea/coffee (5%), and sugar (5%). The rest of the crops grown in Malawi consume the remaining 10% of fertilizer used (Mangisoni et al., 2021).

1.2.3 Programs and instruments encourage fertilizer use

Malawi has a long history of public intervention programs in the fertilizer market (IFDC, 2013). However, the subsidy program is the main instrument, such that in 2021 alone, over 345,000 MT of fertilizers (or 70%) were distributed through the subsidy program (FAM, 2021). The remaining 30% is sold through commercial market outlets.

The guiding policy document, the National Fertilizer Policy (2021) aims to increase by 75%, the number of farmers accessing high-quality fertilizers through commercial channels by the year 2026. It lays out strategies for achieving this, such as, increasing access to credit and loan facilities for farmers, encouraging the private sector to package fertilizers in different sizes to suit different categories of farmers, and encouraging farmers to form cooperatives and farmer groups to negotiate for better prices, just to mention a few.

While inorganic fertilizers are extremely important for increased productivity, organic and other bio-organic fertilizers are also being promoted in Malawi to sustainably improve soil fertility, increase nutrient holding capacity, and nutrient use efficiency by the crops. The Department of Land Resources Conservation in the Ministry of Natural Resources is mandated to promote these integrated soil fertility management practices. Other partners such as The World Agroforestry Center (ICRAF) have extensively promoted Integrated Soil Fertility Management (ISFM) techniques, such as the integration of leguminous plants with maize and planting nitrogen-fixing trees that maintain or improve soil health (Krah *et al.*, 2019). Studies on the adoption of ISFM have shown an increase in the adoption of ISFM among farmers in Malawi (Holden *et al.* 2017; Kanyamuka, 2017; Maertens et al., 2020).

2. Results of the Systematic Review

2.1 Fertilizer Use and Profitability

A total of 10 peer-reviewed studies focusing on crop response to fertilizer use in Malawi were reviewed. One common feature of these papers was the focus on maize in the analysis of crop response rates to Nitrogen. While some papers had looked at inter-cropping with cassava and pigeon peas, the reported National Use Efficiency (NUE) scores were mainly for maize intercropping with other crops. The common and reported fertilizers for maize, in the reviewed papers, are NPK (basal dressing) and Urea (top dressing). Several research designs have been adopted in the papers reviewed, ranging from strictly on-station trials to on-farm trials following researcher-recommended practices and on-farm trials with farmer management practices. Some papers used secondary data from the Integrated Household Surveys (IHS).

The reported mean values of Nitrogen used per hectare varied between 15 kg/ha to 86 kg/ha for the different crops and management systems. The results for yield response rates also varied between -2.4 kg maize/kg of N to 38.7 kg maize/kg of N applied. The National Fertilizer Policy (2021) reports that the average maize response rate to nitrogen is 11.82 kg maize/kg of N. Further, the yield response rates to N under different farm conditions vary from 31 kg maize/kg of N at on-station trials, to 32.7 kg maize/kg of N for on-farm trials under farmer management conditions to 38.7 kg maize/kg of N for on-farm trials under researcher management conditions.

Using Burke *et al.* (2022) yield response rate of 6 kg maize/kg of N, Mangisoni *et al.* (2020) yield response rate of 7.89 kg maize/kg of N, and Kamanga *et al.* (2014) yield response rate of 19.3 kg maize/kg of N, we calculate the Value Cost Ratios (VCR) using maize output prices reported by IFPRI (IFPRI Monthly Maize Market Report 2018, 2017, and Pauw and Edelman, 2015) for the years and the corresponding fertilizer prices from various sources (Malawi Government, 2018; Duchoslav and Rusike, 2021; IFDC, 2013). For all three studies, we found VCRs of less than 1 (0.075 for Burke *et al.* (2022), 0.128 for Mangisoni *et al.* (2020), and 0.322 for Kamanga *et al.* (2014)), indicating that for every Malawi kwacha spent on Nitrogen, we obtain less than MK1 in the value of maize. Burke *et al.* (2022), Komarek *et al.* (2018) and Kamanga *et al.* (2014) outlines possible ways of increasing fertilizer use response rates and farm profitability.

2.2 Constraints and Solutions in Literature

Snapp *et al.* (2014) identified five main factors affecting nitrogen use efficiency on maize plots in Malawi and made necessary recommendations for increasing nitrogen use efficiency. These include 1) inadequate weeding and pests control that reduces uptake and utilization of Nitrogen and Phosphorous by the crop; 2) limited use of crop rotation and intercropping, especially legumes that biologically fix nitrogen in the soils; 3) late fertilizer delivery and application that is key in reducing nutrient loss and increasing the efficiency of nutrient usage; 4) low soil organic matter and soil quality; and 5) acidity and low phosphorous in the soil. Snapp *et al.* (2014) recommended taking an integrated approach to soil fertility management that includes crop diversification for pests and weeds control; correctly timed and targeted application of fertilizer; rotation with nitrogen-fixing legumes; and appropriate dissemination of technologies through Farmer Field Schools.

Regarding fertiliser-use profitability, studies have shown that a combination of fertilizer use, and field and soil management practices are key for maximizing NUE and increasing fertilizer profitability. For example, Kamanga *et al.* (2014) found that economic returns to maize output almost doubled if fertilizers were used, and plots were weeded at least twice. Komarek *et al.* (2018) also noted that the average economic profits from maize increased by almost 75% when rotation with legumes such as groundnuts was followed. The study found that the maize-groundnut rotation yielded a higher NUE and was more profitable with reduced risks compared to the intensely fertilized maize monoculture system.

Most fertilizer recommendations studies that have been done in Malawi have focused on addressing nitrogen and phosphorus deficiencies in the soil (Mutengi *et al*, 2015). However, soil analyses that have been done across the eight Agriculture Development Divisions (ADDs) of the country have shown that nutrient deficiencies vary significantly. For example, potassium deficiency was 25% more deficient in some districts in Northern Malawi but as low as 1% in some districts in Southern Malawi (Mutengi *et al,* 2015). There are also wide variations between and within farms in the studied districts. The challenge with the current blanket fertilizer recommendations is that they fail to address the diverse nutrient deficiencies across soil types. Currently, fertilizer blending companies such as the Malawi Fertilizer Company blend and supply tailored fertilizers, based on demand, to meet specific soil and crop requirements for maize, tobacco, tea, soya, nuts (ground and macadamia), and sugarcane (FAM, 2021).

Since most of the fertilizer consumption in Malawi is derived from the input subsidy program, it is necessary that some of the solutions should be implemented through the program. Some of the challenges the subsidy program has faced include low crop response to fertilizer, ineffective beneficiary targeting, and limited influence on sustaining the uptake of agricultural technologies (Nyondo *et al,* 2022). The recent upsurge in fertilizer prices also hinders Malawi's ability to achieve the national goal of increasing fertilizer use through the subsidy program (Duchoslav and Rusike, 2021; Nyondo *et al,* 2021). A good fertilizer subsidy program should take a holistic approach that includes efforts to improve soil health and agronomic practices that smallholder farmers can adopt to raise yield response to fertilizers (Chadza & Duchoslav, 2022; Nyondo *et al,* 2021).

Simtowe (2015) noted that there are inadequate laboratories and facilities for conducting fertilizer quality analyses in Malawi, where fertilizer testing is mainly done by the Malawi Bureau of Standards at their laboratory in Blantyre. There is also a lack of qualified Quality Controllers at the border posts to thoroughly conduct quality checks. AGRA (2018) also noted similar challenges and highlighted the example of national soil laboratories which have been largely unsuccessful in curbing the influx of low-quality fertilizers. There is a need to strengthen the capacity of local fertilizer testing laboratories through staff capacity building, training, and equipping the laboratories to meet international standards for soil, organic and inorganic fertilizer testing.

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Appendix 3: Mozambique Country Analysis

1. Country Context

In Mozambique, the agriculture sector is important for the economy as it has contributed on average 24.5% to the Gross Domestic Product (GDP) for the past 10 years (WDI:2010-2020). Approximately 67% of the population is employed in agriculture (Marassiro et al., 2021). Therefore, it is an important source of income and food security mainly in rural areas. Thus, the Government is engaged in formulating policies, plans, strategies or regulations to transform and modernize the agriculture sector and made commitments at national, regional, continental as well as international levels.

Notwithstanding, Government's efforts, the agriculture sector is characterized by majority of smallholder farmers that practice subsistence rain-fed agriculture. Specifically, the sector is composed by 4.3 million farmers of which 97.8% are small sized (< 2 ha), 2% are medium sized (between 5 and 10 ha) and less than 1% are large sized (>10 ha) (IAI, 2020). Additionally, the sector is characterized by low productivity and production. For example, in 2020 the average productivity of Maize was 0.8 ton/ha compared to neighbouring countries such as Malawi with 2.0 ton/ha, Tanzania with 1.6 ton/ha, South Africa with 2.6 ton/ha and Zimbabwe with 1 ton/ha (Knoema, 2022). The low productivity can be explained by the low use of inorganic fertiliser (7.8%) and organic fertiliser (8.8%); fertilizers, irrigation (9.5%) as well as low access to extension (6.9%) and financial services (0.6%).

The Mozambique country study discussed trends in fertilizer usage as well as its profitability based on crops' yield response obtained from 21 studies between the period 2011 and 2022. Most studies were established on experimentation stations (92%), only 8% were on-farm followed by a researcher. The main crops covered were maize, cassava, rice, soybean, wheat and cowpea.

1.2 Mozambique's progress in terms of fertilizer use

1.2.1 Trends in Fertilizer use

Despite the many programs and projects developed to increase fertilizer use, the overall fertilizer consumption in the past 40 years is below 15 kg/ha with an average of 6 kg/ha since the Abuja declaration (Figure 1). Following the Abuja declaration, consumption levels were fluctuating with a peak in 2008 (more than 10 kg/ha) and the lowest having been recorded in 2007 (less than 5 kg/ha). Consumption levels are still far lower than the 50 kg/ha agreed on during the Abuja declaration as well as 25 kg/ha for PEDSA. Additionally, fertiliser use is much lower than the ASoS with an average of 17 kg/ha, as well as with neighbouring countries such as South Africa (72.8 kg/ha); Tanzania (15.6 kg/ha) and Malawi (35.9 kg/ha).

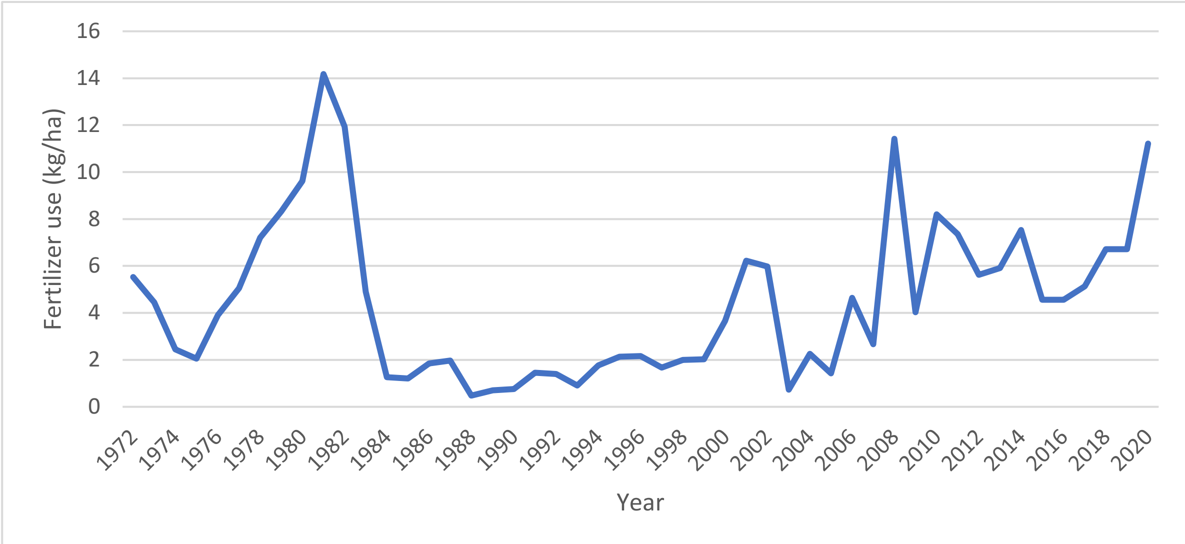

Figure 1: Fertilizer Consumption in Mozambique (Kg/ha)
Source: World Development Indicators (WDI)

Currently, the most commonly used fertilizer is urea (58%) followed by NPK (22.5%) and ammonium nitrate (8.24%) and the least used is potassium nitrate (<0.001%) (FAOSTAT). According to AGRA (2018), the most commonly used fertilizer in 2016 was NPK (12:24:12) including similar products and specialty blends (66%), followed by urea (23%) and the least used was sulphate of ammonia (1%).

The NPK fertilizer (12:24:12) and urea (46%) are mainly used in food crops such as maize, rice and vegetables while in cash crops such as tobacco the main fertilizers are urea (46% N), NPK (10:24:20) and CAN (26% N). In sugarcane the main fertilizers are Urea (46% N), NPK, CAN (26% N), DAP, MOP and Ammonium Sulphate. About 96% of the imported fertilizers are directly for estates or concessions that produce Tobacco, Sugar and Soybean and as mentioned by Zavale et. al. (2014). The remaining 4% of imported fertiliser mainly goes to smallholder farmers.

