Commercial Agriculture for Smallholders and Agribusiness

Exploring fertilizer alternatives and opportunities for improving use efficiency in Africa and South Asia

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Commercial Agriculture for Smallholders and Agribusiness

CASA aims to drive global investment for inclusive climate-resilient agri-food systems that increase smallholder incomes.

The programme makes the case for increased agribusiness investment by demonstrating the commercial and development potential of sourcing models involving empowered smallholder producers and by tackling the information and evidence gaps holding back investment.

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Acronyms and abbreviations

CASA	Commercial Agriculture for Smallholders and Agribusiness
CO_2	Carbon dioxide
CoE	Centre of Excellence for Crop Rotation
DFI	Development finance institution
FAO	Food and Agriculture Organization
IEA	International Energy Agency
IFDC	International Fertilizer Development Center
MT	Metric tonne
N, P and K	Nitrogen, phosphorus and potassium
pH	A scale used to specify the acidity or basicity of an aqueous solution
R&D	Research and development
SOC	Soil organic carbon
WFP	World Food Programme

Executive summary

There is an estimated 345 million people facing food insecurity in 2023, more than double the number in 2020[1]. Increasing mineral fertilizer[2] prices and longstanding problems with inefficient fertilizer use have contributed to this growing problem. In response to this challenge, this report explores supplementary and alternative products that offer the potential to reduce reliance on mineral fertilizers, as well as solutions for improving fertilizer use efficiency. Improved efficiency leads to reduced greenhouse gas emissions, amongst other benefits. Adopting these products and practices on a large scale, within an integrated approach to long-term soil health, has the potential to enhance food security, improve smallholder yields and livelihoods, and mitigate climate and environmental impacts.

This report aims to do the following:

- Provide a snapshot of current approaches to fertilizer use in Sub-Saharan Africa and South Asia, exploring the problems associated with overuse and underuse of mineral fertilizers.
- Introduce a set of alternative and supplementary products, as well as technologies and business models that offer the potential to improve fertilizer use efficiencies.
- Identify opportunities for, and bottlenecks to, large-scale adoption of alternative fertilizer strategies, highlighting the role that governments, investors, donors, and private firms can play in accelerating progress in this space.
- Showcase eight case studies from Africa and South Asia of companies working on fertilizer alternatives and solutions to promote more efficient fertilizer use. Three of these companies have been supported by the Commercial Agriculture for Smallholders and Agribusiness Technical Assistance Facility (CASA TAF)[3].

Key strategies and products:

Nuanced context-specific fertilizer strategies

1. **Alternative fertilizer strategies must prioritize long-term soil health**, which is vital for food security, crop quality, and environmental benefits like erosion control, flood management, and carbon sequestration. Soils around the world are already badly degraded. Alternative fertilizer strategies have the potential to reverse – or at a minimum not contribute to – soil degradation.

2. **Both overuse and underuse of mineral fertilizers are problematic.** While mineral fertilizers have played a pivotal role in driving agricultural productivity, underuse in Sub-Saharan Africa and overuse in South Asia harm soil health and the environment. Inefficient use releases potent greenhouse gases, while underuse leads to expanding the cultivated area, damaging ecosystems, and emitting CO_2.

3. **There is an opportunity to replace blanket messaging on mineral fertilizer use with more nuanced approaches.** Past strategies, like the 2006 Abuja Declaration and South Asian fertilizer subsidies, emphasized increasing use. A more nuanced, context-specific approach is needed that prioritizes long-term soil health, considers the full spectrum of available products and technologies, and recognizes the needs of smallholder farmers.

Alternative and supplementary products

4. **The case studies highlight emerging opportunities across three groups of supplementary and alternative products:**

[1] World Food Programme (2023) *A global food crisis*. https://www.wfp.org/global-hunger-crisis
[2] Mineral (also known as inorganic, chemical, or synthetic) fertilizers are made from synthetic compounds, typically derived from inorganic salts or minerals.
[3] CASA is a commercial agriculture programme funded by the UK Foreign, Commonwealth and Development Office. For more information on CASA TAF see: https://www.casaprogramme.com/technical-assistance/

- **Green ammonia**, produced using renewable energy, promises zero-carbon production of ammonia, which is a vital component in nitrogen-based fertilizers. Challenges include the high cost of production infrastructure, the need for stable water and renewable energy sources, and the challenge of formulating ammonia products that are suitable for smallholders. Localized modular production could address cost and availability issues by sidestepping traditional distribution chains.
- **Organic products**, including compost, slaughter waste, crop residue recycling, sewage sludge, manure, and biochar[4], can play a valuable role in promoting long-term soil health. However, lower nutrient concentrations mean that they cannot replace mineral fertilizers entirely. The physical bulk and low value by weight of these products limits their scalability, and their climate and environmental impacts can be mixed. Waste-to-fertilizer models may offer opportunities to distribute high-quality organic products at sub-national scale.
- **Biological Products** are microorganisms and other substances that support plant growth by improving nutrient availability in the soil. The products have shown the potential to increase yields by 20–30% over a single growing season and the limited quantities required improve the prospects for use at a large scale. Despite this, use among smallholder farmers in Sub-Saharan Africa and South Asia remains low due to limited product awareness, cost, and variable availability. The effectiveness of these products also relies on product quality, appropriate handling and storage, and user knowledge. Key opportunities include supporting the commercialization of robust, locally relevant strains, and improving product development, marketing, and distribution for the smallholder segment.

Improved use efficiency

5. **The report's case studies also profile emerging technologies and business models that promote more efficient fertilizer use.** The report considers several emerging technologies, including **portable soil health analysis and remote sensing** to support tailored advice, and **integrated soil health advisory services**. Bottlenecks to scaling up these technologies and models include the cost and accessibility of technology-based solutions, and the need for long-term, hands-on support for smallholder farmers to get the maximum benefit from them.

A multifaceted challenge

6. **No single solution will solve Africa and South Asia's fertilizer problems alone.** Improved fertilizer strategies will require a blend of different products, coupled with intensive support on effective use and general improvements to agronomic practices. Achieving this at a large scale in the smallholder segment – noting the significant differences between different groups of smallholder farmers – remains a key challenge.

Challenges and Opportunities

Policymakers, development partners, investors, and the private sector can all play important roles in developing and scaling alternative and supplementary fertilizer products and improving use efficiencies. Key opportunities in this regard include the following:

1. Influencing longstanding farming practices

The challenge: The case studies highlight the challenges of changing longstanding smallholder farming practices. One key factor is limited awareness of alternative products and technologies, and limited knowledge of their benefits. The incentives to test new fertilizer strategies are also not straightforward. Reducing or increasing fertilizer use, and the adoption of unfamiliar products and processes, presents additional risks, both real and perceived. Changing farming practices can also lead to lower yields over the short term,

[4] Biochar is a catch-all term describing any organic material that has been carbonized under high temperatures in the presence of little, or no, oxygen (a process called pyrolysis). Biochar is used as a soil amendment to improve soil fertility and structure, sequester carbon, and enhance water retention.

while benefits from improved soil health can be difficult to quantify. To tackle this problem the following opportunities have been identified:

- **Agribusinesses** running smallholder outgrower schemes should promote and distribute alternative and supplementary products, in conjunction with soil analysis and other technology-based solutions, as part of a bundled package of inputs.
- **Governments (with donor support if required) should lead programmes that promote high-tech and lower-tech solutions in parallel**, supported by ongoing education and monitoring. Tools like portable soil sensors and soil management apps can provide valuable data on soil health and fertilizer needs. Lower-tech tools – for example, soil health cards based on qualitative information (e.g. soil life, visible salts, smell, and workability)[5] – can offer a lower-cost, more accessible alternative for smallholder farmers.
- **Donors and private firms** can explore market-based incentives that promote long-term soil health: for example, working with agri-insurance providers to develop crop insurance products that monitor and incentivize efforts to ensure long-term soil health.

2. Promoting higher-quality alternative products

The challenge: The quality of Biological Products and organic fertilizers significantly influences their effectiveness. Lower-quality products diminish potential yields and fail to provide the full benefits for soil health, and negative customer experiences with inferior-quality products are likely to discourage repeat use. The following opportunities to improve product quality have been identified:

- **Donors and governments** should make product quality a key criterion for providing support to companies in the space (e.g. via a startup incubator, challenge fund, or other incentive scheme), and investors should assess product quality as part of any commercial or concessional investments in the sector.
- **Standards bodies, with donor support where required**, should scale up the use of certifications and quality testing for Biological Products. Donors and governments should build awareness of the importance of the quality of Biological Products and organic products among government extension services, product distributors, agricultural associations, and farmer co-operatives.
- **Biological Product manufacturers** can reduce supply chain risks by developing more robust products: for example, by investing in formulations that are more resilient to temperature extremes, and co-funding research (**together with development partners**) on indigenous microorganisms that may be better adapted to local conditions than imported strains (these products are also more likely to gain certification for local use).

3. Investing in local green ammonia production

The challenge: Green ammonia offers several potential benefits, particularly zero-carbon production at local scale. However, there are many challenges: developing forms of ammonia that are useable by smallholder farmers (the output – anhydrous ammonia – is a volatile gas that requires specialized technology and knowledge for safe direct application), high capital costs for production infrastructure, and the need for affordable and reliable renewable energy. A key opportunity is in smaller-scale, modular green ammonia production. Modular production has the potential to lower entry barriers for developers and offers more consistent, affordable ammonia supply via shortened supply chains, lower logistics costs, and reduced transport emissions. To support this emerging technology the following opportunities have been identified:

- **Donors and investors** should support the piloting and scale-up of smaller-scale, modular green ammonia production in areas of low or inefficient fertilizer use. There is

[5] Testen, A., Mamiro, D., Nahson, J., Amuri, N., Culman, S., & Miller, S. (2018) *Farmer-Focused Tools to Improve Soil Health Monitoring on Smallholder Farms in the Morogoro Region of Tanzania*. Plant Health Progress, 19, 56-63.

an opportunity for **development finance institutions** (**DFIs) and impact investors** to provide lower-cost capital and risk guarantees to project developers.

- **Donors** should support the development of smallholder farmer-friendly products. There is an immediate opportunity to (co)fund feasibility studies for smallholder pilot projects: for example, on the potential to convert anhydrous ammonia (which is not suitable for smallholder use) into useable forms like ammonium sulphate.
- **Industry leaders, associations, and donors** have an opportunity to build partnerships between green ammonia producers and renewable energy providers (access to renewable energy is a key requirement, and bottleneck, for green ammonia projects).
- **Governments, with donor support if required**, should develop policies and incentives that stimulate the adoption of green ammonia among smallholder farmers, including subsidies for initial adoption, tax breaks for producers, and support for research into smallholder farmer-friendly products.