In 2012/13 as well as 2013/14 agriculture seasons, maize had the highest usage of fertilizers with more than 1,500 MT (metric tons) while rice had the lowest with less than 500 MT. In 2017 approximately 1,000 MT of fertilizers were used in the production of maize, rice and other crops. For the main cash crops (cotton, sugarcane and tobacco), sugar had the highest fertilizer use in 2012/13 and 2013/14 seasons with more than 60,000.00 MT while tobacco was below 60,000.00 MT. However, in 2017 tobacco had the highest fertilizer use compared to sugar.

1.3 Programs and instruments encourage fertilizer use

Similar to many ASoS countries, Mozambique does not have a law to regulate the usage, handling and management of fertilizers. However, with the signed commitments with Abuja, Maputo and Dar es Salaam declarations as well as CAADP (Maputo declaration). In 2011, the Ministry of Agriculture and Rural Development initiated the development of two regulatory frameworks to improve fertilizer usage: 1) the fertilizer national strategy; and 2) the regulation for fertilizer management.

The fertilizer strategy aims to improve the quality and quantity of fertilizers by promoting its demand and supply through provision of incentives for manufacturers and producers. The incentives include training of wholesalers, retailers, agro-dealers and producers, assure free trade for fertilizers, provide subsidies for producers, build laboratories for testing and others.

The regulation for fertilizer management aims to assure fertilizer quality considering the public, animal and environment health. The framework regulates the registration, production, exports, imports, use, transportation, sale, distribution, management and handling of fertilizers.

Before the strategy and regulation were established, the PEDSA (Agriculture Development Strategic Plan) formulated in 2010 and revised in 2011 and supported by the Investment Plan for the Agricultural Sector (PNISA) constituted the main policy and regulatory framework.

Despite the Government's efforts to develop the frameworks, it is important to note that the regulatory frameworks are outdated and due to some challenges associated with legal enforcement and approvals (Mutondo et al., 2021), the recent documents are still not approved.

There are several programs and projects to improve the knowledge, access, affordability and quality of fertilizers in Mozambique including voucher programmes, farmer field schools, input trade fairs and projects. For example, in 2015 FAO launched the first e-voucher program in Mozambique to improve access to improved technologies coupled with farmer field schools for the beneficiaries in Manica, Nampula, Sofala and Zambezia provinces. AFAP also has several projects and programs such as Strengthening Fertilizer Supply Systems through Agribusiness Partnerships in Selected African Countries to strengthen fertilizer supply and delivery of high-quality fertilizers; PRODAZAV to improve input delivery in Zambezi Valley; Beira Corridor Inputs Partnership Project to assure producers have access to quality fertilizers, improved seeds and chemicals and others.

2 Results of the Systematic Review

2.1 Fertilizer Use and Profitability

From the 21 studies gathered, the average nitrogen applied was 60 kg/ha, with a higher rate for Soybean (92 kg/ha) followed by Rice (83.3 kg/ha) and the lower rate was for Maize (50.8 kg/ha). Overall, most crops had, on average, positive yield response except for cowpea with a negative response (table 1 below). Additionally, maize (30.2) and rice (17.3) had a higher response for less nitrogen applied while soybean (3.4) and cowpea (-1.25) had lower response to more nitrogen applied.
Looking at the study location, mainly for maize, the yield response was higher (more than 30 kg of yield for each kg of nitrogen) on experimentation stations compared to on farm experiments (less than 20 kg of yield for each kg of nitrogen).

Table 1: Yield Response vs Study Location

Crop	Location	
	Experiment Station	**On-farm**
Soybean	3.45	-
Wheat	13.25	-
Cassava	10.9	-
Cowpea	-1.25	-
Maize	31.29	15.95
Rice	17.3	-

Source: systematic literature review data, Mozambique

A closer look at the crop yield response in relation to soil texture reveals that maize had higher response on a clay soil, while negative responses were observed in fine sand, sandy clay loam and sandy loam soils. Cassava, Rice, Soybean and Wheat had positive responses. For wheat a higher response was noticed in clay loam compared to a clay soil; for soybean a higher response was for a clay soil; and rice had a higher response in a sandy soil compared to a loam sandy soil.

Table 2: Crop Yield Response by Soil Texture

Soil Texture	Crop					
	Cassava	**Cowpea**	**Maize**	**Rice**	**Soybean**	**Wheat**
Arenosol	-	-	-	-	2.1	-
Clay	-	-	100.97	-	-	8.4

Clay Loam	-	-	-	-	-	18.1
Fine Sand	-	-1.5	-2.25	-	-	-
Haplic Lixisols	-	-	20.2	-	-	-
Inceptisols	10.9	-	-	-	-	-
Lixisols	-	-	-	-	5.5	-
Loam Sand Arenosols	-	-	3.98	-	-	-
Loam Sandy	-	-	16.7	16.8	-	-
Sandy	-	-	19.7	20.4	-	-
Sandy Clay Loam	-	-1.25	-11	-	-	-
Sandy Loam	-	-1	-8	-	-	-
Silty Clay	-	-	25.5	-	-	-

Source: systematic literature review data, Mozambique

Even though there is no information on yield responses for all crops in different soil pH, it is notable that maize recorded higher yield response to fertiliser in neutral soils compared with alkaline or acidic soils. A similar observation is made for wheat yield response.

Table 3: Crop Yield Response (kg/kg N) by soil pH

Crop	pH		
	Acid	Alkaline	Neutral
Cassava	10.9		
Cowpea	-1		-1.4
Maize	20.5	114	33.9
Rice			18.6
Soybean		3.5	
Wheat	8.4		18.1

Source: systematic literature review data, Mozambique

Looking at fertilizer profitability, the crops had on average VCRs (Value Cost Ratios) higher than 2 which implies that fertilizer use is profitable. Even though rice had a lower yield response compared to maize, the fertilizer applied had greater returns compared to the other crops (12.1). On the other hand, maize had higher yield response with lower returns to fertilizer applied. This may be explained by the fact that maize prices are much lower than rice. Additionally, for maize the average profitability was higher on experimentation stations (7.9) compared to on-farm experiments (5.3).

Table 4: Value Cost Ratio vs Study Location

Crop	Location	
	Exp Station	On-farm
Cassava	4.9	-
Maize	7.9	5.3
Rice	12.1	-
Wheat	6.2	-

Source: systematic literature review data, Mozambique

Considering the soil characteristics, fertilizer use for maize was viable on clay soils (VCR > 2) while it was not viable on sandy soils (VCR < 2). Similarly, for wheat clay soils are more profitable for fertilizer use. On the other hand, rice is profitable in sandy soils (VCR > 2) for experiments on station. While on farm experiments, fertilizer use was profitable in both soil textures for maize.

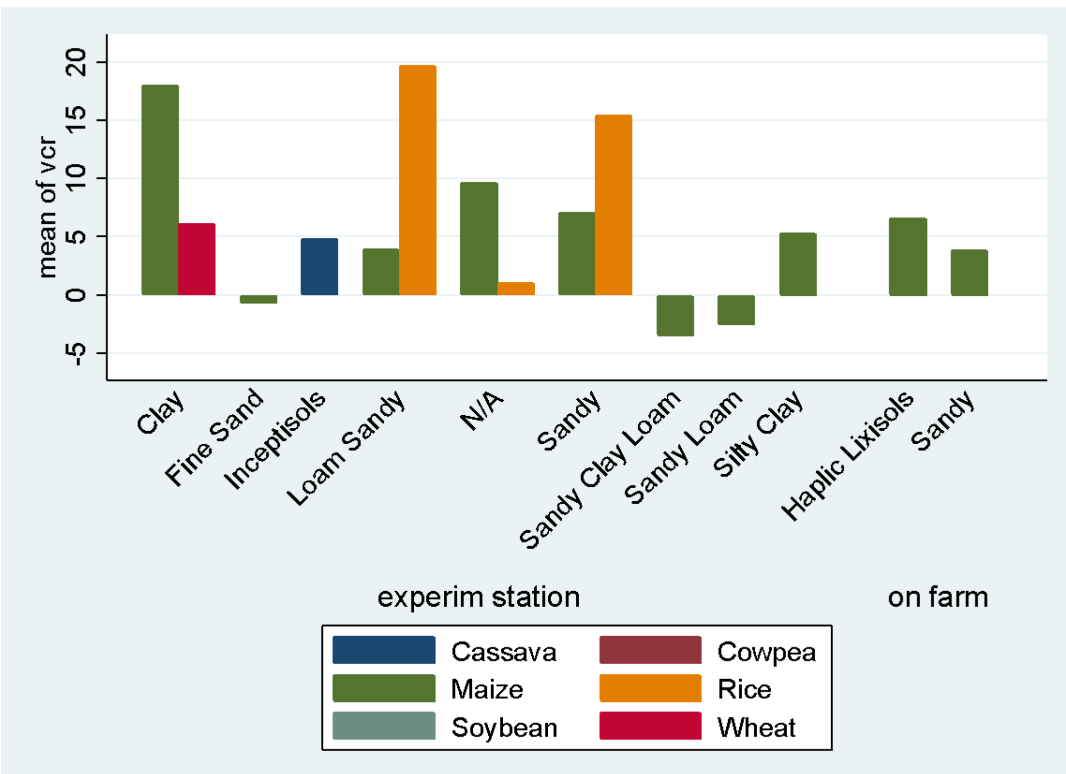

Figure 4: Value Cost Ratio vs Soil Texture
Source: systematic literature review data, Mozambique

Based on soil pH, fertilizer use was profitable in all categories with higher VCR for alkaline soils for Maize and neutral soils for Rice. Additionally, on station experiments in acid soils had higher VCR compared to acid soils on farm for Maize.

Table 5: Value Cost Ratio Vs Soil pH

Crop	Experimentation Station			On-farm
	Acid	Alkaline	Neutral	Acid
Cassava	4.88			
Maize	7.1	23.7	5.3	3.9
Rice			17.6	
Wheat	6.2			

Source: systematic literature review data, Mozambique

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Appendix 4: Namibia Country Analysis

1. Country Context

1.1 The Agricultural Sector in Namibia

Most of the Namibian population directly or indirectly relies on agriculture, making agriculture one of the country's most significant economic sector. Over the past five years, agriculture contributed little more than 4% of the nation's GDP (excluding fishing). Two-thirds of agricultural output value is derived from livestock farming, with the remaining one-third coming from crop farming and forestry. The Namibia Statistics Agency reports that livestock's contribution to nominal GDP increased from 3 percent in 2019 to 3.5 percent in 2020. The Namibian government classifies meat processing as manufacturing, which further adds 0.2% to 0.4% to GDP.

One of Namibia's most pressing problems is food insecurity. Recent extended and recurrent droughts have decreased yields and productivity, worsening an already water-limiting farming environment. An estimated 578,480 people were impacted by food shortages, with a severe drop in the availability of food and water experienced in recent years. Almost 16% of the population is food insecure and in need of food assistance. Namibia has a five-year trade deficit in agriculture and is a net importer of food. Agriculture is the industry that is most severely impacted by structural water deficits (World Bank, 2021).

Despite Namibia's arid and semi-arid climatic conditions, Namibia can produce a wide range of crops, including grains, fruits, and horticultural products. Smallholder farmers predominantly produce most crops for household consumption and large-scale commercial farmers produce mainly for the retail market. Production inputs such as fertilisers, seeds and pesticides are sourced from commercial retail outlets such as Agra, AgriMark, Agrigrow and other retail outlets within Namibia.

Horticulture includes fresh agricultural products such dates, grapes, watermelons, span speck, citrus, potatoes, carrots, butternuts, beans, and groundnuts. Crops, vegetables, fruits, and forestry products have seen an increase in export value in recent years. The Green Scheme and the National Horticulture Development Initiative (NHDI), two programs of the Ministry of Agriculture, Water, and Land Reform (MAWLR), are intended to boost regional agricultural output. The Green Scheme promotes the growth of irrigated agricultural production, with a goal of achieving 27,000 hectares along Namibia's perennial rivers. Less than 9,000 hectares are covered by irrigation, and several of the Green Scheme's projects are struggling financially, therefore the program has fallen short of many of its initial objectives. The government hopes to boost regional production of fruit, vegetables, animal feed, and other horticulture items through the NHDI. An import substitution program known as the Namibian Market Share Promotion is one component of the NHDI (NMSP). According to the NMSP, fresh horticultural produce importers must get a minimum proportion of their supplies from Namibian farmers to be eligible for an import permit. The initial NMSP threshold was established in 2005 at 5%; since then, it has climbed and now stands at 47%. The NHDI (and other programs), according to the Namibian Agronomic Board, have increased local horticultural production by 52% since 2005. The government established the NHDI to provide additional support.

Rainfed crop production according to data from the Namibian Agronomic Board maize, pear millet (mahangu), wheat, and sunflower is also viable. Agronomic Board, the value of the country's horticulture industry climbed from N$55 (U$4.13) million in the third quarter of 2013 to N$87 (U$87) million in the third quarter of 2014. Increased horticultural produce production suggests that there are still enormous prospects in the industry. Dates and grapes are among the top agricultural exports, according to the High Commission of the Republic. Namibia produces on average 137,000 tonnes of cereals per annum consisting of maize 65,000 tonnes, millet 60 tonnes, wheat 8,000 tonnes and other cereals 4,000 tonnes (FAO, 2022). Namibia imports more than 260, 000 tonnes of grains every year to supplement local production.