4. Improving the business case for serving the smallholder segment

The challenge: The business case for targeting the smallholder farmer segment is still being established across most businesses profiled in the case studies. The central challenge is that making products and services attractive and relevant to smallholder customers often drives up unit costs beyond the customers' ability to pay. This is because there are no "one-size-fits all" solutions when it comes to promoting alternative fertilizer strategies, and the more specific the solution, the more it tends to cost. There is also a lack of price premiums for organic foods in Africa, which further disincentivizes farmer uptake. To overcome this challenge the following opportunities have been identified:

- **Donors and investors** should (co)finance production infrastructure for products specifically targeted at smallholders – for example, automated packaging equipment – to lower unit costs.
- **Entrepreneurs and donors** should test locally scalable models for organic fertilizers, particularly waste-to-fertilizer solutions. Associations and donor programmes should broker partnerships: for example, between organic fertilizer producers and large-scale offtakers (e.g. commercial agribusinesses for use across an outgrower network).
- **Investors and donors** have an opportunity to support digital technologies that have the potential to decrease cost-per-user fertilizer information.

5. Supporting links between research and development (R&D) and scaling

The challenge: Several of the profiled businesses received grant funding to support initial research and product development. Beyond this initial phase, access to external financial and non-financial support was mixed. Two key points of transition were identified as particularly challenging: shifting from initial product development to early commercialization, and scaling from early commercialization to large-scale operations. In response to this challenge, the following opportunities have been identified:

- **Impact investors and DFIs,** supported by **development partners and foundations** providing first-loss capital**,** should engage more actively with fertilizer alternatives businesses, from early-stage ventures in Biological Products and fertilizer use technologies through to larger-scale projects supporting green ammonia production, and particularly modular technology.
- **Investors and donor programmes** should support more mature fertilizer alternatives businesses to broaden and deepen their offers through concessional finance – for example, for improving the efficacy, robustness, or cost of existing products and tailoring existing products to new crops, geographies or customer groups.
- **Governments, industry bodies, and donors** should support knowledge exchange and collaboration among research institutions, businesses, and investors. There is an opportunity to increase representation from the commercial sector and potential

investors in events relating to fertilizer alternatives, and to facilitate exchanges between these actors and members of the scientific and technical community.

6. Developing supportive policies and regulations

The challenge: Regulations and standards guiding the development, trade, and use of alternative fertilizers are generally under-developed in the target regions. Countervailing duties, administrative bureaucracy, and customs for various categories of goods obstruct technology acquisition. For example, registration of new Biological Products – in contexts where these regulations exist – can be time-consuming, costly, and difficult to navigate (and this is often not factored into developers' timelines and budgets). To address these issues, the following opportunities have been identified:

- **Governments, with donor support if required**, should update existing fertilizer strategies, policies, and regulations to promote integrated soil health over the long term, including the production, trade, and use of organics and Biological Products.
- **Governments** can re-design subsidies to incentivize farmers to follow the 4Rs of fertilizer use (right source of nutrients, at the right time and place, and in the right quantity[6]), and to invest in alternative or supplementary products and practices that improve nutrient use efficiency and restore soil health. Transition subsidies can support the adoption of fertilizer alternatives by offsetting initial yield losses, higher costs, and educational expenses during the farmers' adaptation to new practices and products.
- **Governments, firms, and donors** should establish or support regional coordinating bodies: for example, the West African Fertilizer Control Committee. They should include research and private sector players in coordinating bodies to support access to technical and commercial perspectives.
- **Industry bodies and standards organizations** have an opportunity to implement general standards on the development and use of Biological Products.

[6] Vanlauwe, B., Amede, T., Bationo, A., Bindraban, P., Breman, H., Cardinael, R., Couedel, A., Chivenge, P., Corbeels, M., Dobermann, A., Falconnier, G., Fatunbi, W., Giller, K., Harawa, R., Kamau, M., Merckx, R., Palm, C., Powlson, D., Rusinamhodzi, L., Six, J., Singh, U., Stewart, Z., van Ittersum, M., Witt, C., Zingore, S., & Groot, R. (2023) *Fertilizer and Soil Health in Africa: The Role of Fertilizer in Building Soil Health to Sustain Farming and Address Climate Change.* IFDC.

1. A context of worsening food security, increased fertilizer prices, and increased fertilizer use inefficiencies

Global food security is under significant pressure. The World Food Programme (WFP) estimates that over 345 million people face food insecurity in 2023, more than double the number in 2020[7], reflecting a growing challenge to deliver against Sustainable Development Goal 2 – Zero Hunger – which has aims including ending malnutrition, ensuring universal access to safe and nutritious food, and doubling the productivity and incomes of smallholder farmers[8].

Key drivers of food insecurity include economic shocks, conflict, climate change, and increased fertilizer prices[9]. The impact of these drivers is felt across the entire food system, including more expensive agricultural inputs, reduced yields, and disrupted supply chains. Those least equipped to contend with these shocks, including smallholder farmers and poor consumers, face the most acute challenges.

The cost and availability of fertilizer – a critical agricultural input – have been profoundly affected, with inflation and rising interest rates putting pressure particularly on fertilizer-importing countries with high levels of external debt. Long-term increases in natural gas prices, and more recently Russia's invasion of Ukraine, have contributed to driving up fertilizer prices to all-time highs in 2022 (see Figure 1), contributing to an estimated 5% drop in global fertilizer consumption in 2022 and a 2–3% year-on-year decline in staple crop production[10]. This "fertilizer crunch"[11] has had a disproportionate impact on smaller markets that rely on fertilizer imports, with prices in parts of Sub-Saharan Africa doubling[12] or tripling[13] between 2020 and 2022.

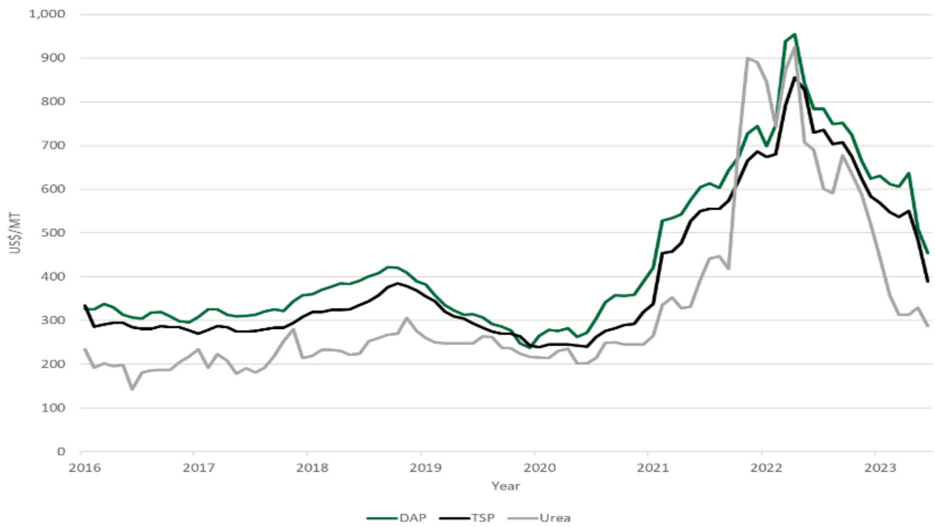

Figure 1: Global fertilizer prices 2016–2023 (US$/metric tonne (MT)[14]

[7] WFP (2023) *A global food crisis*. https://www.wfp.org/global-hunger-crisis
[8] The Global Goals (2015) *Goal 2: Zero Hunger*. https://www.globalgoals.org/goals/2-zero-hunger/
[9] WFP (2023) *A global food crisis*. https://www.wfp.org/global-hunger-crisis
[10] International Fertilizer Association (2022) *Five fertilizer market dynamics that tell the story of 2022.* https://www.fertilizer.org/news/five-fertilizer-market-dynamics-that-tell-the-story-of-2022/
[11] World Economic Forum (2023) *This is how war in Europe is disrupting fertilizer supplies and threatening global food security*. https://www.weforum.org/agenda/2023/03/ukraine-fertilizer-food-security/
[12] WFP (2022) *How a donation of fertilizers for countries in Africa comes not a minute too soon.* https://www.wfp.org/stories/how-donation-fertilizers-countries-africa-comes-not-minute-too-soon
[13] World Bank (2022) *A transformed fertilizer market is needed in response to the food crisis in Africa.* https://blogs.worldbank.org/voices/transformed-fertilizer-market-needed-response-food-crisis-africa
[14] World Bank Commodity Markets data: https://www.worldbank.org/en/research/commodity-markets

Despite a decrease over the past year (Figure 1), fertilizer prices remain above long-term averages, putting continued pressure on food systems around the world. Furthermore, the events of 2020-22 – and more recent developments including Russia halting its participation in the Black Sea trade deal – highlight longstanding underlying vulnerabilities, particularly in regions with already low or inefficient fertilizer use. This context underscores the need to transition to more resilient fertilizer strategies to support long-term food security.

Against this backdrop, this report explores innovations that have the potential to support more efficient use of traditional mineral fertilizers and to promote supplementary and alternative products. Drawing on case studies from Sub-Saharan Africa and South Asia – regions that are at high risk of food insecurity and experiencing significant fertilizer use challenges – the study explores the real-world challenges and opportunities facing businesses operating in this space. The report highlights the role that development partners, governments, investors, and the private sector can play in supporting alternative fertilizer strategies that reduce vulnerability to price shocks, enhance food security, and help to minimize climate and environmental impacts.

2. Soil health, food security, and the environment

A discussion of alternative fertilizer strategies must start with soil health, defined by the International Fertilizer Development Center (IFDC) as “the ability to generate sufficient crop yields while maintaining the future productive capacity of soils and the ecosystem services soils regulate and deliver”[15]. Soil health is critical from a food security perspective because it directly influences both the yield and nutritional quality of crops: healthy soils offer better nutrient cycling and water retention. Healthy soils also support climate and environmental outcomes: mitigating erosion, controlling flooding, increasing biodiversity, cleaning water, and sequestering carbon[16]. Without healthy soils, the ability to produce enough food to support global food security is severely compromised.

Despite widespread knowledge of the importance of healthy soils, soil degradation is significant and is accelerating. The UN Food and Agriculture Organization (FAO) estimates that a third of soils globally are currently degraded[17], with the potential to rise to 90% by 2050[18]. The figures for Africa are even higher, with up to two thirds of productive land currently degraded[19].

Inefficient and improper fertilizer use is a key driver of soil degradation. One common mechanism is nutrient mining – a negative balance between nutrient input and output in the soil – which exhausts nutrient stocks and soil organic carbon (SOC)[20], with knock-on issues including erosion and acidification, as well as releasing CO_2 into the atmosphere. Nutrient mining can be worsened by underuse of mineral fertilizers, as essential nutrients are depleted without being replenished. Indiscriminate use can cause problems too: for example, through over-application of certain minerals (e.g. nitrogen) and under-application of others (e.g. potassium and phosphorus) (see Section 3). A 2019 study focusing on maize production in Sub-Saharan Africa highlighted that due to nutrient mining, nitrogen input must increase by between nine and 15 times by 2050 to ensure self-sufficient production[21].

Assessing soil health

Soil health is measured using a combination of physical, chemical, and biological indicators, such as SOC, pH level, nutrient content, soil texture and structure, microbial activity, and water-holding capacity. These factors interact to create optimal conditions for plant growth and offer a variety of climate and environmental benefits.

Mitigating further degradation and rehabilitating degraded soils – while critical for long-term food security – are context-specific interventions, often requiring hyper-localized solutions. In addition, crop growth is limited by the most deficient nutrient, making targeted and balanced nutrition crucial. These points highlight the need for context-specific fertilizer strategies that balance long-term soil health with the immediate financial and nutritional needs of smallholder farmers.

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[15] Vanlauwe, B., Amede, T., Bationo, A., Bindraban, P., Breman, H., Cardinael, R., Couedel, A., Chivenge, P., Corbeels, M., Dobermann, A., Falconnier, G., Fatunbi, W., Giller, K., Harawa, R., Kamau, M., Merckx, R., Palm, C., Powlson, D., Rusinamhodzi, L., Six, J., Singh, U., Stewart, Z., van Ittersum, M., Witt, C., Zingore, S., & Groot, R. (2023) *Fertilizer and Soil Health in Africa: The Role of Fertilizer in Building Soil Health to Sustain Farming and Address Climate Change.* IFDC.
[16] Government of Western Australia (2022) *What is soil organic carbon?* https://www.agric.wa.gov.au/measuring-and-assessing-soils/what-soil-organic-carbon
[17] FAO (2021) *The state of the world's land and water resources for food and agriculture – Systems at breaking point. Facts and Figures*. https://www.fao.org/land-water/solaw2021/facts/en/
[18] FAO (2022) *Saving our soils by all earthly ways possible.* https://www.fao.org/fao-stories/article/en/c/1599222/
[19] Berrahmouni, N., & Mansourian, S. (2021) *Review of forest and landscape restoration in Africa.* FAO and AUDA-NEPAD.
[20] SOC plays a key role in soil health, agricultural productivity, and climate change mitigation due to its capacity to sequester carbon dioxide from the atmosphere.
[21] Berge, H., Hijbeek, R., van Loon, M., Rurinda, J., Tesfaye, K., Zingore, S., Craufurd, P., Heerwaarden, J., Brentrup, F., Schröder, J., Boogaard, H., Groot, H. L. E., & Ittersum, M. (2019) *Maize crop nutrient input requirements for food security in sub-Saharan Africa*. Global Food Security, 23, 9-21.

3. Fertilizer products and usage

This section provides an overview of fertilizer use in Sub-Saharan Africa and South Asia, including the dominant group of mineral fertilizer products[22], as well as emerging alternatives, including green ammonia, organic fertilizers, and Biological Products (see Table 1). It also considers strategies for enhancing the efficiency of fertilizer use to optimize agricultural productivity and environmental sustainability.

Table 1: Examples of traditional mineral fertilizers and alternative products

Type	Category	Examples
Traditional	Mineral	NPK (nitrogen, phosphorus, potassium), urea, mono-ammonium phosphate, di-ammonium phosphate, muriate of potash
Alternative	Organic	Animal manure, compost, food waste, crop residues, vermicompost, seaweed extract, fish emulsion, bone meal, blood meal, biochar
	Biological Products	Living organisms, including nitrogen-fixing bacteria (Rhizobia), phosphate-solubilizing bacteria, and arbuscular mycorrhizal fungi[23]

1. Mineral fertilizers

Headlines:

- Mineral fertilizers have been critical drivers of agricultural productivity over the past century.
- Use in Sub-Saharan Africa is well below optimal levels, while inefficient use is widespread in South Asia.
- Underuse and overuse both fail to support long-term soil health and create a range of climate and environmental problems.

Mineral fertilizers supplying nitrogen, phosphorus, and potassium (NPK) have been a crucial component of modern agriculture. By addressing soil nutrient deficiencies they play a vital role in the production of approximately half of the world's food[24], and (together with high-yielding cereal varieties, new farming technologies, and pesticide use) played a key role in Asia's Green Revolution, which saw cereal production in the region nearly double between 1970 and 1995[25].

[22] Alternative terms are chemical or synthetic fertilizers.
[23] The soil microbes that colonize the majority of the plant root and establish a connection between the plant and the substrate, help in the production of plant growth hormones, increase the nutrient availability, and also inhibit root pathogens.
[24] International Fertilizer Association (2023) *Food and nutrition security* https://www.fertilizer.org/about-fertilizers/why-we-need-fertilizers/food-and-nutrition-security/
[25] Hazell, P. B. R. (2009) *The Asian Green Revolution* (IFPRI Discussion Paper No. 911). International Food Policy Research Institute.

These products offer high nutrient concentrations, low logistical costs relative to bulkier alternatives, and immediate availability of nutrients to plants.

However, despite these benefits, the use of mineral fertilizers is often poorly managed, posing environmental challenges that include water pollution, soil degradation, and contribution to greenhouse gas emissions. In addition, volatile prices and unpredictable availability present ongoing access and affordability challenges, particularly for smallholder farmers.

The importance of NPK for plant growth

N, P, and K are critical nutrients for plant growth. Nitrogen supports photosynthesis, phosphorus facilitates energy transfer and root development, while potassium is essential for water regulation and enzyme activation in plants.

Use of mineral fertilizers in Sub-Saharan Africa and South Asia

Globally, fertilizer use is inefficient. Nutrient use efficiency – the efficiency of applied nutrients in increasing grain or biomass yield, calculated as the increase in yield per unit of nutrient applied – remains low. On average, less than half of the nitrogen supplied to crops is utilized. In Sub-Saharan Africa, one reason for this is the acidic nature of many soils – either naturally occurring or caused by poor soil management – which limits nitrogen uptake by crops. One study has estimated that the amount of nitrogen applied to wheat, rice, and maize could be reduced by 14–29% globally while maintaining yields[26]. As nutrient use efficiency increases, fewer nutrients are lost into the natural environment and costs are reduced for producers.

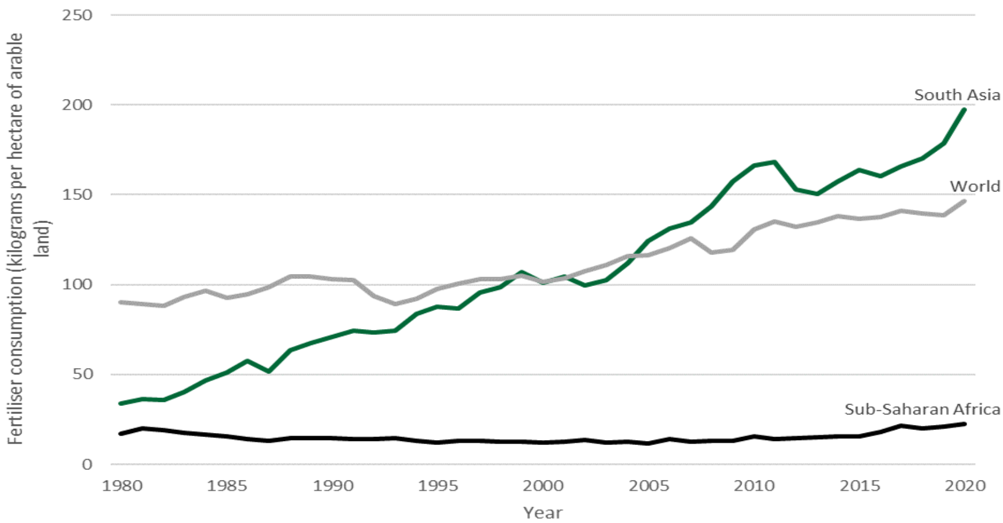

Figure 2: Fertilizer consumption (kilograms per hectare of arable land) – South Asia, Sub-Saharan Africa, world[27]

Fertilizer use is uneven between, and within, Sub-Saharan Africa and South Asia. Average application rates in Sub-Saharan Africa were 22.5 kg per hectare of arable land in 2020, well below the international average of 146 kg per hectare[28], but with significant variations between countries. Such limited average fertilizer use is a significant constraint to

[26] West, P. C., Gerber, J. S., Engstrom, P. M., Mueller, N. D., Brauman, K. A., Carlson, K. M., Cassidy, E. S., Johnston, M., MacDonald, G. K., Ray, D. K., & Siebert, S. (2014) *Leverage points for improving global food security and the environment.* Science (New York, N.Y.), 345(6194), 325–328.
[27] FAO data, accessed via World Bank Open Data: https://data.worldbank.org/indicator/AG.CON.FERT.ZS?end=2020&locations=ZG-1W-8S&start=1980
[28] All fertilizer use data from FAO (2020), accessed via https://databank.worldbank.org/

agricultural productivity[29], with an estimated eight times more fertilizer needed to achieve potential yields across the continent[30].

Despite producing twice as much mineral fertilizer as it consumes, Africa still imports 90% of its fertilizers, due to inefficiencies in shipping, distribution, and imperfect market information[31]. Production infrastructure is capital-intensive and concentrated in a limited number of industrial hubs[32]: for example, OCP Group's phosphate operations in Morocco and a major new urea and ammonia plant opened by the Dangote Group in Nigeria. For such plants, bulk exports are often more commercially attractive than local distribution. Processing infrastructure – for example, blending facilities – is more widespread, with over 100 plants active across the continent[33]. These plants may offer opportunities for local customization of fertilizers to better match specific soil and crop needs, potentially improving soil management and yield outcomes.

Fertilizer strategies in Africa have tended to promote increased blanket use of mineral fertilizers. In Africa, the 2006 Abuja Declaration on Fertilizer for the African Green Revolution, and the associated Africa Fertilizer Financing Mechanism[34] aim to increase fertilizer use to 50 kg per hectare, with limited consideration of long-term soil health or the use of alternative products. More recent strategies[35] and action plans[36] outline longer-term, more integrated approaches, including recognizing the importance of soil health and nutrient management, climate and environmental challenges, and the role of alternative fertilizer products. Nevertheless, the execution of these new strategies is in the initial stages and will need to overcome legacy issues associated with blanket approaches.

Conversely, in South Asia, the average fertilizer application rate in 2020 was 197 kg per hectare. This is well above the global average, although also with regional variations. In some South Asian countries – for example, Bangladesh and India – there is overuse of certain fertilizers (particularly blanket application of nitrogen-based products) and underuse of other products. A key driver of this has been long-term subsidy regimes that have encouraged excessive urea application and under-application of P and K fertilizers, leading to significant climate and environmental impacts, as discussed below.