The government (via the Agronomic Board) has established policies to control the trade of white maize, wheat, mahangu (pearl millet), and products derived from these three grains to protect local farmers, promote increased production of grain products, and meet Namibia's food security goals. Only with permissions from the Agronomic Board and the Ministry of Agriculture, Water, and Land Reform can controlled grain crops be imported or exported. Specific limits apply to each regulated grain; however, these restrictions do not include price regulations. The usage and importation of bioengineered (genetically modified) crops are regulated under the Biosafety Act of 2006 (International Trade Administration, U.S. Department of Commerce, 2021)

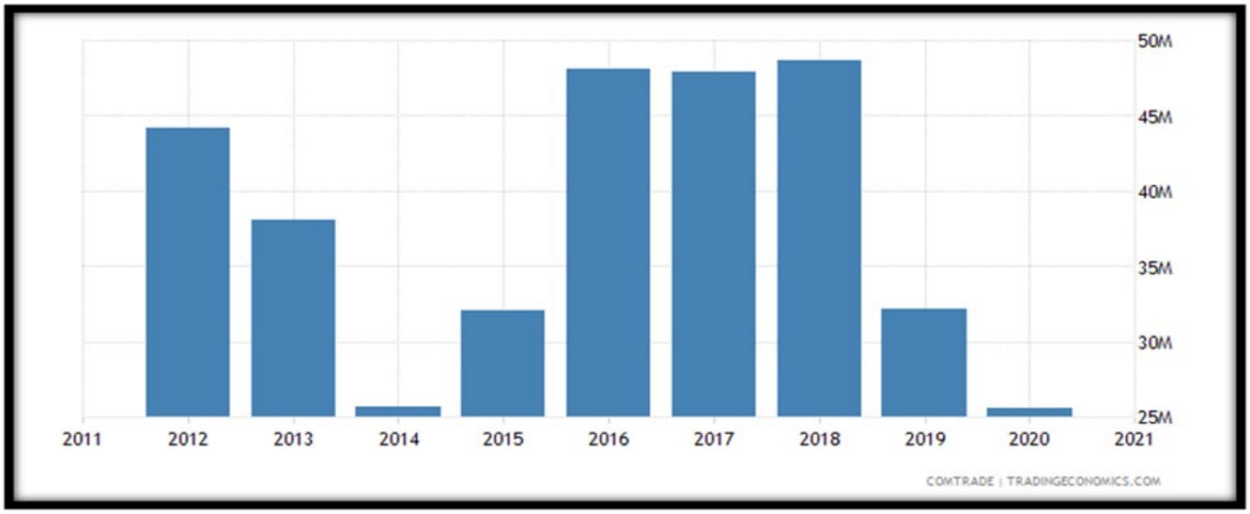

Figure 2: Fertiliser imports by year

Source: COMTRADE Statistics, 2011-2021

1.2 Namibia's progress in terms of fertiliser use

1.2.1 Trends in Fertiliser use

According to the COMTRADE database on international trade maintained by the United Nations, Namibia's imports of fertilisers totalled US$25.61 million in 2020 (Figure 2). The data, historical chart, and statistics for Namibia Imports of Fertilisers were last updated in August of 2022 (COMTRADE Statistics, 2022). Between 2014 and 2018, the lowest recorded fertiliser use was 6.10 kg/ha in 2014, while the highest fertiliser use intensity of 27.30 kg/ha was recorded in 2018. Fertiliser use intensity in Namibia was reported at 3.7 kg/ha in 2020, according to the World Bank collection of development indicators, compiled from officially recognized sources (Trade Economics, 2022).

In 2020, NPK fertilisers import for Namibia was 69 MT. The amount of NPK fertilisers imported have fluctuated substantially in recent years, with a general increasing trend between 1999 and 2018. Namibia is a net importer of fertiliser from South Africa for domestic use in in crop production. Namibia's fertiliser consumption per hectare in 2018 was 27.3 kg. According to Namibia Statistics Agency (2018), 3.8% of commercial and resettled farmers use organic fertiliser compared to 3.7% that uses inorganic fertiliser. Communal farmers rely on government fertiliser subsidies and manly use manure as source of fertiliser.

In communal areas, the predominant subsistence smallholder farmers have limited access inputs. Furthermore, smallholder farmers who have the means to buy fertiliser face transportation difficulties because they cannot afford to own or hire a vehicle, which is compounded by poor road infrastructure. Fertiliser is available to commercial farmers in Namibia's major cities. Fertiliser transportation is often expensive, due to a poor rail transport network.

Namibia has a distinct wet to dry areas gradient that in general transitions from North-Northeast to South-Southwest (wet-to-dry respectively), that is amplified by the annual rainfall pattern differences. The major crops in Namibia are maize, sorghum, and millet. Table 1 shows the organic and inorganic fertilisers used for specific crops produced in Namibia.

Table 1: Crops with Most Fertiliser Use

Region	Fertiliser Used	Crop
Wet	Kraal manure Urea	Maize
Wet	Kraal manure Superphosphate LAN	Sorghum
Wet	Kraal manure LAN	Millet
Wet	Superphosphate, MAP, LAN	Ground nuts
Wet	MAP +Zn No N-based fertilisers	Cowpeas

Source: systematic literature review data, Namibia

2. Fertiliser constraints and opportunities for improving management

Empirical research on fertiliser uses and crop response to nitrogen is very limited in Namibia. Most research has concentrated on crop breeding. There are therefore major gaps regarding the understanding of fertiliser use and crop response in the country. Investment in fertiliser response trials in major crop production zones for maize, sorghum, millet, groundnuts, and cowpeas is needed. Universities should take the lead in this effort in collaboration with ANAPRI, AFAP, IFDC and ATPI.

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Appendix 5: Nigeria Country Analysis

1 Country Context

1.1 The agricultural sector in Nigeria

According to the National Bureau of Statistics (2021), agriculture remains the largest sector in Nigeria contributing an average of about 24% to the nation's GDP from 2013 to 2021. This sector is broadly divided into four sub-sectors, namely; crop production, fishing, livestock and forestry with crop production being the largest segment accounting for about 87.6% of the sector's total output. In addition, the Nigerian agricultural sector has remained the highest employer, accounting for about 35% of the country's labour force (Statista, 2022).

1.2 Nigeria's progress in terms of fertilizer use

1.2.1 Trends in Fertilizer use

Nigeria uses both locally produced and imported fertiliser, predominantly urea and NPK. Fertiliser consumption reached its peak in 2021 (1,859,305 MT). This is associated with the government's Presidential Fertiliser Initiative (PFI, 2021) that focused on getting raw materials to processors instead of the importation of ready-made fertiliser. When disaggregated by fertiliser type, urea was the most consumed fertiliser type, which is probably associated to the production of urea in Nigeria (Figure 1).

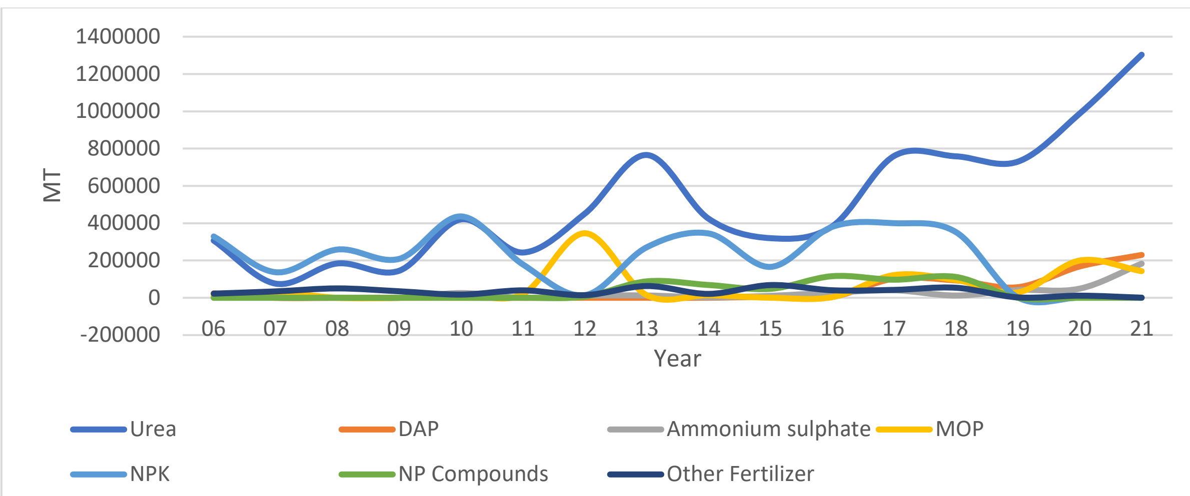

Figure 1: Fertiliser consumption in Nigeria (2006-2021)
Source: Africa Fertilizer (2022) and FAOSTAT (2022)[22]

Fertiliser consumption varies by crop due to differences in nutrient requirements. Liverpool-Tasie, et al., (2015) observed that fertiliser use was prevalent among maize farmers. According to the fertiliser producers and suppliers' association of Nigeria and federal fertiliser department, data on fertiliser use by crop is hardly compiled. Most of the sources keep data related with increase in crop productivity and not fertiliser use by crop.

[22] Note that data from 2006 to 2009 was sourced from FAOSTAT while data from 2010 to 2021 was sourced from Africa Fertilizer.

However, a survey compiled by FFD (2014) on fertiliser recommendation (nutrient per hectare) across agroecological zones in Nigeria revealed maize to be the crop with highest fertiliser recommendation.

1.3 Programs and instruments encourage fertilizer use

Since the 1970s, the Nigerian government has tried to stimulate fertiliser demand, grow the commercial fertiliser sector and lower fertiliser prices using various instruments. The strategies adopted to stimulate fertiliser use include subsidies, use of extension agents to promote soil fertility management technologies, and programs to increase farmers' access to credit (Liverpool-Tasie, et al., 2014).

2. Systematic Review Results

2.1 Fertilizer Use and Profitability

Figure 2 shows fertiliser response and profitability for maize. Nitrogen application was highest in studies conducted on researcher managed on-farm sites (137 kg/ha), followed by those on experimental station; conducted mostly on University field research stations (99 kg/ha) and farmer managed plots (based on household surveys). Maize crop response to a unit of nitrogen fertiliser applied shows that maize yield on experimental station (26 kg/kg on N) and researcher managed (23 kg/kg of N) plots were better than farmer managed plots (4 kg/Kg of N).

It is apparent that profitability of maize response to nitrogen application (VCR) was better on researcher managed fields (16) and experimental station (8.65) compared with farmer managed plots (0.36). Value Cost Ratio (VCR) greater than 2 show good profitability from fertiliser use (Liverpool-Tasie et al., 2014; Liverpool-Tasie et al., 2015). The results imply that fertiliser use in maize systems is imperative for desired yields and profitability in Nigeria. However, when not properly managed, fertiliser application will not viably increase crop yields.

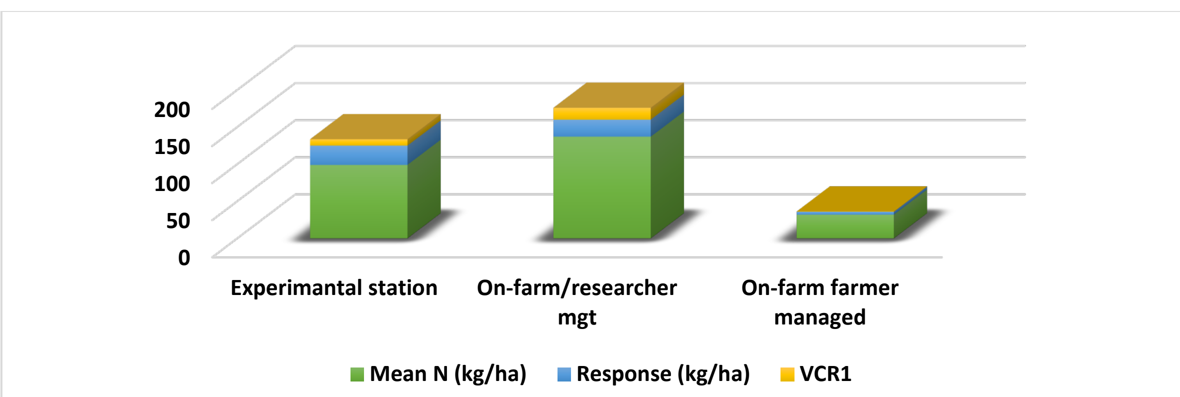

Figure 2: Yield response to fertiliser and corresponding profitability for maize
Source: systematic literature review data, Nigeria

Farmers in Nigeria use less than the required amount of fertiliser, mostly due to constraints of affordability and accessibility (Uduji et al., 2019; Mgbenka et al., 2016). Also, the low technical know-how of smallholder farmers as regards to appropriate application of fertiliser is contributory to sub-optimal yields (Liverpool-Tasie et al., 2015; Rapsomanikis, 2015). Additionally, poorly drained and leached soils are characteristic of most agricultural areas in Nigeria (Akinwumiju et al., 2020; Asadu, 2015; Tittonell and Giller, 2013).

2.2 Constraints and Solutions in Literature

Across the studies, it was deduced that increasing fertiliser use without proper management potentially reduces yield and profitability of most crops (Nwokoro et al., 2022). This may be due to nutrient management gaps, poor nutrient application techniques, use efficiency, poor soils as well as natural and human factors such as climate and low fertiliser adoption (Donkor et al., 2019). It is imperative that concerted efforts are made to enact feasible policies on effective use of fertilisers by stakeholders across the fertiliser and agricultural value chain.

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Appendix 6: Senegal Country Analysis

1. Country Context

1.1 The agricultural sector in Senegal

Agriculture is an essential sector of the Senegalese economy, both as a supplier of food and non-food materials. It also acts as a market for upstream (e.g., fertilizer production) and downstream (processing) industries. It employs 60% of the population and contributed only 15.3% of GDP in 2021 (World Bank, 2022). It is dominated by family farms that combine cash crops and subsistence food crops, with extensive rearing of livestock. At the same time, modern farms are being developed, with the help of local and foreign investments in high value-added products such as horticulture (fruits and vegetables) mainly for export, and in rice, onion and potato sectors for the domestic market.

Agriculture occupies a prominent place in the ESP, which has the thrust on: (i) strengthening food security and rebalancing a trade balance that has deteriorated due to food imports; (ii) developing competitive, high value-added integrated sectors; and (iii) preserving socio-economic balance and boosting the rural economy. These programs are being implemented with the objective of increasing the area planted and increasing the consumption of quality inputs subsidized by the state and accessible to producers.

1.2 Senegal's progress in terms of fertilizer use

1.2.1 Trends in Fertilizer use

Although fertilizers are crucial, their use remains below the 50 kg/ha nutrient target set in the 2006 Abuja Declaration. In Senegal, fertiliser use is used by less than half of cereal producers (about 37%). Fertilizer application rates are very low for staple crops, ranging between 15 and 22 kg per hectare. NPK fertilisers are the most commonly used fertilisers, followed by DAP and urea.

Table 1 shows the share of cereals producers using chemical fertilizers by region. Overall, this proportion is highest in Dakar, Saint-Louis and in the groundnut basin (Kaolack, Kaffrine, Fatick). This can be explained by a number of factors. Firstly, farmers in Dakar usually have easy access to fertilizers. Secondly, the Groundnut Basin and the region of Saint Louis have been the pioneers of the agricultural intensification, with the cultivation of groundnuts, dry cereals, and rice. This was supported with the help of extension services. Third, the regions of the East, South and South East are areas where the cultivation of maize has rapidly increased.

Table 1: Share of households using chemical fertilizers and level of use by region

Regions	Share of households using fertilizer (%)	Level of use (kg/ha)	
		Average for users	Average for all households
Dakar	79.0	139.7	87.0

Ziguinchor	20.5	87.3	16.5
Diourbel	19.1	25.5	3.5
Saint-Louis	78.1	295.1	175.7
Tambacounda	34.9	49.8	18.8
Kaolack	65.0	31.3	17.5
Thies	20.2	32.3	6.2
Louga	13.0	52.0	5.9
Fatick	35.9	32.6	10.3
Kolda	48.5	40.5	13.3
Matam	5.4	201.6	3.3
Kaffrine	46.5	29.8	10.2
Kédougou	44.3	53.3	16.6
Sedhiou	59.7	31.2	15.5
National	**37.1**	**46.6**	**14.7**

Source: Authors, using PAPA data collected in 2017.
Notes: Proportions are weighted by the sampling weights

In Senegal, NPK, DAP and urea are the top three used fertilizers mainly applied to cash crops. The main cultivated crops, in order of area cultivated are groundnut (49%), millet (26%) and rice (9%) (IFA, 2019). They are followed by cowpea, maize, and sorghum. Figure 1 shows the quantities of N, P_2O_5 and K_20, by crop. Cereals alone consume more than 50% of the total amount of chemical fertilizer. The crops using the most fertilizers are rice, groundnut, millet, and maize.

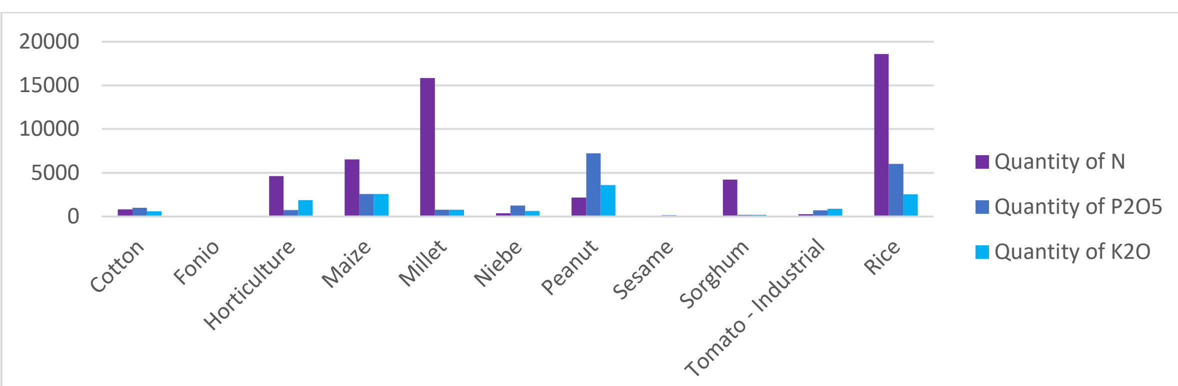

Figure 1: Nutrients applied (Tons) in 2019
Source: Authors, using IFA data published in 2022

Cereals accounted for 85% of national nitrogen fertilizer consumption in 2019 with rice, receiving the largest amount of nitrogen fertilizers, representing 35% of national use. Rice is followed by millet with 30% and maize with 12% Groundnut, has a small share in total consumption (4%). Vegetables and fruits contributed modestly (9%) to national nitrogen fertilizer consumption (IFA, 2022).

2 Results of the Systematic Review

2.1 Fertilizer Use and Profitability

Literature on fertilizers yield response is very scarce in Senegal. Our review is based on ten papers covering four crops: rice, millet, maize, and sorghum. Three studies are on-farm experiment while seven are on-station (Kanfany et al., 2014; (Djaman et al., 2016; Djaman et al., 2018; Sarr et al., 2013; Tounkara et al., 2020; Faye et al., 2020; Komla et al., 2016; Faye et al., 2021; Badiane et al., 2012).

Figure 3 shows that the use of fertilizers on crops increases yields. Rice has the highest response rate while maize has the lowest. For millet, the fertilizer NKP 15.15.15 is preferably used while urea (46.0.0) is preferred for rice production. When it comes to the comparison between on station and farm studies, only pearl millet has both and results show a higher response rate on station. The high VCRs seems to suggest that fertiliser use for all the crops is profitable in Senegal, with rice being the most profitable and maize the least profitable crop.

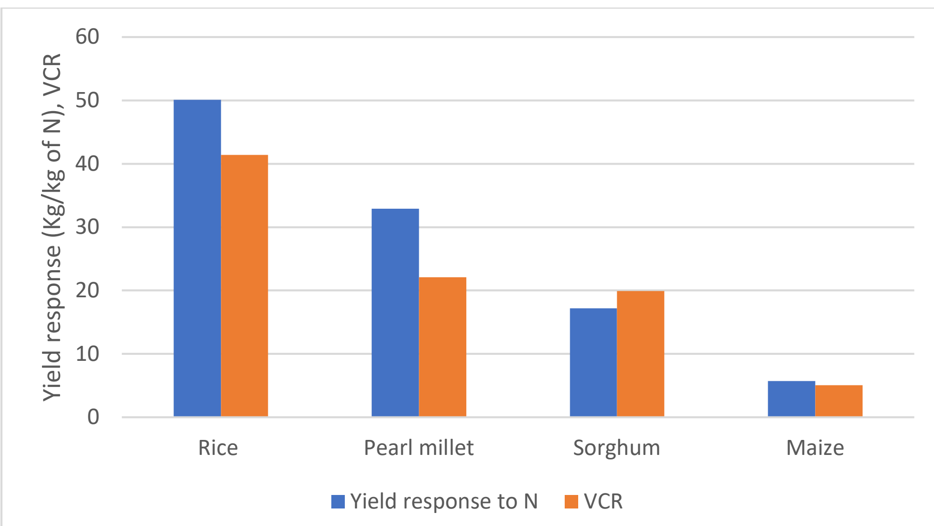

Figure 3: Crop yield response rate per crop and VCRs, Senegal
Source: systematic literature review data, Senegal

2.2 Constraints and solutions in literature

The main constraints to fertilizer use and profitability identified are the cost of fertilizers and soil degradation. We can add to these constraints the lack of quality control of imported fertilizers and the consequences of climate change, which call for an update of current recommended mineral fertilizer doses. First, regarding the price, the government subsidizes inputs (seeds and fertilizers) but retail prices are still high for average farmers because the supply is far from sufficient. Second, soil erosion is considered one of the main causes of stagnation or decline in agricultural productivity and the provision of new ecosystem services. Other related issues that contribute to reduced agricultural land productivity include organic matter depletion, nutrient depletion, and loss of soil biodiversity. Soil fertility depletion and nutrient imbalances in small-scale farms are caused by extraction of nutrients from the soil, which outweighs their replacement. Major factors that contribute to reduced soil fertility are complete removal of crops from cultivated fields, unbalanced fertilization as well as little or no use of fertilizers.

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Appendix 7: Tanzania Country Analysis

1. Country Context

1.1 The agricultural sector in Tanzania

Agriculture sector is the mainstay of Tanzania's economy as it is the main source of food, employment, raw materials for industries and foreign exchange earnings. The contribution of agriculture to the national Gross Domestic Product (GDP) was estimated at 26.9% as at 2020 (Statista, 2022). The sector employs 75% of the population (Shee et al., 2020), dominated by smallholder farmers who mainly depend on rain-fed agriculture (Michelson et al., 2021). According to the 2016/17 Annual Agricultural Sample Survey, the country has a total of 44.5 Million hectares of arable land and 11 million hectares under cultivation whereby 2.7 Million hectares are under permanent cultivation, 8 million hectares are farmed seasonally during long rains, 4.3 Million hectares during short rains and 53% of cropping land is double cropped (AFAP, 2019). Tanzania produces various types of crops mainly categorized into cereal, cash, oil seed, pulses and roots crops (NSCA, 2021). Notably, maize is the most produced food crop in Tanzania accounting for 62.6% of the cropland, followed by rice (21.6%), pulses (15.1%), and wheat (0.7%).

Most of the croplands in Tanzania have low fertility with nitrogen being the most limited nutrient (Marandu et al., 2014). Phosphorus, potassium and sulphur deficiencies are widespread, with occasional occurrence of copper (Cu), zinc (Zn) and manganese (Mn) deficiencies (Senkoro et al., 2017). Fertilizer use in Tanzania is still extremely low and remains below the recommended rates and mainly applied on maize and rice (Michelson et al., 2018; AFAP, 2019). For instance, in 2017, a total of 349,491 MT were used with maize production receiving 56% of the fertilizer, applied at 48 kg/ha, whilst rice received 12% of total fertilizer use at a rate of 38 kg/ha (AFAP, 2019). The current yields of maize and rice are very low, with an average range of 1 t/ha to 1.5 t/ha for maize (Delaune, 2018), 0.5 t/ha to 2 t/ha for upland ecologies and 4.5 t/ha to 6 t/ha for irrigated rice (Mboyerwa et al., 2022).

1.2 Tanzania's progress in terms of fertilizer use

1.2.1 Trends in Fertilizer use

World Bank (2020) reported that the average use of fertilizer in Tanzania was about 15.9 kg/ha. This is much lower than the target set by the African Union in the Abuja declaration 50 kg/ha and the global average of 135 kg/ha (FAOSTAT, 2018). Furthermore, according to Tanzania National Sample Census of Agriculture (NSCA), (2021), only 2.8 million hectares, equivalent to 20.1% of the total cultivated area, was applied with fertilizers in the 2019/20 agricultural year. The primary fertilizers used in the country include Urea, Diammonium Phosphate (DAP), Calcium Ammonium Nitrate (CAN), and Nitrogen-

Phosphorous-Potassium fertilizer (NPK) (Michelson et al., 2018). More than 90% of all fertilizers used in the country are imported and the price is high. Generally, fertilizer use in Tanzania has increased steadily from 1961 to 2018, with substantial fluctuations in recent years (Figure 1).