In South Asia, India is a significant producer of mineral fertilizers, but still relies on imports to meet local demand: for example, importing around 30% of its annual urea consumption[37]. Fertilizer plants in India are often strategically located close to raw material sources, such as natural gas reserves, which are crucial for urea production. They are also often situated near major agricultural areas with high levels of demand, enhancing distribution efficiency. Pakistan and Bangladesh, which produce mineral fertilizers in smaller quantities, are reliant on imports to meet local demand, while pricing and distribution are government controlled.

Approaches to reduce mineral fertilizer use (and to phase in alternative and supplementary products) need to take a gradual, informed approach. Attempts to stop the use of mineral products too abruptly are likely to have major impact on yields and could destabilize essential food systems. The experience of Sri Lanka illustrates this challenge. In 2021, the country's government unexpectedly introduced a ban on mineral fertilizers. The aftermath

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[29] FAO & ITPS (2015) S*tatus of the World's Soil Resources (SWSR) – Main Report.* Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils.

[30] McKinsey & Company (2019) *Winning in Africa's agricultural market* https://www.mckinsey.com/industries/agriculture/our-insights/winning-in-africas-agricultural-market

[31] World Bank (2022) *A transformed fertilizer market is needed in response to the food crisis in Africa.* https://blogs.worldbank.org/voices/transformed-fertilizer-market-needed-response-food-crisis-africa

[32] Africa Fertilizer Map: https://www.africafertilizermap.com/

[33] AfricaFertilizer (AFO) Plant Directory: https://africafertilizer.org/app/#/en/en/plant-directory/

[34] African Development Bank (2022) *Africa Fertilizer Financing Mechanism – Strategic Plan 2022–2028.* https://www.afdb.org/en/documents/africa-fertilizer-financing-mechanism-affm-strategic-plan-2022-2028

[35] For example: World Bank (2023) *Fertilizers and Soil-Health Roadmap for West Africa and the Sahel.* Report from the High-Level Roundtable on Fertilizers: Investing in the Future by Improving Soil Health, Lomé, Togo.

[36] African Union (2023) *Africa Fertilizer & Soil Health Summit.* https://ifdc.org/wp-content/uploads/2022/09/AFSH-Summit-brochure-final.pdf

[37] Reuters (2022) *India aims to end urea imports from 2025.* https://www.reuters.com/business/india-aims-end-urea-imports-2025-pegs-fy23-fertilisers-subsidy-272-bln-2022-11-02/

saw a significant drop in crop yields, with rice production falling from 3.4 million tonnes in 2020–21 to 2.9 million tonnes in 2021–22[38]. This contributed to an economic crisis, culminating in a default on US$ 40 billion of foreign debt[39]. Despite reversing the ban six months later, the supply of fertilizers in the country struggled to stabilize due to global price increases and the country's own foreign exchange issues.

Climate and environmental impact of mineral fertilizers

Underuse and inefficient use of mineral fertilizers have negative environmental impacts. Inefficient use results in the release of methane, carbon dioxide, ammonia, and nitrous oxide, which are potent greenhouse gases[40]. Globally, an estimated 30–50% of fertilizer nutrients end up contaminating groundwater or volatilizing into the air[41].

South Asia has seen the largest increase in nitrogen emissions globally due to heavy and inefficient use of nitrogen-based fertilizers. The region has also become a major emitter of ammonia and saw a 36% increase in nitrous oxide emissions from 2000 to 2015[42]. Overuse of nitrogen fertilizers can lead to nutrient mining by disrupting the soil's nutrient balance, causing a deficiency in other essential elements like phosphorus and potassium. As a result, the soil's overall fertility degrades over time, diminishing its ability to sustain healthy crop growth. This contributes to significant environmental impacts, including water pollution, eutrophication[43], soil degradation, groundwater contamination, and biodiversity loss, as well as soil acidification, salinization, and depletion of organic matter. This damage has a long-term impact on agricultural productivity.

Underuse of fertilizers brings its own set of challenges. In Sub-Saharan Africa, where farming is predominantly extensive[44], increased crop production is often achieved by expanding the cultivated area rather than improving yields via intensification. The expansion of cropland is accelerating in the region, with the annual expansion rate nearly doubling between 2000 and 2019[45]. This expansion releases significant amounts of CO_2 and often comes at the expense of natural ecosystems and biodiversity[46], with Sub-Saharan Africa currently experiencing an annual net loss of 4 million hectares of forest[47]. The pressure on Africa's natural ecosystems will escalate as the continent's population growth is expected to be the highest in the world by 2050[48].

Finally, the production of mineral fertilizers has significant environmental impacts. Ammonia – a key component in nitrogen-based fertilizer – is one of the world's most produced chemicals, with an estimated 70% used in fertilizer production[49]. Currently, over 90% of ammonia production relies on the Haber-Bosch process, an industrial method used to

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[38] The Guardian (2022) "*It will be hard to find a farmer left": Sri Lanka reels from rash fertiliser ban.* https://www.theguardian.com/world/2022/apr/20/sri-lanka-fertiliser-ban-president-rajapaksa-farmers-harvests-collapse

[39] Financial Times (2023) *Sri Lanka's farmers learn lessons from organic debacle.* https://www.ft.com/content/3c9094eb-12bb-4058-acea-35b0240fa665

[40] AGRA. (2019). *Feeding Africa's soils: Fertilizers to support Africa's agricultural transformation.* Nairobi, Kenya. Alliance for a Green Revolution in Africa (AGRA).

[41] Chojnacka, K., Moustakas, K., & Witek-Krowiak, A. (2020) *Bio-based fertilizers: A practical approach towards circular economy.* Bioresource Technology, 295, 122223.

[42] Pawar, P. V., Ghude, S. D., Jena, C., Móring, A., Sutton, M. A., Kulkarni, S. H., Beig, G., Sobhana, S. B., & Kulkarni, R. (2021) *Analysis of atmospheric ammonia over South and East Asia based on the MOZART-4 model and its comparison with satellite and surface observations*. Atmospheric Chemistry and Physics, 21, 6389-6409.

[43] Excessive enrichment of water bodies with nutrients, often due to runoff from the land, causing a dense growth of plant life and harm to animal life as a result of a lack of oxygen.

[44] Limited inputs (e.g. fertilizer, machinery, labour) relative to the land area under cultivation.

[45] P. Potapov, S. Turubanova, M.C. Hansen, A. Tyukavina, V. Zalles, A. Khan, X.-P. Song, A. Pickens, Q. Shen, & J. Cortez. (2021) *Global maps of cropland extent and change show accelerated cropland expansion in the twenty-first century.* Nature Food.

[46] Nearly 79% of cropland expansion came at the expense of natural landscapes. See World Resources Institute (2022) *5 Takeaways on Cropland Expansion and What It Means for People and the Planet.* https://www.wri.org/insights/cropland-expansion-impacts-people-planet

[47] Mansourian, S., & Berrahmouni, N. (2021) *Review of forest and landscape restoration in Africa.* FAO and AUDA-NEPAD, Accra.

[48] Our World in Data (2021) *To protect the world's wildlife we must improve crop yields – especially across Africa* https://ourworldindata.org/yields-habitat-loss

[49] IEA (2021) *Ammonia Technology Roadmap.* IEA, Paris.

synthesize ammonia from nitrogen (extracted from the air) and hydrogen (derived from natural gas). Despite being efficient, the process is highly energy-intensive. Production of ammonia fertilizers accounts for around 1% of total global energy use and 1.4% of CO_2 emissions[50]. The extraction of raw materials such as phosphorus and potassium also presents a significant environmental risk. Mining activities can damage natural ecosystems, while chemicals involved in production can lead to long-term water pollution.

Green ammonia

Headlines:

- Green ammonia, and particularly modular technologies, offers a possible opportunity for decentralizing and lowering the carbon footprint of fertilizer production, reducing costs and improving access to fertilizer users.
- Key challenges include the costs of deployment, the requirement for reliable water and renewable energy supplies, and the challenge of developing ammonia-based fertilizer products that are safe and effective for smallholder farmer use. There are immediate opportunities to support R&D in these areas.

Green ammonia, produced using renewable energy, water, and air, offers a more sustainable solution for nitrogen-based fertilizer production. A key benefit is that despite being energy-intensive, the production of green ammonia can be carbon-neutral.

How is green ammonia produced?

Green ammonia is produced via electrolysis, where water (H_2O) is split into hydrogen (H_2) and oxygen (O_2) using renewable electricity. The hydrogen is then combined with nitrogen (N_2) from the air to create anhydrous ammonia (NH_3) (the same output as traditionally produced ammonia via the Haber-Bosch process).

While most green ammonia production is still at pilot stage, developments are accelerating. The International Energy Agency (IEA) estimates that by 2030 nearly 8 megatons of near-zero-emissions ammonia production capacity is expected to be operational, corresponding to 3% of total capacity in 2020[51]. While production is still nascent in South Asia and Sub-Saharan Africa, there is a growing pipeline of planned projects: for example, in South Africa[52], Kenya[53] and India[54].

In terms of bottlenecks to scale, the high capital costs of large-scale production and storage infrastructure have limited the pool of potential developers. Electricity accounts for approximately 85% of the total cost of production[55], meaning that access to affordable renewable energy sources is also a critical consideration. Modular solutions (see the case study, below) offer a way to decentralize and

[50] Carbon Brief (2022) *Q&A: What does the world's reliance on fertilisers mean for climate change?* https://www.carbonbrief.org/qa-what-does-the-worlds-reliance-on-fertilisers-mean-for-climate-change/
[51] IEA (2021) *Ammonia Technology Roadmap*, IEA, Paris https://www.iea.org/reports/ammonia-technology-roadmap License: CC BY 4.0
[52] Hive Energy (2021) *World's largest green ammonia plant for Nelson Mandela Bay, South Africa.* https://www.hiveenergy.co.uk/2021/12/15/worlds-largest-green-ammonia-plant-for-nelson-mandela-bay-south-africa/
[53] Ammonia Energy Association (2022) *COP27: raised ambitions for Africa.* https://www.ammoniaenergy.org/articles/cop27-raised-ambitions-for-africa/
[54] ACME (2022) *ACME Group and Govt of Karnataka sign MoU to invest Rs 52000 crore for Green Hydrogen project.* https://www.acme.in/media-release/160/acme-group-and-govt-of-karnataka-sign-mou-to-invest-rs-52000-crore-for-green-hydrogen-project
[55] The Royal Society (2020) *Ammonia: Zero-Carbon Fertiliser, Fuel and Energy Store.* Policy Briefing, The Royal Society, London.

localize production, reduce the level of upfront investment required, and bypass costly traditional ammonia supply chains.