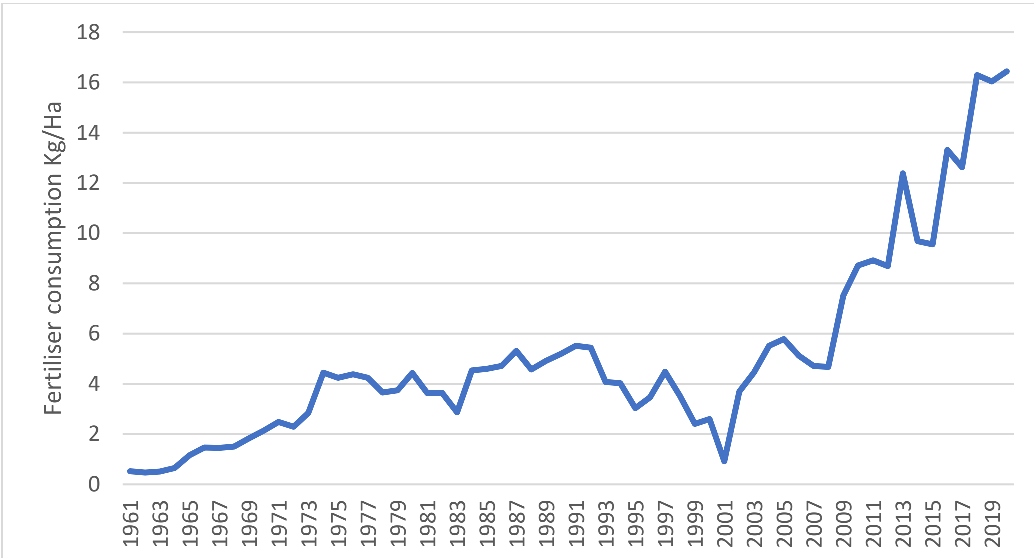

Figure 1: Trend of fertilizer use in Tanzania, (fertiliser application rate kg/ha) from 1961 to 2018
Source: FAOSTAT, 2018

The reviewed studies showed that Urea, DAP, NPK, Minjingu Mazao (NP_2O_5CaO), Ammonium Sulphate (SA), and Triple Superphosphate (TSP) are the most commonly used fertilizers used in Tanzania. Urea, DAP and constitute the largest share of the fertilizers used (Mather, *et al.,* 2016; Tegemeo Institute, 2017; Kihara, *et al.,* 2020; Kiwia, *et al.,* 2022). Furthermore, Figure 2, affirms that urea was most commonly used fertiliser across the country among farmers, particularly on major crops which are maize and rice followed by NPK and DAP.

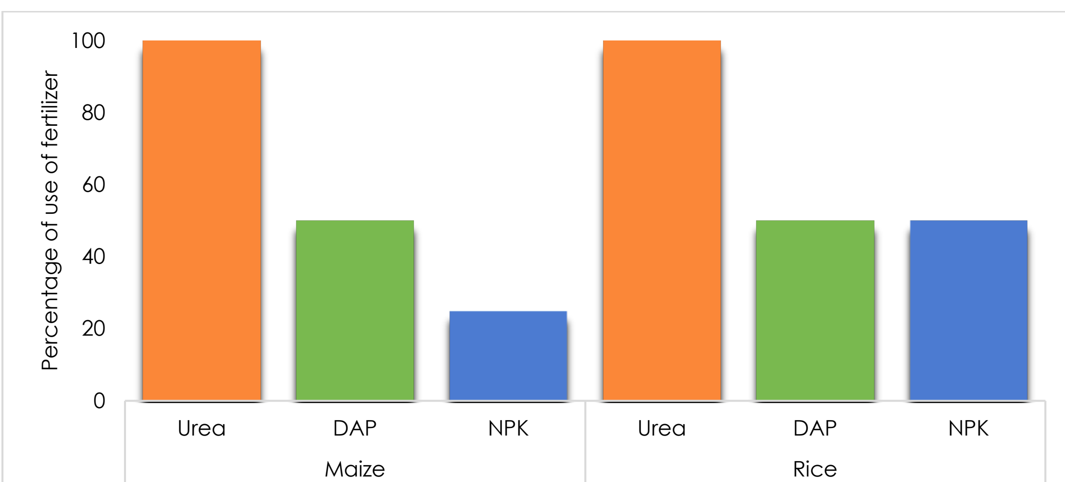

Figure 2: Main fertilizer used in Tanzania

Source: Systematic Literature Review: Mourice *et al.,* 2014; Delaune, 2018; Komarek, *et al.,* 2019; Rurinda *et al.,* 2020; Kadigi, *et al.,* 2020; Kihara *et al.,* 2020; Senthilkumar *et al*., 2021; Mboyerwa, *et al.,* 2022; Aseru *et al.,* 2022; Kiwia *et al.,* 2022.

1.3 Programs and instruments encourage fertilizer use

A number of initiatives have been taken by the Government of Tanzania to increase the use of fertiliser in the country. The Government regularly provides subsidies on fertilizer using various mechanisms. In 2008, the government introduced the National Agricultural Input Voucher Scheme (NAIVS) for maize and rice farmers covering about half of all the districts in the country. The programme focused on the provision of fertilizer and seed subsidies to poor farmers cultivating a maximum of one hectare of maize or rice (URT 2014). The programme had positive results but failed in the long run due to inefficient designing and implementation.

The government of Tanzania introduced fertilizer the bulk procurement system in 2017 in order to lower retail prices and increase access to fertiliser use. However, the system failed in 2021 due to unexpected poor performance caused by price volatility. Recently, the government of Tanzania has launched a new fertilizer subsidy programme which subsidize up to USD 22.3 per 50 kg/bag of fertilizer.

2 Results of the Systematic Review

2.1 Fertilizer Use and Profitability

The studies reviewed show notable differences in the rate of fertilizer application between farmer managed trials and researcher managed on-farm trials and on-station trials. For farmer managed farms, on average the amount of Nitrogen applied on maize ranged from 35.2kg/ha to 59kg/ha (Mather *et al*., 2016 and Palmas *et al.,* 2020). For farmer managed and researcher-managed on-farms trials, the amount of N applied ranged from 40 kg/ha to 140 kg/ha for maize and 80 kg/ha to 125 kg/ha for rice (Mourice *et al.,* 2014, Delaune, 2018, Komarek *et al.,* 2019; Rurinda *et al.,* 2020; Kadigi *et al.,* 2020; Kihara *et al.,* 2020; Senthilkumar *et al*., 2021; Mboyerwa *et al.,* 2022; Aseru *et al.* 2022; Kiwia *et al.,* 2022).

The review established that the average maize yield response to nitrogen ranged from 13 kg/ha to 48.57 kg/ha (Delaune, 2018 and Rurinda, *et al.,* 2020) while the average yield response to nitrogen on rice ranged from 10 kg/ha to 33 kg/ha for all the reviewed management practices (Senthilkumar, *et al*., 2021; Aseru, *et al.,* 2022 and Mboyerwa, *et al.,* 2022). However, the results in Figure 3 show that the yield response to N applied was variable depending on the farm management practise used. Figure 3 also shows that maize yield response to N was higher on researcher-managed on-station trial (43.75 kg/ha), followed by researcher managed (35.06 kg/ha) and farmer managed (31.75 kg/ha) on-farm trials (Mather, *et al*. 2016; Delaune, 2018; Komarek, *et al.* 2019; Palmas, *et* *al.* 2020; Kadigi, *et al.* 2020; Rurinda, *et al.* 2020 and Kiwia, *et al.* 2022). On the other hand, the yield response to N for rice was only reported on researcher-managed on-farm trials and on-station trials, which had a comparable average yield response of 20 kg/ha (Senthilkumar, *et al*. 2021; Aseru, *et al.* 2022 and Mboyerwa, *et al.* 2022). The findings from the review show that yield responses to N were higher under controlled on-station conditions than in farmers' fields (Delaune, 2018; Komarek, *et al.* 2019; Rurinda, *et al.* 2020). Also, the review shows that agronomic responses to fertilizer are often much lower in farmers' fields than on researcher-managed trials, and such responses are substantially variable over geographic space (Palmas, *et al.* 2020).

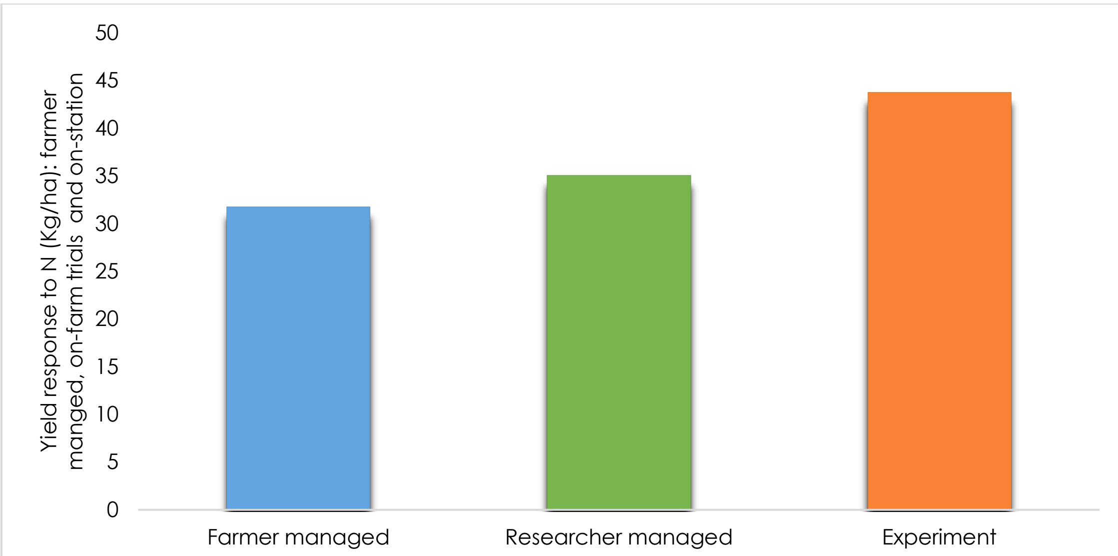

Figure 3: Agronomic Efficiency of Nitrogen (AEN) in Tanzania

Source: Reviewed papers from Mather *et al*., 2016; Delaune, 2018; Komarek *et al.*, 2019; Palmas *et al.,* 2020; Kadigi *et al.,* 2020; Rurinda *et al.,* 2020; Kiwia *et al.,* 2022; Senthilkumar *et al*., 2021; Aseru *et al.,* 2022; Mboyerwa *et al.,* 2022.

2.2 Identified constraints and solutions in literature

A number of constraints with regards to fertiliser use and profitability include:

- High price of fertiliser compared to farmers purchasing power;
- Existence of sub-standard and counterfeit fertilizer in the country (in 2016 it was reported that 40% of fertilizer for sale in the country was counterfeit);
- Lack of site-specific fertilizer recommendations;
- Limited awareness of the benefits of fertilizer amongst many farming communities in the country as historically, fertilizer was not commonly used smallholder farmers;
- Poor coordination by the regulating agencies in the fertilizer industry which causes confusion, e.g., existence of multiple regulatory agencies with the same mandates;

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Appendix 8: Uganda Country Analysis

1. Country Context

1.1 The agricultural sector in Uganda

The importance of agriculture is well reflected in the Uganda vision 2040, dedicated to making a contribution of attaining a middle income status (MAAIF, 2016). However, crop yields and productivity are becoming dismally low due to deteriorating soil fertility (Rware et al., 2020; Diiro et al., 2015), yet there is a skyrocketing demand for food and fertilizer has a huge potential to bridge the gap (Rware et al., 2020). In 2018, 76% of the Ugandan population engaged in agricultural activities, the share of the sector to GDP was 24.2% and employed about 71% of the workforce (Veljanoska, 2021). Agriculture is mainly carried out using rudimentary technologies and about 27% of the country`s population live below the threshold of poverty line (Adong et al., 2019).

Despite 80% of Uganda's land area being arable, only 35% is being put to use (NPA, 2020).There are about 4.2 million subsistence farmers in Uganda and approximately 66% of individuals live in farming households, tilling approximately 91 million hectares of land (Godfrey & Ocen, 2015). Freeman & Qin (2020) highlighted that the major crops grown include; traditional cash crops such as coffee, tea, sugarcane, cocoa, tobacco and the non-traditional crops include; rice, beans, maize, soy and palm. Fertilizer as an agricultural input accounts for approximately 70 percent of all crop inputs except labour, accounting for around 35 percent of total input cost (Wilson & Lewis, 2015).

1.2 Uganda's progress in terms of fertilizer use

1.2.1 Trends in Fertilizer use

The fertilizer application rate in Uganda among the lowest in Africa (Palladium/NUTEC MD, 2018) and the East Africa sub-region, where Kenya stands at 35 kg/ha and Tanzania at 13 kg/ha (Rware et al., 2020) per hectare. In comparison, the average fertilizer use in Uganda was 2.4 kg/ha of nutrients in 2015 (Palladium/NUTEC MD, 2018). A World Bank report highlighted that in 2016, the average fertilizer application rate for Uganda was 1.9 kg/ha, which was considerably lower than the rates for Zambia (89.4 kg/ha), Malawi (21.6 kg/ha) and Mali (44.2 kg/ha) (Veljanoska, 2021).

Reports from Uganda National Panel Surveys from 2009/10 to 2018/19 revealed a steady increase in the proportion of farmers using fertilizer. In 2009, 6.9% of households were using fertilizer, which increased to 10.4% in 2011/12, and 25.4% in 2018/19 (Figure 1).

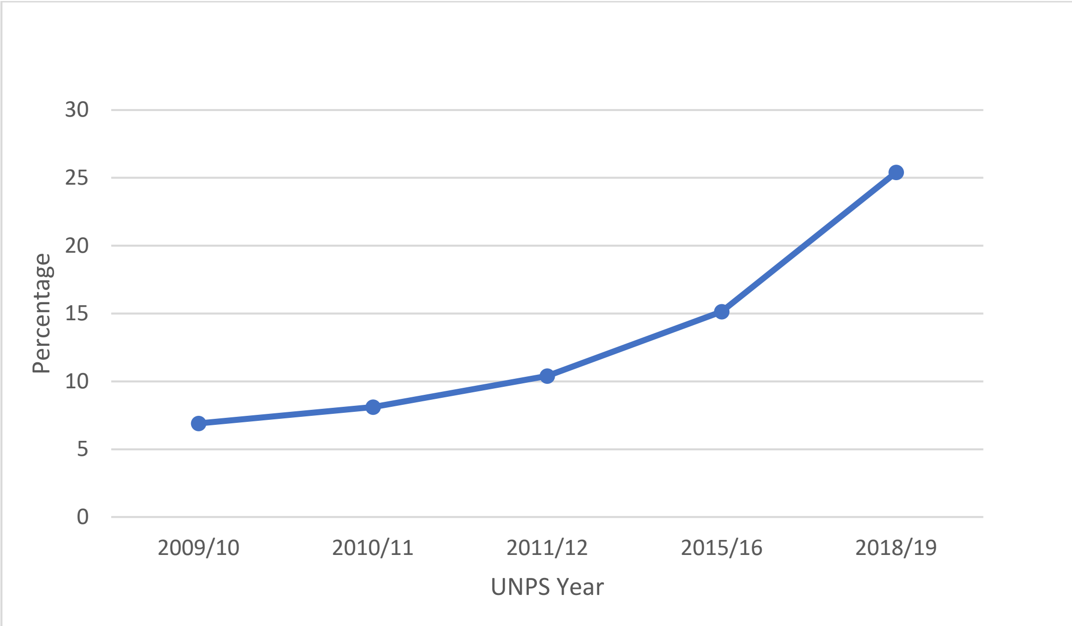

Figure 1: Proportion of farmers using fertiliser in Uganda
Source: UBOS (2020b); UBOS (2016); UBOS (2015); UBOS (2013b); UB4OS (2013a)

Reports by Uganda Bureau of Statistics (UBOS) 2019 and 2018 indicate a disparity in fertilizer use by region. For instance in 2019, households in the jurisdiction of Mukono Zonal Agricultural Research and Development Institute (ZARDI) which is located in the central region had the highest access to fertilizers at 16.3%, followed by Bulindi in mid-western region at 14.4%. Serere in the Eastern region had the least percentage of households that are using fertilizer (0.3%). In 2018, Mbarara ZARDI (western region) recorded the highest percentage of households using fertilizer (64.8%), followed by Kachwekano ZARDI (southwestern region) with 39.6% whereas Ngetta ZARDI had the lowest fertilizer use (2.4%) as shown in Table 1.

Table 1: Percentage of Agricultural households using fertilizers

ARDI/REGION	2019/2020	2018
Abi (Northwestern)	2.2	3.9
Buginyanya (Eastern)	13.2	22.3
Bulindi (Midwestern)	14.4	10.3
Kachwekano(Southwestern)	14.2	39.6
Mukono (Central)	16.3	32.8
Ngetta (Northern)	1.9	2.4
Nabulin (Northeastern)	2.6	3.0
Serere (Eastern)	0.3	20.6

Mbarara (Western)	5.8	64.8
Rwebitaba (Western)	9.9	14.0
Uganda (Overall)	**9.6**	**23.9**

Source: UBOS(2021); UBOS(2020)

1.3 Programs and instruments to encourage fertilizer use

A number of programs have been implemented in Uganda to facilitate fertilizer uptake in Uganda. For instance the International Fertilizer Development Corporation implements activities that include; farmer trainings, technology dissemination, establishment of demonstration plots, outreach projects and creation of public-private partnerships (IFDC, 2020). The Agriculture Cluster Development Programme (ACDP) avails fertilizers at subsidised prices to the farmers through the e-voucher system (ACDP, 2021).

2 Results of The Systematic Review

Figure 2 shows crop yield response and VCRs based on the systematic review for Uganda. According to this data, rice had the highest yield response, followed by millet and maize had the lowest. Correspondingly, VCRs were highest for rice and least for maize.

2.1 Fertilizer Use and Profitability

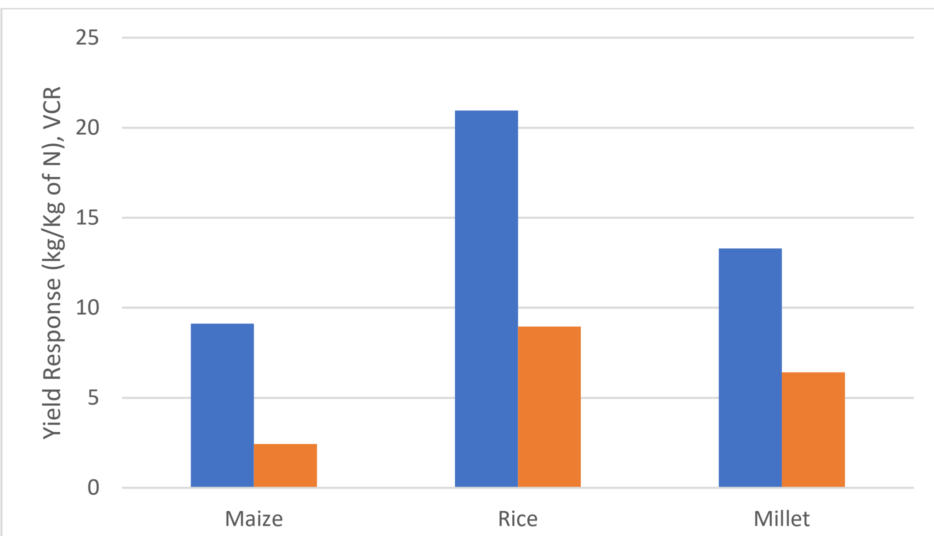

Figure 2: Crop yield response and VCRs, Uganda
Source: Systematic Literature Review data, Uganda

2.2 Identified constraints and solutions in literature

The main challenges for fertilizer use are associated with both quantity and quality issues, including counterfeit products on the market, inconsistences and incorrect labelling, high prices and poor packaging, in labelling, weight and nutrient content. These problems have been found in samples from importers, fertilizer retailers and registered shops from all 4 regions of the country studied by Mbowa (2015).

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Appendix 9: Zambia Country Analysis

1 Country Context

1.1 The agricultural sector in Zambia

Zambia is "maize-centric" in terms of the predominant production and consumption relative to other staples, as well as Government's policy focus. Maize is by far the most significant crop in terms of both production and consumption. Almost 90% of the 1.5 million smallholder farm households in the country produce maize, which makes up 53% of the total cultivated area (Chapoto and Subakanya, 2019; Mofya-Mukuka and Hichaambwa, 2016).

Zambia's agricultural policies are intended to support high productivity, reduce rural poverty and raise incomes of rural households (IFDC, 2013). The country's policies are anchored on two main programmes implemented by the Government namely, Fertilizer Input Support Programme (FISP) and maintenance of the Strategic Grain Reserve via the Food Reserve Agency (FRA). Although fertiliser use has increased especially in the years following the Malabo declaration, concerns around smallholder's low crop productivity have been echoed by several stakeholders.

The low productivity despite the increase in fertiliser use is indicative of low returns from fertiliser use. In Zambia as well as elsewhere on the African continent where policies have been focused on increasing fertliser-use, it has been realised that raising fertiliser-use alone does not automatically raise crop productivity. A mix of good agricultural practices by farmers supported by the right policy framework that also recognizes the need for soil health are needed to truly realise high crop yields (Burke et. al., 2022; Vanlauwe et. al., 2014).

1.2 Zambia's progress in terms of fertilizer use

1.2.1 Trends in Fertilizer use

In Zambia the most commonly used fertilizers are the NPK basal and N top dressing fertilizers. Basal NPK fertilizer is applied at planting or early in the season, while top dressing N fertilizer is applied at the time of growth of the crop (Burke et. al., 2017). Fertilizer consumption data show that there has been an increase in fertilizer use overtime from 4 kg/ha in 1961 to about 80 kg/ha in 2020 (Figure 1).

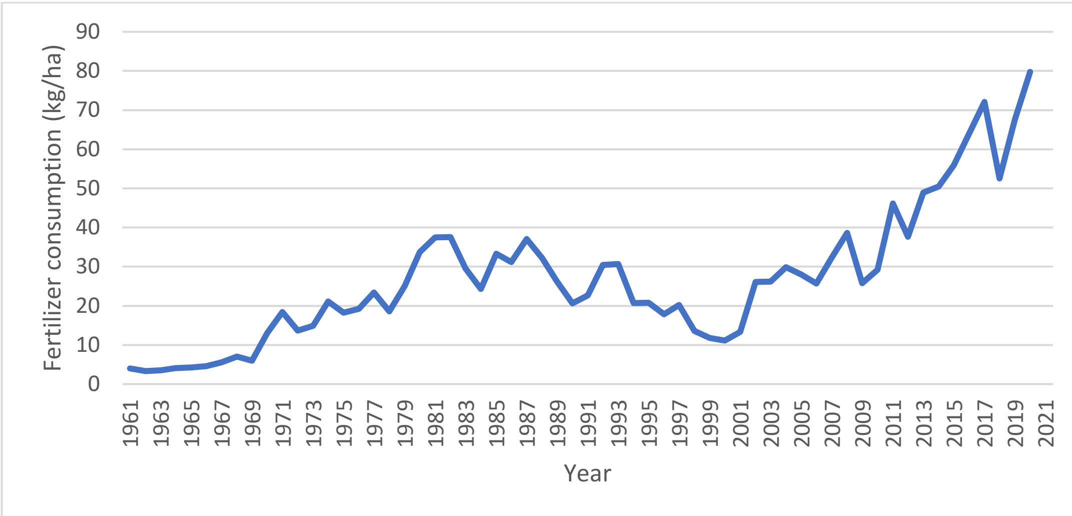


Figure 1: Trends in Fertilizer consumption in Zambia
Source: World Bank, various years

Average application rate of fertilizer did not vary that much between two rounds of the Rural Agricultural Livelihoods Survey (RALS) done in 2015 and 2019. Fertilizer use by smallholder farmers was estimated at 155 kg/ha of basal fertilizer and 153 kg/ha for top dressing during the 2013/2014 agricultural season while that for the 2017/2018 Agricultural season basal and top dressing fertilizer use was estimated at 152 kg/ha and 151 kg/ha respectively (See Chapoto and Zulu, 2015; Chapoto and Subakanya, 2019). At Province level, Figure 1 shows that fertilizer application rates where lowest for Southern Province and highest for Northern Province for both Basal and top dressing fertilizer during the 2017/2018 agricultural season.

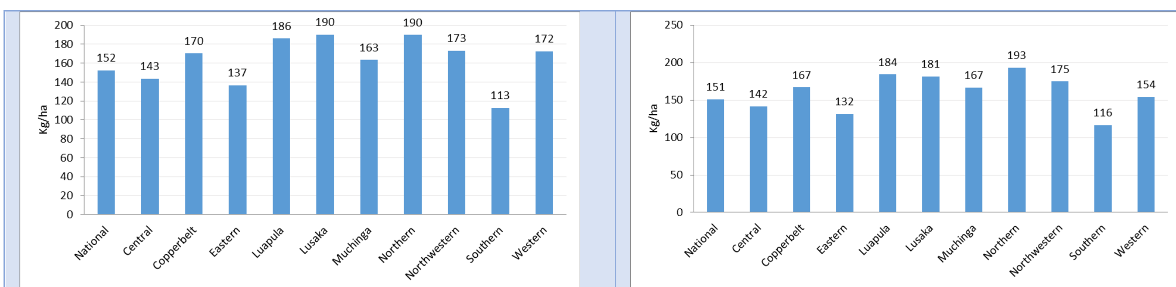


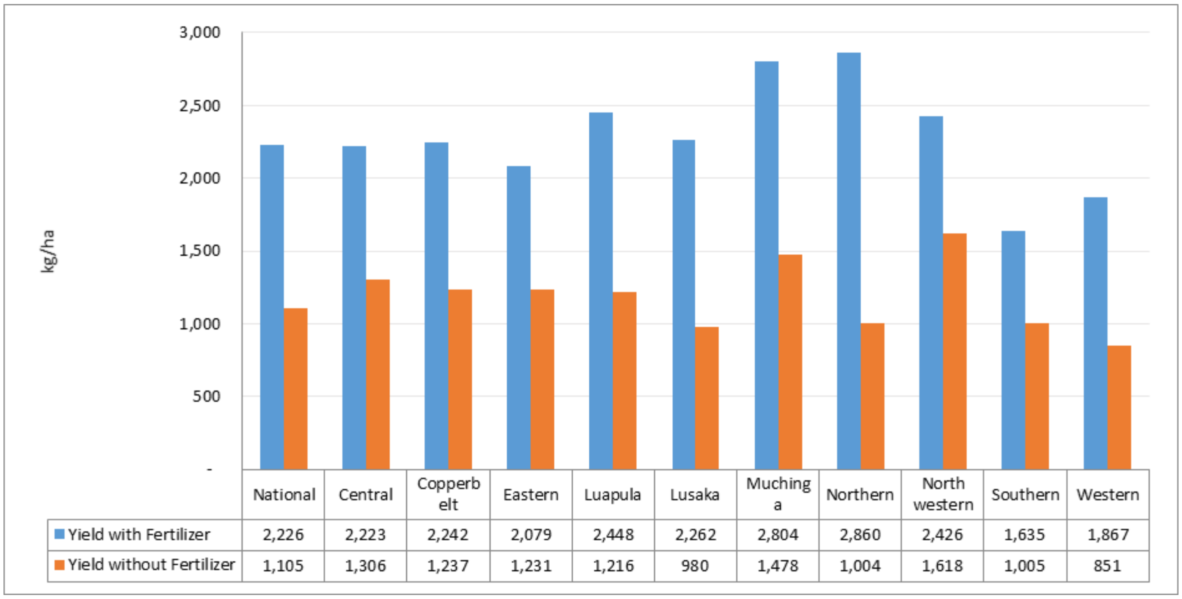
Figure 2A: Average basal dressing fertilizer application per ha (Kg/Ha)

Figure 2B: Average Top dressing fertilizer application per ha (Kg/Ha)

Figure 2: Fertilizer application rate in Zambia (kg/ha)
Source: Chapoto and Subakanya, 2019

More than 50% of the smallholder farmers in Zambia acquired fertilizer from the Government's FISP program with only about 44% and 37% acquiring from a private trader/retailer in 2015 and 2019 respectively (Chapoto and Subakanya, 2019).