Safe and effective use of locally-produced green ammonia by smallholders is also a challenge. Anhydrous ammonia – the output from both green and traditional ammonia production processes – is a volatile and corrosive gas that is stored under high pressure and is a health and safety risk if improperly handled[56]. Direct use of anhydrous ammonia as a fertilizer requires specialized knowledge and equipment, which is out of reach for most smaller-scale farmers. There are several options to enable use by smallholders: for example, granularizing the product, converting it to lower concentration aqueous ammonia for fertigation, or combining it with a carrier material. A key challenge is identifying and adopting solutions that are viable and cost-effective for local use (see Talus Renewables case study, below).

Although green ammonia offers lower production emissions, problems associated with its use as a component in fertilizer – for example, inefficient use causing water pollution and nitrous oxide release – remain. Additionally, the large amounts of water required for production can put pressure on water-scarce regions.

Case study 1: Talus Renewables (green ammonia, multi-country)

Overview

Talus Renewables,[57] a company based in the United States, has developed a modular and autonomous system for producing green ammonia. This technology operates based on renewable energy sources and uses only water and air as inputs, thereby providing a locally sourced, cost-effective alternative to traditional sources of ammonia. The modular, containerized system is designed for quick deployment and scalability. The company is currently commissioning a plant in East Africa for a multinational agribusiness and is exploring options for extending its technology to smallholder farmers.

How does the initiative promote the use of fertilizer alternatives or improve the efficiency of use?

Underuse of fertilizers in Sub-Saharan Africa is driven by limited access and high prices. The production of ammonia, which is a crucial raw material for fertilizers, is traditionally undertaken in large, centralized plants. It is challenging to raise the funds to invest in these large-scale projects in Sub-Saharan Africa, meaning that most ammonia is imported, increasing costs and supply chain risk. Talus' modular system could support improved fertilizer use by:

Improving access through local production, which would shield farmers from volatile international markets and displace a costly and unpredictable supply chain.
Reducing cost compared to traditional sources, with the cost per metric tonne of nitrogen from anhydrous ammonia estimated to be 47% less than the cost per tonne of nitrogen from urea in western Kenya from 2006 to 2021.

The availability of a local, lower-cost source of ammonia could increase access to fertilizers in areas of low use, increasing yields and promoting soil health by mitigating nutrient mining. The system also eliminates carbon emissions during the production process, significantly reducing climate impact.

Motivations for startup

The company's founder funded initial R&D philanthropically. Recognizing the need for a more scalable solution in the green ammonia market, which was then limited to large-scale projects, Talus focused on creating a reliable, cost-effective, and power-efficient system with the capability

[56] For example, a risk of respiratory distress and chemical burns to the skin and eyes.
[57] https://www.talusag.com/

to adjust to intermittent renewable power.

Talus' primary aim is to serve local communities and to do so on a fully commercial basis. The company currently targets larger-scale customers, such as commercial farms, mining companies, and power plants. Although short-term operations benefit from green hydrogen tax credits in the United States, the company's long-term vision is to scale up deployments in Sub-Saharan Africa and other frontier markets.

As part of this plan, Talus is in the final stages of commissioning a plant for a multinational agribusiness in East Africa. While the current methods of application are not suitable for non-mechanized farmers, Talus sees an opportunity within the smallholder segment. Through its outgrower schemes, the agribusiness in East Africa is expected to provide a platform for testing different application techniques and products for smaller-scale users.

What have been the constraints to scale-up and how have these been addressed?

Anhydrous ammonia is unsuitable for use by smallholders. The direct use of anhydrous ammonia as a fertilizer requires specific equipment and technical knowledge – for example, the need for a large (~5,000 litre) pressurized tank for direct injection, and specialized health and safety provisions – making it unsuitable for direct use by smallholders. To increase adoption among smallholder farmers, Talus is investigating alternative solutions, such as low-concentration aqueous ammonia, granularization into more user-friendly fertilizer compounds like ammonium phosphate and ammonium sulphate, and using substances like biochar as a carrier. The company is also exploring alternative business models: for example, "fertilizer-as-a-service" offerings.

Limited access to reliable, renewable power. Another challenge is accessing consistent renewable power for decentralized production. Energy is the largest cost driver for producing ammonia. Talus has designed its system to operate on intermittent power, which is made possible through innovations in system component sizing and software control systems. This enables the system to be powered with solar microgrids.

Limited customer ability to cover large, upfront costs. For most potential customers or partners, the upfront payment that would be required to purchase a green ammonia production system outright is prohibitive. To mitigate this, Talus offers a 15-year "take or pay" model, instead of selling the systems, which helps to increase the number of potential partners that can access their system.

Reaching smallholders on a commercially viable basis. Talus looks to lease its systems to large, creditworthy customers which serve as anchor users and offer access to large, smallholder, outgrower networks. Talus is also exploring partnerships with other organizations with existing distribution networks and relationships with smallholder farmers.

Continued scaling requires investment. Following the initial funding, several rounds of investment were needed to support ongoing R&D and to develop the first commercial system. Funds were also used to build an engineering and operations team and to expand the supply chain. Most of the investment has been on commercial terms, with concessional finance provided by a major DFI more recently. Future funding rounds will support growth into new geographies and markets, including the smallholder farmer segment.

Projected impact

Over the next three to four years, targets include the following: 1,000 tonnes per day of owned capacity, representing ~US$ 1 billion of invested capital; Talus green ammonia systems servicing commercial and independent farms across Americas, Africa, and Asia; mining projects in the US, South America, and Africa; and power generation projects in the US.

Lessons learned: the company's perspective

- Modular green ammonia production is still at a relatively early stage. Significant improvements in manufacturing design are required to reduce assembly costs while improving the reliability of the system.
- Large-scale roll-out of Talus' systems will require gaining certifications in multiple new markets. The timescale, cost, and complexity of these certification processes are difficult to predict in advance, given the novelty of the technology.

2. Alternative products

Considering the challenges associated with mineral fertilizer use, this section highlights two groups of alternative or supplementary products: organic products (e.g. compost, manure and biochar) and Biological Products (i.e. naturally derived and living organisms that support nutrient uptake and use). These solutions are of particular interest due to their potential for promoting long-term soil health and their relevance to smallholder farmers.

Organic products

Headlines:

- Organic products can play a significant role in improving long-term soil health.
- Lower nutrient concentrations mean that they are not a like-for-like substitute for mineral fertilizers.
- The bulky nature of these products puts a natural limit on scalability.
- The climate and environmental impacts of organic products are mixed and nuanced.

Organic products include compost, slaughter waste (blood meal, bone meal, and fish meal), recycled crop residue, sewage sludge, manure, and biochar. In general, these products support long-term soil health by increasing SOC and improving soil structure and water-holding capacity (the potential benefits of biochar as a soil improver are presented in the Kentaste case study, below). Under the right conditions, they can also support microbial activity, which can support nutrient cycling, enhance resistance against diseases and pests, and promote overall plant health and productivity. A meta-analysis conducted in 2020 showed that combining high-quality organic products with mineral fertilizers enhanced agronomic efficiency (the increase in yield per unit of nutrient applied) by 20% and reduced SOC losses by 18% across seven cropping seasons, compared with the sole use of mineral fertilizers[58].

The availability and uptake of organic products vary considerably across and within Sub-Saharan Africa and South Asia, influenced by factors including variations in farming practices, the level of access to organic materials, local knowledge and traditions, policies, and farmer income levels. In most remote farming communities, organic "waste" is a misnomer: these are resources with competing uses and are generally in short supply compared to demand.

Cost–benefit considerations also influence the use of organic fertilizer products, noting that there are significant variations between contexts. Organic products are significantly less nutrient-dense than mineral fertilizers (see Table 2), which makes a like-for-like substitution difficult. Nutrient density is influenced by product quality, which for a product like manure is determined by factors including cattle diets and manure management practices. Organic products are also typically bulky and require larger volumes to be effective, increasing transportation, storage, and application costs. In addition, it can take several years to see tangible benefits in terms of soil health. This means that the initial impact on yields – and returns – may be modest, which can disincentivize use, particularly among smallholder farmers with immediate needs for food and income.

[58] Agronomic efficiency increased by 20% and SOC losses fell by 18% over seven growing seasons. See: Gram, G., Roobroeck, D., Pypers, P., Six, J., Merckx, R., & Vanlauwe, B. (2020) *Combining organic and mineral fertilizers as a climate-smart integrated soil fertility management practice in sub-Saharan Africa: A meta-analysis.* PLoS ONE, 15(9), e0239552.

Table 2: Comparison of average nutrient concentrations between selected organic and inorganic products

Source of nutrients	N	P	K
	(% of dry matter)		
Organic sources			
Cattle manure	1.9	0.8	1.7
Chicken manure	2.9	1.4	1.5
Compost (decayed organic matter)	1.2	0.4	0.9
Inorganic sources			
Urea	46	0	0
Mono-ammonium phosphate	11	21	0
Di-ammonium phosphate	18	20	0
15-15-15 blend	15	7	13
10-20-20 blend	10	9	17

There are contexts in which organic fertilizer use can be profitable: for example, when supplying markets with organic farming premiums (e.g. in North America and Europe). A 2015 meta-analysis[59] found that, with such premiums, organic farming showed 22%–35% higher net present values and 20%–24% higher benefit-cost ratios than conventional farming. Without these premiums, values were significantly lower (-27% to -23% and -8% to -7%, respectively). This suggests that for most smallholder farmers in Africa and South Asia, a blend of organic and mineral fertilizers – where available – may offer the optimal benefit-cost ratio.

In regions of Sub-Saharan Africa with particularly low use of mineral fertilizers, use of organic fertilizers is often the norm due to on-farm availability of materials like animal manure and plant residues. For small-scale farmers, properly managing manure can make a significant difference in soil health and crop yields. While wealthier farmers can optimize nutrient retention by using advanced storage methods, poorer farmers face challenges that lead to considerable nutrient wastage (for example, nitrogen losses during collection and limited resources for investing in storage infrastructure)[60]. Evidence from the case studies suggests that the formal market for organic fertilizers is still nascent. Examples of emerging business models with the potential for scale at a local level include waste-to-fertilizer (see the box on Regen Organics) and waste-to-biochar (see the Kentaste case study, below).

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[59] Crowder, D. W., & Reganold, J. P. (2015) *Financial competitiveness of organic agriculture on a global scale*. Proceedings of the National Academy of Sciences of the United States of America, 112(24), 7611–7616.

[60] Rufino, M.C., Tittonell, P., van Wijk, M.T., Castellanos-Navarrete, A., Delve, R.J., de Ridder, N., & Giller, K.E. (2007) *Manure as a key resource within smallholder farming systems: Analysing farm-scale nutrient cycling efficiencies with the NUANCES framework.* Livestock Science, 112(3).