Comparisons of maize yields between fertilizer users and non-users reveals that farmers that used fertiliser had, Figure 2 shows that households that had not used fertilizer on their maize fields got almost half the yield of those who used fertilizer. The picture is the same when yield response is disaggregated at provincial level.



	National	Central	Copperbelt	Eastern	Luapula	Lusaka	Muchinga	Northern	North western	Southern	Western
Yield with Fertilizer	2,226	2,223	2,242	2,079	2,448	2,262	2,804	2,860	2,426	1,635	1,867
Yield without Fertilizer	1,105	1,306	1,237	1,231	1,216	980	1,478	1,004	1,618	1,005	851

Figure 2 Maize yield with and without fertilizer
Source: Chapoto and Subakanya, 2019

Further, Chapoto et. al., (2016) found that it did not matter whether soils had adequate phosphorous or not. Yields in fertilized fields were higher by more than 1000 kg/ha.

1.3 Programs and instruments encourage fertilizer use

Reducing poverty and food insecurity, by increasing productivity, and increasing incomes of rural households are among the objectives in Second National Agriculture Policy, the National Social Protection Policy and the 8th National Development Plan. The government has been making efforts to increase coverage of usage of fertilizer through programs such as FISP as fertilizer is seen as one of the key inputs in increasing productivity. The government's efforts to increase fertilizer use by farming households, has increased fertiliser use, which is now higher than many other countries in the region and on the African continent. Of interest is the push of investments into fertilizers to increase crop yields. The push of investment into fertilizer spans several decades in Zambia and is largely driven by the governments FISP.

The main objective of FISP is to increase crop productivity, food security and income of households by improving famers' access to affordable inputs and to enhance participation of the private sector in supplying of inputs to the smallholder farmers (MAL, 2015; MoA, 2016a; MoA, 2016b). In Zambia, FISP was initiated in 2003 where farmers were provided with inputs required for 1 ha of land. Later in 2010, the input pack was halved to cater for half a hectare. Evidence showed that the majority of farmers were cultivating less than a hectare and farmers who did not need the excess inputs would sell to those who needed it (wealthier farmers). In the 2012/2016 agricultural season, an e-voucher system of delivering the FISP was piloted in 13 districts of Zambia where 241,000 farmers were targeted (MAL, 2015). It was expanded to 602,521 farmers in the 2016/2017 agricultural season across 39 districts (MOA, 2016a). The 2023 budget highlighted that the government would implement the FISP through the comprehensive agriculture support programme where inputs would be more than doubled. Each beneficiary is required to be on the program for 3 years after which they will have to be weaned off. However, graduation of farmers from FISP has not been achieved since its inception.

2 Results of the Systematic Review

2.1 Fertilizer Use and Profitability

Crop yield response to fertilizer application was highly variable across studies. Using farm survey data, results show that an additional kg of basal fertilizer increased maize output by 3.0 kg while an additional kg of top dressing fertilizer increased maize output by 4.3 kg (Burke et al., 2017). We standardize the crop response rates with other countries by converting to kg of crop yield per kg of Nitrogen. Thus for basal dressing fertiliser, the crop yield response rate is equivalent to 30kg/kg of N, while for top dressing, it is 9.3 kg/kg of N.

Yield response varied with soil types. There was a decrease crop yield response in clay (excluding Acrisols) or sandy soils while maize yields increased with increasing soil pH. In soils with a pH above 5.5, an additional kg of fertilizer increased maize output by 7.6 kg while at pH levels below 4.4 yield was reduced to 2.1 kg/kg. Further, factors such as timely acquisition of fertilizer from the FISP and use of mechanical/animal draught power had a positive effect on yield (Xu et al., 2009).

Using marginal product (MP) which provides better insights into whether a farmer will be incentivized in using fertilizer, Xu et al., (2009) found that each kg of Nitrogen used gave an output of 16 kgs of maize. As a measure of farm output profitability, Value Cost Ratios (VCRs) are used due to limited information on costs (see methodological note for details).

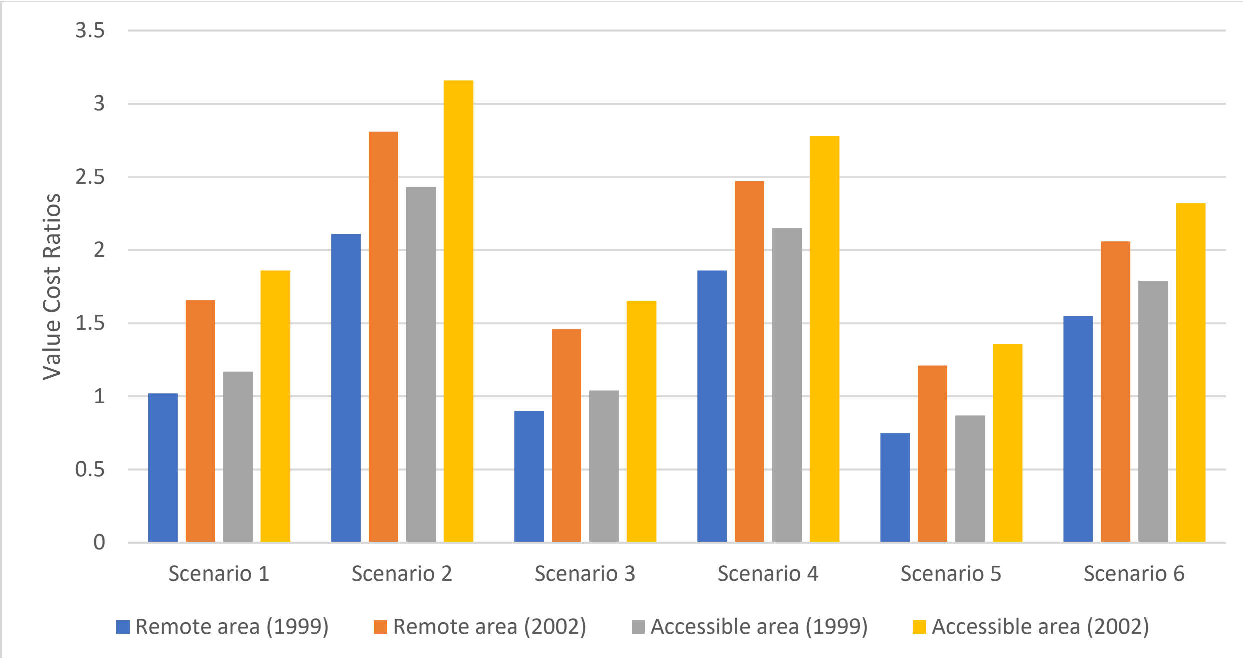


Figure 3: Estimated value–cost ratios for alternative rates of nitrogen application dependent upon timeliness of fertilizer availability

Notes: Scenairo 1: 28kgs at the 25th percentile with fertilizer not available on time
Scenairo 2: 28kgs at the 25th percentile with fertilizer available on time
Scenairo 3: 46kgs at the 50th percentile with fertilizer not available on time
Scenairo 4: 46kgs at the 50th percentile with fertilizer available on time
Scenairo 5: 69kgs at the 75th percentile with fertilizer not available on time
Scenairo 6: 69kgs at the 75th percentile with fertilizer available on time
Source: Adopted from Xu et al. (2009)

Using 6 different scenarios as depicted in Figure 3 , Xu et al., (2009) found:

1. An AVCR of 1.77. Further, AVCR by accessibility shows that for accessible areas AVCR is 1.88 while in remote areas its 1.65 at maize-nitrogen price ratios of 8.60 and 8.06 in the years 1999 and 2002 respectively.
2. Keeping nitrogen level constant while varying availability of fertilizer, it was found that both the MP and AP would almost double with the lower value correlated to not having fertilizer when needed.
   Farmers had a lower VCR the more remote they were. In 2002, with 69kg of fertilizer application and fertilizer available when needed, accessible farmers had a VCR of 2.32 while remote farmers had a VCR of 2.06.

In another study, basal fertilizer was found to be profitable only in soils that had pH values above 5.5 with an AVCR of 5.3. In pH ranges of 4.4 to 5.5, AVCR was at 2.5. It becomes unprofitable to use basal fertilizer at pH levels of 4.4 and below where the AVCR was found to be 1.4 (Burke et al, 2017). These results involved Simulating of 4 scenarios as shown below.

Table 3: Average Value Cost Ratios under different simulations for basal fertilizer

Commercial fertilizer and maize prices (price of maize 782 ZMK/kg, price of fertilizer 3,556 ZMK/kg)	AVCR <1.5 at any soil PH
Subsidized price of fertilizer with commercial price of maize (Price of maize=782 ZMK/kg, price of fertilizer=1000 ZMK/kg)	Fertilizer use profitable at soil PH >5.5
Price of maize subsidized with commercial price of fertilizer (price of maize=1300 ZMK/kg, fertilizer price=3556 ZMK/kg)	AVCR=1.8 with a soil PH >5.5
Both subsidized maize and fertilizer prices (Price of maize=1300 ZMK/kg, fertilizer price=1000 ZMK/kg)	AVCR=5.3 when soil PH >5.5 AVCR=2.5 when soil PH between 4.4 and 5.5 AVCR=1.4 when soil PH <4.4

Source: Burke et al. (2017)

2.2 Constraints and solutions in literature

Studies have identified possible factors contributing to low use of fertilizer. In Zambia, blanket fertilizer recommendations are set at 200 kg/ha for both basal and top dressing fertilizer. This blanket recommendation does not take into account soil pH levels which could lead to overall low response rates and low profitability. Evidence show that there is a positive response to basal fertilizer on soils with a higher pH (Burke et al., 2017). It is therefore important for farmers to establish the response capacity of their soils by testing for pH and other properties to enable them to use the right type of fertilizer in the required quantities.

There is also a need to expand on soil testing facilities in the country for farmers to have access these facilities. Farmers are also prone to use of counterfeit fertilizers which result in poor yield response and limit fertiliser use. There is need to use quality fertilizers for sustainable household and national food security. Zambia depends on international markets for its fertilizer supplies because the local production of the commodity is very limited. The Nitrogen Chemicals of Zambia (NCZ), a state-run fertilizer manufacturing plant, has not only limited capacity to produce fertilizers; but will need up-grading and repair of equipment. Hence apart from increase in soil testing facilities, an increase in fertilizer testing facilities is required.

As Zambia depends on imported fertilizer, it is prone to international price shocks which affect the pricing of the commodity. Poor infrastructure such as rail, roads and at the port of entry add to the high cost of fertilizer realized at the time the farmers are purchasing the fertilizer.

Even with some farmers receiving input subsidies from programmes such as the FISP, consumption of fertilizer in Zambia remains low. FISP has also been characterized by factors such as late delivery of inputs and poor targeting.

Most of the soils are low in organic matter; hence technologies such as conservation agriculture (CA) are being promoted to help in increasing soil organic matter (Chapoto et. al., 2016). Practices such as intercropping, use of mulch and integrating of crops with trees can potentially improve soil fertility, but adoption by farmers has remained low.

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Appendix 9: Zimbabwe Country Analysis

1 Country Context

1.1 The agricultural sector in Zimbabwe

Agriculture plays a crucial role in the Zimbabwean economy in terms of employment, incomes and poverty reduction. It contributes 15-18% of Gross Domestic Product (GDP), 23% to the total formal employment, and provides livelihoods to approximately 70% of the rural population. It also supplies about 63% of industrial raw materials with the share of agriculture in manufacturing value added at 60%, and the share in export earnings at 30%. Fifteen out of the 31 industry clusters in Zimbabwe depend on agriculture for feedstock. Maize, tobacco and cotton account for more than 50% of the agricultural GDP, with tobacco contributing 25%, followed by maize at 14%, and cotton at 25 %.

Zimbabwe's agricultural productivity remains low. The low productivity is partly driven by low supply of agricultural inputs and limited effective demand. Therefore, increasing agricultural productivity requires access to and utilization key inputs such as hybrid seeds, fertilizers and other agro-chemicals. Since the onset of the land reform programme in the early 2000s, the agricultural sector has undergone a remarkable transformation, with a sharp decline in commercial production. The macroeconomic conditions have been unfavourable and this has had adverse effects across different nodes of the agricultural value chain.