South Asia has a more established market for organic fertilizers, as well as growing government support for sustainable farming practices. India in particular has adopted a number of subsidy schemes to encourage the production and use of organic products: for example, Paramaparagat Krishi Vikas Yojana (PKVY)[61], which is a policy for promoting city compost, and the Mission Organic Value Chain Development for North Eastern Region. However, the budget assigned to these and related initiatives is significantly below annual subsidies for mineral fertilizers, and some remain undersubscribed, with just 2.7% of the country's total area under cultivation covered by these schemes[62].

The climate and environmental impact of organic products is mixed and nuanced. Production and transportation can be carbon intensive due to the bulky nature of these products, while improper and inefficient use carries some of the same risks as mineral fertilizers: for example, nutrient runoff (albeit to a lesser extent given lower nutrient concentrations). The production and use of animal manure emits methane, which is a powerful greenhouse gas[63].

Another consideration is the impact of organic products on microbial processes in the soil that play a role in determining emissions like nitrous oxide. Depending on the product and context, the impact of organic fertilizers can stimulate either nitrification or denitrification, and this can be difficult to predict in advance[64]. Nitrification is generally favourable as it converts nitrogen to a form that can be more readily assimilated by plants, potentially enhancing nitrogen use efficiency. On the other hand, denitrification, under certain conditions, can lead to increased production of nitrous oxide. While organic products can offer significant benefits when used appropriately, it is important not to assume that these products automatically increase nutrient use efficiency or are entirely risk-free.

Regen Organics, Kenya

Regen Organics is a waste-to-value agribusiness in Kenya that collects urban organic waste and converts it to compost and animal feed inputs containing Black Soldier Fly larvae. The initial motivation for Regen was to reduce sanitation waste, but the scope has expanded to include food waste from both formal and informal partners. Startup funding was critical to build the business to scale, and in 2022 the business disposed of over 43,000 MT of waste with their system, which was converted to over 6,000 MT of compost. 1,500 agrovet dealers distribute their products country-wide. To scale the uptake of organic fertilizers and incentivize initiatives like Regen's, the company notes that there is a need for the government to focus on soil health and agriculture, and to commit to supporting the adoption and appropriate use of composts and other organic compounds.

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[61] "Traditional agricultural development scheme".
[62] Khurana, A., & Kumar, V. (2022) *State of Biofertilizers and Organic Fertilizers in India.* Centre for Science and Environment, New Delhi.
[63] Richards, M., van Ittersum, M., Mamo, T., Stirling, C., Vanlauwe, B., & Zougmore, R. (2016) *Fertilizers and low emission development in sub-Saharan Africa.* CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).
[64] Lazcano, C., Zhu-Barker, X., & Decock, C. (2021) *Effects of Organic Fertilizers on the Soil Microorganisms Responsible for N2O Emissions: A Review.* Microorganisms, 9(5), 983.

Case study 2: Kentaste (biochar, Kenya)

Overview

Kentaste Products Limited[65] is the largest coconut processing company in East Africa, with a capacity of over 100,000 coconuts per day. Located on the coast of Kenya, the company sources raw material from over 3,000 smallholder farmers and has been contending with waste management challenges in its supply chain, primarily the accumulation of coconut husks, which are a byproduct of their processing operations. CASA TAF partnered with Kentaste to investigate the feasibility of producing biochar from coconut husks as a waste management solution and in parallel utilizing this product to improve soil health and water retention on coconut farms within their supply chain.

How does the initiative promote the use of fertilizer alternatives?

Kentaste's interest in sustainable alternatives to traditional fertilizers led them to explore the potential of biochar production. Through CASA TAF, the company was introduced to the concept of biochar and its potential benefits, initiating a shift towards more sustainable waste management and soil amendment practices. Field trials were conducted on maize and coconuts to evaluate the effects of biochar on crop yield and soil health.

The results of the trials are inconclusive to date since biochar's effects on soil health can take several years to become apparent, as it fundamentally alters the soil's composition and nutrient dynamics. Additionally, the trials were conducted under adverse weather conditions – specifically an extreme drought – which may have confounded the results.

Drivers and constraints

The motivation for Kentaste's adoption of biochar was their ongoing waste management challenge. The abundant supply of coconut husks provided a readily available feedstock for biochar production. CASA TAF played a crucial role in supporting the feasibility study of biochar, testing low-cost technologies to produce biochar from coconut husks and conducting various field trials applying biochar on coconuts and maize. However, there were some constraints, such as the uncertainty surrounding the quality of biochar produced from coconut husks compared to using other types of feedstocks, and the small scale of the project limiting the potential connection to carbon project developers or offtakers.

Lessons learned: the company's perspective

The project's impact is yet to be determined due to the inconclusive results from the biochar field trials and contextual factors like the short duration of the trials and the drought conditions during them. While the financial implications are yet to be defined, the company is continuing to explore the opportunities biochar presents.

One lesson from the initiative is that designing and managing research on a new product can be a complex process. There are benefits in engaging specialist technical and scientific expertise alongside the commercial and market knowledge offered by the firm. There is also a potential role for patient capital: for example, impact investors and donors working with early movers like Kentaste to build understanding of biochar's long-term potential (both commercial and in terms of improving soil health). This could have benefits for the firm itself (a new business line), the local farming community (improved soil health), and the wider market (robust information on commercial models for biochar production is widely disseminated).

[65] https://www.kentaste.com/

Biological Products

Headlines:

- Biological Products have demonstrated the potential for achieving significant improvements in productivity in a single growing season.
- Relatively small amounts are required, making scalable solutions more feasible.
- Product quality, handling, and storage, and user knowledge, have a significant impact on efficacy.
- The market is relatively small but growing, particularly among larger-scale commercial farms. Awareness and use by smallholder farmers in Sub-Saharan Africa and South Asia remain limited.

Biological Products are naturally derived substances and living organisms that can help to optimize nutrient uptake and use. They are used to supplement either mineral or organic fertilizers, and in some cases can either partially or fully replace those products. Two key product groups are the following:

- Biofertilizers, such as nitrogen-fixing bacteria and mycorrhizal fungi, which enhance nutrient availability through nitrogen fixation, which is the conversion of atmospheric nitrogen into a form that plants can use (usually ammonium). Biofertilizers also improve soil fertility by facilitating natural processes of nutrient cycling.
- Biostimulants, including seaweed extracts and humic acids, which work to improve fertilizer efficiency, enhancing the effectiveness of traditional nutrient inputs.

Biological Products have shown positive outcomes in terms of improved yields, with two of the featured case studies demonstrating yield improvements of up to 30% versus untreated crops. There are also benefits in terms of improving soil health over time: for example, by supporting microbial activity and improving soil structure.

How biofertilizers work[66]

Different products work in different ways. Nitrogen-fixing bacteria like Rhizobium, Azotobacter, and Azospirillum convert atmospheric nitrogen into a plant-usable form, with some forming symbiotic relationships with specific plants. Other biofertilizers solubilize and mobilize phosphorus and other nutrients, making them more accessible to plants. The microbes in biofertilizers can also produce hormones that stimulate plant growth and help to suppress soil-borne diseases and pests, leading to healthier, more robust plants.

Biofertilizers are typically delivered via seed treatment (coating seeds before planting), soil treatment (mixing into the soil), or root dipping (for transplanted crops). The method that is chosen depends on the crop, biofertilizer type, and field conditions.

The global biofertilizer market was estimated at US$ 2.7 billion in 2021, with a projected annual growth rate of 12.3% through to 2030 and sales concentrated in Asia Pacific, North America, and Europe[67]. Use of Biological Products in Sub-Saharan Africa is still nascent, particularly among smallholder farmers.

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[66] For a detailed explanation see Mitter, E. K., Tosi, M., Obregón, D., Dunfield, K. E., & Germida, J. J. (2021) *Rethinking Crop Nutrition in Times of Modern Microbiology: Innovative Biofertilizer Technologies.* Frontiers in Sustainable Food Systems, 5.
[67] Polaris Market Research (2022) *Global Biofertilizers Market* https://www.polarismarketresearch.com/industry-analysis/global-biofertilizers-market

The effectiveness of Biological Products is determined by a range of factors. High product quality is crucial, which includes maintaining optimal concentrations of the specific beneficial microorganism strains and avoiding contamination. As living products, specific storage conditions – in some cases refrigeration – are needed to preserve their efficacy, which can be difficult to maintain during "last-mile" distribution in parts of Sub-Saharan Africa and South Asia. Effectiveness is also determined by factors including climatic conditions, the level of residual nutrients in the soil, existing microbial activity, and soil pH[68]. The timing, frequency, and method of application is therefore critical and should be tailored as far as possible to specific crop and soil conditions.

In terms of climate and environmental impact, Biological Product production is significantly less energy-intensive than the production of mineral fertilizers, and the products are less bulky[69], resulting in fewer greenhouse gas emissions during production and distribution. Under the right conditions, Biological Products can reduce or eliminate the need for mineral fertilizers, reducing the associated emissions and soil and water pollution[70].

Case study 3: Legume Technology (biofertilizer, multi-country)

Overview

Legume Technology[71] is a UK-based business that specializes in the development and manufacture of legume-specific rhizobium inoculants. While most of its customers are currently larger-scale farmers in Europe and the United States, Legume Technology's products are available around the world, including in several African markets. As part of an expansion strategy to reach more smallholder farmers, the company has identified an opportunity to automate the production of small packages.

How does the initiative promote the use of fertilizer alternatives?

Legume Technology's rhizobium inoculants colonize legume root systems, converting atmospheric nitrogen into ammonia and thereby reducing or eliminating the need for nitrogen-based fertilizers. Furthermore, introducing the product into crop rotations can improve soil health and support carbon cycling, yielding additional advantages for farmers. Legume Technology's innovative "grow-in-the-bag" system combines the growth medium and bacteria directly in the packaging, ensuring a high concentration of bacteria while minimizing contamination, thereby optimizing colonization and nitrogen-fixing efficiency. Using pharmaceutical-grade filling machines and packaging, the product offers an extended shelf life of up to 18 months and can be used over two growing seasons.

What have been the constraints to scale-up and how have these been addressed?

Initially, the company was self-funded and the resulting capital constraints led to innovations in production processes. For example, industrial specification bioreactors were out of reach financially, leading the company to experiment with lower-cost solutions like the grow-in-the-bag system. This system requires sterile packaging materials and strict quality control but offers advantages in terms of product quality.

For scale-up, the company has partnered with Green Universe Agriculture Group, which has increased investment into the business and grown throughput in recent years. Challenges relating to expanding further into Africa, particularly the smallholder farmer segment, include the following:

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[68] Schütz, L., Gattinger, A., Meier, M., Müller, A., Boller, T., Mäder, P., & Mathimaran, N. (2018) *Improving Crop Yield and Nutrient Use Efficiency via Biofertilization—A Global Meta-analysis.* Frontiers in Plant Science, 8.

[69] The company reports that 1–3 kg of biofertilizer can be sufficient to treat 1,000 kg of seed.

[70] Saffeullah, P., Nabi, N., Liaqat, S., Anjum, N. A., Siddiqi, T. O., & Umar, S. (2021). *Organic Agriculture: Principles, Current Status, and Significance.* In Microbiota and Biofertilizers (pp. 17-37). Cham: Springer.

[71] https://legumetechnology.co.uk/

“Scaling down” to meet the specific needs of smallholder farmers: for example, by developing smaller package sizes. Manufacturing smaller packages is labour intensive, with a high cost-per-unit compared to larger format packs. The company has identified an opportunity to invest in automated packaging machinery – at a cost of US$ 1–2 million – however, this is not a pressing business priority given the high level of demand for the existing larger volume packs from larger-scale customers.

Educating smallholder farmers on the product and its application. With these products still relatively new in African markets, there is a need to raise awareness of their benefits and to build knowledge on how to use them effectively. Legume Technology works with several Africa-based distributors to build awareness and knowledge – for example, through farmer outreach – but this has proven to be a hands-on process, with few shortcuts.

Policies and regulations. Getting the products registered has proven to be difficult and time-consuming. In South Africa, for example, it can take up to seven years from application to registration. A significant aspect of these regulations is the requirement for repeated advocacy trials, which can be prohibitively lengthy. As a solution, the company aims to build connections with local distribution partners to support the registration process.

Accessing reliable supply chains. While the products have a comparatively long shelf life under optimal conditions, the bacteria may not survive in higher temperatures. In response to this problem, the company is continuing to explore ways to make the products as robust as possible. This includes exploring the use of more stable carrier mediums such as peat, and solutions like thermal covers for pallets and cool boxes for motorbike transport. The objective is to ensure the product reaches the farmers alive, maintaining its quality and efficacy throughout the supply chain.

Impact

The use of inoculants has a fast, tangible impact on farm yields and reduces fertilizer use for both the legume crop and subsequent cereal crops. Over a series of field trials, it has been demonstrated that the products can increase yields by up to 30% compared to untreated crops. Legume Technology currently sells into the following nations: Mali, Senegal, Kenya, Angola, South Africa, Zambia, Togo, and Benin. In 2022 product sales in Africa totalled 17,710 kg, which treated approximately 5,000 tonnes of seed over roughly 28,184 hectares. The company sees Asia, Central America, and Indonesia as markets with significant potential for smallholders that it would consider pursuing in the future.

Lessons learned: the company’s perspective

Targeting smallholder farmers is more challenging, and less commercially attractive, than working with larger farms, and requires investment across the supply chain, from production (e.g. automated packaging) to distribution (e.g. maintaining product integrity) and sales (e.g. educating customers on effective use). There is, however, a clear opportunity once key hurdles are cleared: for example, product registration and developing smaller-scale packaging infrastructure. Development partners and early-stage investors can play an important role in solving these challenges.

On-the-ground presence – for example, through the company’s distribution partners – is critical. This supports registration and can play a key role in raising awareness among new customer segments.

Case study 4: DeHaat (biofertilizer, India)

Overview

DeHaat[72], an AgriTech company based in India, operates as an input supplier, an offtaker, and an extension and advisory services provider. Recognizing the need for more sustainable farming practices, DeHaat has been promoting and selling its own mycorrhizal biofertilizer, a soil amendment that helps plants by increasing and improving their rhizosphere and uptake of nutrients in soil, thereby improving nutrient use efficiency and reducing the amount of chemical fertilizers needed. CASA TAF has partnered with DeHaat to refine their extension channel mix and messaging as part of an inclusive business plan that aims to drive farmer loyalty, while also improving outcomes for farmers.

How does the initiative promote the use of fertilizer alternatives?

DeHaat's biofertilizer, which contains living fungi that form symbiotic relationships with plant roots, has demonstrated that it can achieve improved plant health and growth, which is particularly visible in enhanced root systems. By promoting and selling this product, DeHaat contributes to sustainable farming practices and potentially increases its offtake from smallholder farmers. CASA TAF has assisted DeHaat with a pilot to promote the use of such products and practices. The pilot is testing the provision of customized advice to farmers using both in-person and digital channels. The goal is to maximize farmer adoption of these practices and deliver advice as efficiently as possible by using a mix of direct and digital contact points. This is aimed at creating a scalable, cost-effective model for agricultural training and advisory services.

Drivers and constraints

The development and promotion of DeHaat's biofertilizer aligns with its business model of maximizing crop yield for its farmer network. The more smallholder farmers produce, the more DeHaat can offtake, driving a mutually beneficial relationship. However, challenges lie in promoting a new product in a market dominated by chemical fertilizers, and increasing awareness among farmers about its benefits. CASA TAF's support in refining DeHaat's messaging and outreach has been pivotal in overcoming these constraints.

Lessons learned: the company's perspective

Though impact evaluation only began this year, there have been anecdotal reports from farmers on improved root growth in plants using DeHaat's biofertilizer, suggesting promising results. Moreover, multiple farmers have reported increased yields, specifically for potatoes. While detailed financial metrics are not yet available and the food security impacts of the project are yet to be fully understood, the expectation is that farmers will require less chemical fertilizer and will experience improved yields.

Although key lessons are still being gathered, due to the project's early stage, the experience of DeHaat underscores the importance of aligning sustainability initiatives with business objectives. This case study offers valuable insights into how AgriTech companies can contribute to sustainable farming while benefiting from the increased productivity that such innovations can bring.

[72] https://agrevolution.in/

3. Increasing efficiency of fertilizer use

Headlines:

- Use of fertilizer products – traditional and alternative – should be considered as part of an integrated approach to managing long-term soil health.
- Users often need hands-on support to get maximum benefit from technology-based solutions.
- In several areas, viable technologies exist but there are bottlenecks to large-scale adoption among smallholder farmers.

The individual solutions presented above should not be viewed in isolation. Instead, sustainable intensification, "where agricultural yields are increased without adverse environmental impact and without the conversion of additional non-agricultural land"[73], requires taking an integrated approach to managing soil health. This needs to balance immediate needs for increased production with the long-terms goals of maintaining future productive capacity and mitigating climate and environmental impacts.

Regarding fertilizer use, the "4Rs Principle"[74] is a central concept and refers to applying the right source of nutrients, at the right time, in the right place, and in the right quantity[75]. This acknowledges that each crop and each soil has specific requirements and provides a framework for integrating a variety of different products – both traditional and alternative – in ways that support long-term soil health.

As outlined in the sections above, fertilizer use remains inefficient in most parts of Sub-Saharan Africa and South Asia, and progress towards the "4Rs" is uneven. A range of interlinked issues hold back progress, including challenges promoting site-specific fertilizer application at a large scale, limited awareness of alternative products and limited information on their use, policy and regulatory gaps, and the dominant market position of large mineral fertilizer companies. Blanket messaging – for example, increasing mineral fertilizer use in Africa and reducing its use in South Asia – needs to be replaced with more nuanced, context-specific fertilizer strategies that consider both the spectrum of available products and technologies, as well as the practical needs of different groups of smallholder farmers.

In parallel, there are increasing opportunities to leverage new technologies and business models to accelerate progress. This section profiles a series of solutions which offer the potential to support an integrated approach to soil health management and improved fertilizer use at scale. These solutions include soil testing technologies, remote sensing, tailored advisory services, and aggregation models that support improved soil management strategies.

[73] Pretty, J., & Bharucha, Z. P. (2014). *Sustainable intensification in agricultural systems.* Annals of Botany, 114(8), 1571-1596.
[74] Bruulsema, T. W., Fixen, P. E., & Sulewski, G. D. (Eds.). (2012). *4R plant nutrition: A manual for improving the management of plant nutrition.* Norcross, GA, USA: International Plant Nutrition Institute (IPNI).
[75] Vanlauwe, B., Amede, T., Bationo, A., Bindraban, P., Breman, H., Cardinael, R., Couedel, A., Chivenge, P., Corbeels, M., Dobermann, A., Falconnier, G., Fatunbi, W., Giller, K., Harawa, R., Kamau, M., Merckx, R., Palm, C., Powlson, D., Rusinamhodzi, L., Six, J., Singh, U., Stewart, Z., van Ittersum, M., Witt, C., Zingore, S., & Groot, R. (2023). *Fertilizer and Soil Health in Africa: The Role of Fertilizer in Building Soil Health to Sustain Farming and Address Climate Change.* IFDC.

Case study 5: iSDA Virtual Agronomist (agronomic advisory, multi-country)

Overview

iSDA's Virtual Agronomist[76] is an agronomic advisory platform for African agribusinesses that are working with smallholder farmers to raise farm incomes for millions of smallholders in Africa. Virtual Agronomist provides farmers with individually tailored, science-based advice on fertilizer requirements and other agronomic practices, without requiring a soil test. Soil properties are estimated for each farmer's field using iSDAsoil[77], which is based on over 100,000 training points, combined with remote sensing data. Aggregators, co-operatives and outgrower schemes are the primary users of the service.

Virtual Agronomist aims to increase farm productivity and build loyalty and trust between the company and its network of farmers. An initial price point around US$ 10–15 per farm per season is attractive for farmers and organizations working with higher-value cash crops, and iSDA aims to reduce the price at scale to be attractive to farmers of food crops.

How does the initiative promote the use of fertilizer alternatives or improve use efficiency?

Virtual Agronomist provides a balanced nutrient management plan that is tailored to a smallholder farmer's individual circumstances, including estimates of soil nutrients from iSDAsoil and information on a farmer's soil and crop management history. For example, farmers can interactively see how varying amounts of manure will affect fertilizer application costs so as to optimize end-of-season profit. Virtual Agronomist helps ensure fertilizer formulations and quantities match crop nutrient needs and farmers' individual circumstances, thereby avoiding wastage and minimizing environmental damage.

What have been the constraints to scale-up and how have these been addressed?

In-house product development. iSDA traces its legacy to the African Soils Information Service and received startup investment from the Bill and Melinda Gates Foundation. Scaling the service was initially challenging due to the difficulty in sourcing flexible, customizable software tools from off-the shelf sources. iSDA overcame this challenge by building the product in-house, providing greater agility and tailoring the product to cater for clients' specific needs, and by using open-data platforms like Google Earth Engine to host their soil data.

Scaling the service takes time as it can require several repeated experiences for farmers to realize the value of the agronomic advice they receive. During the past two years iSDA has focused on demonstrating the impact of Virtual Agronomist across crops and countries. Scale-up is starting in earnest this year, with expansion to new countries and partnerships with institutions such as INDABA in Zambia. iSDA will take a two-pronged approach to expansion, focusing on 1) commercial entities that can pay for services that benefit their farmers, and 2) partnerships with extension services of governments, NGOs and corporations that have built relationships with farmers that are based on sustainable funding cycles. The aspiration is for iSDA to be financially sustainable by 2026.