Generally, inputs are costly and unaffordable to farmers, while on the demand side, farmers and other value chain actors also face liquidity constraints in efforts to procure improved inputs. On the supply-side, local production of inputs has been reduced owing to limited availability of foreign currency to facilitate acquisition of other intermediate inputs not locally available. Limited access to agricultural finance among the new farmers has also contributed to low demand, and low capacity utilization among the agro-input manufacturers. Input distribution systems are inefficient, with agro-dealer networks not fully developed.

1.2 Zimbabwe's progress in terms of fertilizer use

1.2.1 Trends in Fertilizer use

Figure 1 summarises Zimbabwe's average fertiliser use, measured in kg per hectare of arable land. Average fertiliser consumption in Zimbabwe has been on the decline from the high level of 68 kg/Ha in 1981 to 18kg/Ha in 2012. Since 2012, fertiliser use shows a steady increase.

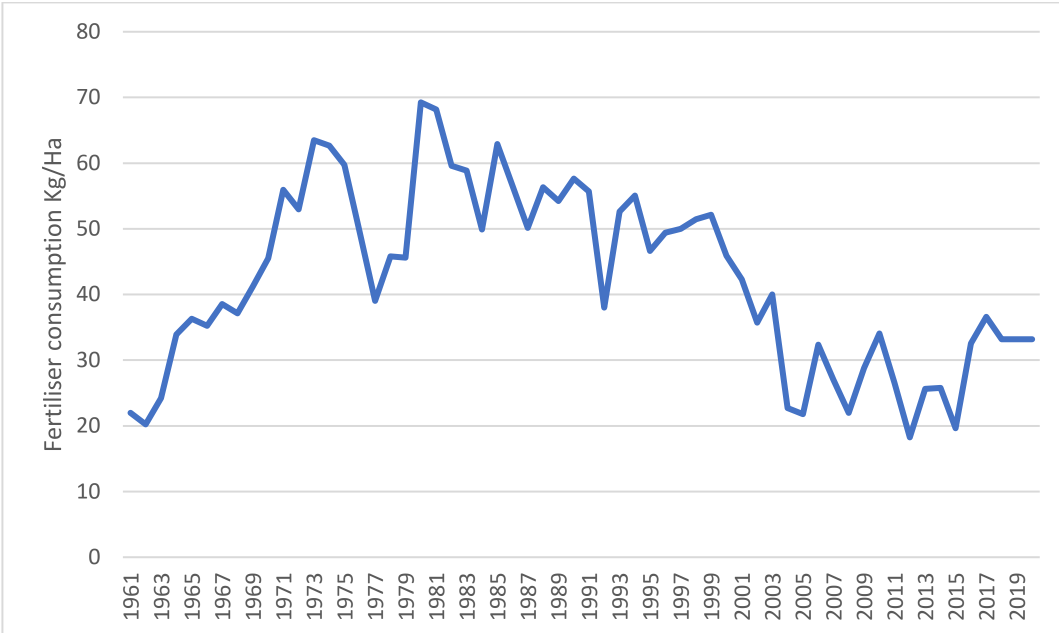

Figure 1 Zimbabwe average fertilizer use, kg per hectare of arable land
Source: World Bank https://data.worldbank.org/indicator/AG.CON.FERT.ZS?end=2018&locations=ZW&start=1991&view=chart

In 2017 production year, the proportion of farm households that used inorganic fertilizer was highest for the commercial farmers (20-50 ha) (75.6% of farmers) and small scale (A1 farmers) (cultivating 3-6 ha) (70.8%); while its was lowest in communal lands (cultivating less than 5ha) (55.2% of all farmers); The use of organic fertilizer is lowest among A1 farmers (35.8 percent) followed by Communal Lands (48.1%) (ZimStat, 2019).

Studies reveal that there is minimal fertiliser use amongst smallholder farmers in Zimbabwe who are located in remote and inaccessible areas affected by higher fertiliser prices due to high logistics and transportation costs, due to poor road, storage infrastructure and long distances from ports to production areas (Kelly and Crawford 2007; Minten, Koru, and Stifel 2013; AGRA, 2019). Higher fertilizer prices combined with low output prices render fertilizer use unprofitable in most of Zimbabwe's smallholder communities, mainly those in remote areas and production zones with low crop response rates (Kelly and Crawford 2007; Duflo, Kremer, and Robinson 2008; Marenya and Barrett 2009; Conley and Udry 2010; Foster and Rosenzweig 2010; Suri 2011; Minten, Koru, and Stifel 2013).

A study carried out in the semi-arid parts of the country in Lupane and Lower Gweru by Makuvaro et al. (2014) revealed that farmers in the study areas apply little fertilizer to their fields mostly because the fertilizers are expensive and / or unavailable. They also use less fertilizer because of water limitations. The main soil ameliorants that are used by farmers are cattle manure and inorganic fertilizers (compound D, with N:P:K (7:14:7) and ammonium nitrate, 34.5% N or urea 46% N, while leaf litter, anti-hill and ash are used to a lesser extent.

Typical practice of the majority of farmers when fertilizer is available is to apply 100 kg/ha of compound D and a top dress of 50-100 kg/ha of ammonium nitrate or 50 kg per ha of urea on maize in both agro-ecological regions III and IV. Agro-ecological region III and IV receive between 550-700 and 450-600 mm of rainfall respectively. Blanket fertilizer recommendations given by extension officers are 200-300 and 150-200 kg per ha compound D (basal) for natural region III and IV respectively, while corresponding top dressing fertilizer rates are 150-200 and 100-150 kg per ha ammonium nitrate respectively. The general recommendation for cattle manure is 20-30 tons per ha, but farmers apply lower amounts due to limited supplies. Farmers and agricultural extension officers pointed out that some farmers use inorganic fertilizers only when they get them from government or NGO drought relief programmes. Agricultural extension staff in the study areas confirmed that there was a decline in fertilizer use in these areas from the late 1990s to the early 2000s, due to phasing out of drought relief programmes which were being implemented by the government (Makuvaro et al., 2014).

The common fertilizer types used in Zimbabwe are (a) straight fertilizers (e.g. ammonium nitrate, urea, sodium nitrate, ammonium sulphate, calcium nitrate, single and double triple phosphates, potassium chloride and potassium sulphate), (b) compound fertilizers (e.g. compound A and D) and (c) blends (e.g. tobacco blend, maize blends). The fertilizers are supplied in granular form and in bags. In developing countries, including Zimbabwe liquid fertilizers are only confined to specialized drip irrigation for high value crops (FAO, 2006: 21). The major fertilizer types used in Zimbabwe are differentiated by the major crops grown in Zimbabwe are shown in Table 1.

Table: 1 Major fertilizer types differentiated by crops where used

Main crop	Main fertilizer type(s) used
Tobacco	Compound S,B, C, S, V, Tobacco blend
Maize	Compound D, AN, Urea, Maize blend
Coffee, fruit trees	Compound J, Coffee blend
Ground nuts	Phosphates, Gypsum
Wheat	Compound D
Horticultural crops	Compound D, C, Vegetable blend, AN

Source: Systematic Literature Review data, Zimbabwe

1.3 Programs and instruments promoting fertilizer use

Zimbabwe's agricultural sector has experienced several transformations since 2000. These changes have not only demanded a new thinking in terms of the future of agriculture, but have provided major challenges for policy makers. Several attempts have been made to change policy perspectives but the pace and intensity of changes did not allow for consolidated implementation. The result has been piecemeal implementation of policies, some of which did not emerge into the public domain. However, the position of agriculture in the economy remains dominant as a major employer and provider of key raw materials for the industrial and manufacturing sectors. The policies and programs to be discussed in this study include: Government Input Scheme (GIS), Productive Sector Facility (PSF), Agricultural Sector Productivity Enhancement Facility (ASPEF), Operation Food Security/Maguta (OFS) and The Champion Farmer Program (CFP), Command Agriculture, Presidential Input Schemes and Exchange Controls.

a) The Government Input Scheme (GIS)

In the year 2000, the Government of Zimbabwe announced that it would be responsible for providing inputs (seeds, fertilizers, etc.) to the farming community for the next six years. Requirements for inputs were appropriated through the Ministry of Agriculture. However, due to resource limitations the Ministry of Agriculture never got what they had budgeted for. Over the years the funding gap grew with the absence of commercial lending from banks that cited lack of collateral security largely as a result of the land reform program. GIS took away the initiative from the farmer and created an unprecedented level of dependence on government.

b) The Productive Sector Facility (PSF)

The Productive Sector Facility (PSF) was introduced by government through the Reserve Bank of Zimbabwe in 2004. The PSF was introduced to take account of the government's increasing inability to fund the input scheme through vote appropriations due to financial and fiscal constraints. Under the PSF for agriculture RBZ made financing available at 25% interest rate for food crop production.

e) Operation Food Security – Operation Maguta (OFS)

Food Security program (Operation Food Security) was the government's response to the continued deterioration of the national food security status. Maguta originated from the government's desire to improve food security in the country. In its simplest form, Operation Food Security was a form of Command Agriculture where the farmer would be guided on what crops to grow. The program had been premised on a yield level of 5 t/ha of maize with a provision of 600 kilograms (12*50 kg bags) of compound D and 400 kg (8*50 kg bags) of Ammonium Nitrate top dressing fertilizer. Within a short period after the launch, these provisions were reduced to 250 kgs of compound D and 150 kgs AN.

g) Command Agricultural Scheme

One of the prominent initiatives, the Command Agriculture was implemented in 2016 to facilitate farmers' access to inputs at reduced costs. Command agriculture is a contract farming scheme necessitated by land redistribution that ruptured Zimbabwe's sources of resilience, distorted credit access, heightened tenure insecurity, and spiked vulnerability to droughts. Farmers have received inputs for major grains and crops such as maize, cotton and tobacco. The Command Agriculture program was introduced for maize in the 2016/17 production season and has since been expanded to other value chains, such as wheat and soya beans. This scheme is a major private sector-backed subsidy programme in which farmers are provided with seeds, fertiliser, fuel and chemicals on a loan basis, with repayment made with a profit from a portion of the harvest the following season.

h) Presidential Input schemes

Launched in 2020, the Pfumvudza program is a Climate Proofed-Presidential Input Support Scheme aimed to support 1.6 million vulnerable households to produce maize with a standardized input package of 5 kg seed and 50 kg basal and 50 kg top dressing fertiliser. Thirty-two kilograms of both basal and top dressing is applied to two standardized 0.06 ha plot each. Maize production is supported with a standardized input package of 3 kg seed and 5 0kg basal and 50 kg top dressing fertilisers. This package is enough to cover a 0.125 ha plot and beneficiaries are expected to strictly adopt Conservation Agriculture Principles (CA) as a climate change adaptation strategy. These plots were coined Nzarayapera/Pfumvudza/Intensive Production Plot. UNDP recommended a well-capacitated extension provision system for technical backstopping, tracking and monitoring, availing of inputs (seeds and fertilizer) in time.

2 Results of the Systematic Review

2.1 Fertilizer Use and Profitability

Tables 2 provides information on VCR in farmer-managed and experimental research carried out in Mashonaland Central Province (Bindura) and Masvingo Province (Twomlow et al. 2006; Mativavarira et al. 2013). The values relate to maize, sorghum and millet. The prices for the respective years were used in computations. Generally, VCRs are low implying that fertiliser use efficiency can be improved. In farmer-managed trials, the VCR ranges from 0.71 for pearl millet and 1.5 for maize. Nonetheless, higher values of about 3.9 were achieved for maize under researcher-managed experiments.

Table 2: Value-Cost Ratios (VCR) for maize, sorghum and millets in Zimbabwe On-farm trials

Crop	Crop yield response	Price Ratio	VCR
Maize	8.9	0.185/1.3=0.17	1.26
Sorghum	6	0.188/1.3=0.14	0.86
Pearl millet	5.5	0.188/1.3=0.13	0.79

Source: Systematic Literature Review data, Zimbabwe

2.2 Identified constraints and solutions in literature

Fertiliser use in smallholder agriculture has often been recognized as critical in the achievement of higher crop intensification and crop yield. Low agricultural potential in this sector is due to numerous factors that are context-specific but generally socioeconomic, physical and policy related (Twomlow et al., 2006). Like many countries in ASoS, Zimbabwe's fertiliser use per unit remains lower than the recommended 50 kg per hectare (World Bank, 2021). Since the year 2006, average fertiliser use has hovered between 25 to 38 kg per hectare. During the same period, the country has experienced macroeconomic, political and socioeconomic instability. These factors have culminated in supply and demand-side challenges, which, in turn, have affected fertiliser use. On the demand size, Zimbabwe has the most expensive fertiliser per unit in Southern Africa. In 2020, for instance, a 50 kg bag of fertiliser was US$25 while in South Africa and Zambia, it costed about US$12 and US$15 respectively. This has resulted in low Value Cost Ratios (VCRs) in maize-based systems. In the 2000s, the VCR for maize was 2.6 (Morris et al. 2007), and it has decreased to less than 1 between 2010 and 2020. The high cost coupled with high risk from climatic variability often implies that farmers are less likely to use inorganic fertilisers. On the supply side, the fertiliser industry has been facing input bottlenecks especially of phosphate, nitrogen and ammonia, which are essential inputs in the manufacture of fertilisers. The government of Zimbabwe has therefore been a major player in the fertiliser value chain from input supply, production, processing, and distribution of fertilisers. This has stifled private sector involvement in the industry.

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