Impact

Virtual Agronomist has been tested with over 2,000 farmers in Kenya, Uganda, Tanzania and Cote d'Ivoire, and is now expanding to include Ghana, Zambia, Malawi and hopefully Nigeria. The target is to scale to 100,000 farmers during 2024. The system is currently initialized for coffee, maize, sugar cane, sorghum, barley, sunflower, rice and soyabean. Virtual Agronomist advisory has increased maize yields in Cote d'Ivoire by an average of 40%, with the potential for this to double as yield-limiting constraints are addressed season after season. In Uganda, adoption of Virtual Agronomist advisory led to a 54% mean increase in the yield for sorghum, while in Tanzania it led to an average 40% yield increase for sunflower. Preliminary results from Tanzania reveal a 99% average increase in the yield for rice.

[76] https://www.isda-africa.com/virtual-agronomist/
[77] https://www.isda-africa.com/isdasoil/

Lessons learned: the company's perspective

- Virtual technology needs to be backed up with hands-on support, particularly for new users, to build trust in, and knowledge of, the product.
- Farmers have longstanding ideas about what their crops need, some of which are sub-optimal. Repeated positive experiences and demonstrations are required to change behaviours.
- iSDA employs agronomists, technologists and last-mile experts. This multidisciplinary approach has been a critical success factor in building and launching the product.

Case study 6: AgroCares (portable soil analysis, multi-country)

Overview

Founded in 2013, AgroCares[78] is an agricultural technology company based in the Netherlands that specializes in data-driven solutions that can optimize farming operations. The company's products include a handheld real-time soil scanner, a "lab in a box" soil analysis service, and a range of digital applications guiding fertilizer use and farm management, with the aim of making nutrient testing for soil, feed and leaf available to farmers globally. The company currently operates in 35 countries across Europe, Canada, Asia and Africa.

How does the initiative promote the use of fertilizer alternatives or improve use efficiency?

AgroCares' soil analysis system provides guidance on which fertilizers to use, required quantities, and optimal timing and application methods, with the central aim of improving yields while promoting long-term soil health. The portable scanner, which uses near-infrared spectroscopy, detects key nutrients (e.g. N, P and K), as well as SOC and pH levels. The company emphasizes that it is often necessary to resolve issues with SOC and pH levels before introducing a new fertilizer strategy.

The scanner's use of near-infrared spectroscopy offers near-instant results, allowing faster and more responsive soil management, including on-the-spot advice to farmers. While near-infrared has some limitations in terms of wavelength coverage, it provides enough reliable information on key soil parameters to enable decision-making.

What have been the constraints to scale-up and how have these been addressed?

AgroCares serves a diverse customer base, including private sector clients (for example, fertilizer companies and agri-tech providers), government extension services, and development agencies like the World Bank and WFP. Two factors have supported scale-up. First, the products are suitable for different crops, soil types and geographies, which offers a large potential customer base. Second, several of these crops – for example, cocoa and coffee – have significant sustainability interests – for example, requirements for more sustainable approaches to production, and increasing consumer awareness of sustainable production – which has helped to grow AgroCares' profile and attract external interest. Challenges to scaling the model have included the following:

There are no shortcuts to capacity building. After eight years of operating in Africa, the company notes that capacity building (of service providers) requires ongoing hands-on, in-person work. To support this, AgroCares has built strategic partnerships with in-country distribution partners that offer local knowledge and coordinate user education. AgroCares provides educational materials and in-house training to support this process.

Commercial operations in the smallholder farmer sector can be challenging. While the technology is one of the more affordable solutions on the market, the cost of the scanners (EUR 6,500) can still pose a barrier to uptake. AgroCares works on a subscription model, with recurring licence fees, to address this.

High upfront costs. In addition to product development, initial costs include building extensive databases on soil conditions in each new market. The company has accessed several rounds of concessional and commercial investment to support these activities.

[78] https://www.agrocares.com/

Influencing longstanding practices. Wet chemistry (with most analysis done in a liquid phase, usually in full-scale lab) is still widely regarded as the benchmark for soil analysis. In response, AgroCares works to explain the technology in relatable ways, adapting the offer to align with current farming practices.

Impact

The company has so far sold around 1,600 portable scanners, reaching 80,000 farmers in 2022 for soil testing. Cambodian farmers employing AgroCares solutions have successfully sustained crop yields while cutting mineral fertilizer use by 30-40%. Similarly, in Africa, farmers sticking to the same mineral fertilizer volume as applied in past seasons, coupled with the usage of lime and organic matter, have witnessed promising potential to boost crop yields. Improvements could range from 20 to 30%, and even escalate to 50% in certain instances.

Lessons learned: the company's perspective

- Understand your customer and concentrate on solutions with high scalability potential. Direct work with farmers was beneficial for gaining insights; however this did not provide a pathway to scale by itself.
- Begin by focusing on a narrow set of specific value chains before diversifying. This helps maintain a clear strategic direction and to optimize resource allocation.
- Establishing strong relationships with local ministries of agriculture and universities can add credibility and offer access to local knowledge.

Case study 7: Agventure Centre of Excellence for Crop Rotation (integrated soil health, Kenya)

Overview

Agventure[79] is a farmer-owned company that promotes sustainable farming practices in non-irrigated cereal-based systems. It has developed an "ecosystem of services" approach that aims to increase the resilience and profitability of participating farmers by supporting soil-building through crop diversification. Members are provided with agronomy advice that is backed by soil testing, in-field crop and input trials, data, finance, and insurance, as well as reliable output markets and quality inputs. Marketing through Agventure's Pure Mountain brand for pulses and canola rotation crops provides steady offtake.

To build farmer capabilities in the wider farming community, Agventure launched the Centre of Excellence for Crop Rotation (CoE) in 2013. CoE is a not-for-profit business unit targeting several thousand large-scale and smaller farmers (noting that a minimum requirement is that farms need to be under mechanical cultivation) that offers on-the-ground ecosystem of services support in combination with access to markets. CoE farmers are engaged by Agventure under an offtake agreement on a contract-to-contract basis.

How does the initiative promote the use of fertilizer alternatives or improve use efficiency?

A key priority for Agventure is promoting long-term soil health. To support this, the company promotes a reduction of inorganic input use on member farms and supports conservation agriculture through 1) crop rotation, 2) transitioning to zero-tillage or minimal tillage and controlling traffic on fields to prevent compaction and protect soils, and 3) building access to diverse markets to enable profitability for all crops in the rotation.

To support the uptake of fertilizer alternatives, Agventure is testing biostimulants, seed coatings and other organic treatments through their in-house "Seed & Trials" department. The aim is to identify relevant, effective products and then promote these to member farmers as part of the

[79] https://www.agvke.com/

ecosystem of services. The company is exploring options for standardizing information on fertilizer alternatives and disseminating knowledge to member farmers via social media, digital services, field days and extension officers.

Farmers contracted through the CoE receive soil testing on every field during every season to determine which inputs are required for their crops. This step is critical as there is wide variation in soil needs and no one-size-fits-all solution is suitable. Typically, CoE farms have degraded soils and decreased productivity following decades of continuous monocropping, with many seasons required to replenish these soils. Agventure's introduction of rotation crops, such as sunflower and canola, has opened markets for their partner farms.

What have been the constraints to scale-up and how have these been addressed?

Recognizing that their system of farming, the crops they promote, and the scale they need to succeed does not reach every farmer, Agventure focuses only on mechanizable farms in areas recognized as having "high potential" for rotation crops like canola and sunflower. These farms are large and sophisticated compared to average Sub-Saharan Africa farm sizes but are nevertheless in need of services that the CoE offers: soil analysis, training, agronomy advice and market linkage.

Constraints to scale included **convincing farmers** to embrace the novel system Agventure promotes, to trust that offtake agreements are legitimate, and to accept the lower immediate financial return of rotation crops compared to cereal crops. Nevertheless, in 2020, smaller farmers contributed nearly 20% of Agventure's total offtake.

Once farmers have begun to focus on soil health and are committed to working with Agventure, it is sometimes difficult for them to participate due to **lack of the financing** needed to buy seed, inputs, and machinery. Here, Agventure steps in to help link farmers to finance. They work with Kenya's Equity Bank to develop a financing package for their farmers that gives them access to the services they need and builds credit.

To bridge this **gap between immediate needs and longer-term objectives** (for example, in regard to soil health) Agventure has introduced break crops, such as canola, which is the first step towards soil improvement. Farmers enter into a contract with Agventure under which they commit to these practices on a season-by-season basis, thereby aligning immediate actions with future soil health benefits.

Impact

Establishing the CoE and including outgrower farmers has increased Agventure's overall output and justified the investment in the canola value chain. Over the past 10 years, Agventure has reached over 10,000 smaller farmers, with a field officer team in high potential regions working daily to recruit new farmers. As the profitability of rotation crops increases, and farmers continue to use fewer inputs, on-farm profits rise. Farmers who integrate crop rotation into their production practices show higher profitability compared to those in monocropping systems. The focus on soil health has led to increased water and nutrient retention, reduced soil erosion, higher yields, increased soil carbon sequestration, and reduced on-farm energy use.

Lessons learned: the company's perspective

Key factors contributing to uptake include establishing linkages between input and offtake markets and providing financial assistance. Moreover, context is crucial, especially in regard to soil health, for which a one-size-fits-all solution does not apply.

Both large agribusinesses and smaller farmers stand to gain from collaborative partnerships. Larger farms can attain scalability in new product lines by integrating outputs from smaller farms, effectively broadening their supply chain. Conversely, smaller farms can tap into new markets and access services traditionally available only to larger farms.

Case study 8: Farmerline (soil testing and input optimization, Ghana)

Overview

Farmerline[80], an AgriTech company based in Ghana, serves as an input supplier, offtaker, and provider of extension and advisory services within the agricultural value chain. In response to the food and fertilizer crisis driven by the Russian invasion of Ukraine, Farmerline partnered with CASA TAF to provide advisory services to smallholder farmers that are based on specific recommendations arising from soil testing activities. One of the key recommendations is to use organic fertilizers.

Promoting sustainable practices

Through CASA TAF's crisis support, Farmerline is implementing a soil testing and input optimization programme that provides bespoke recommendations to smallholder farmers. These include advice on using organic fertilizers and other inputs optimally to enhance soil health and crop yield.

Drivers and constraints

The soil testing and input optimization programme's primary objective is to improve smallholder farmers' productivity by providing data-driven, tailored advice on input usage based on existing soil conditions. While farmers reported increased awareness of the use and application of organic fertilizers, there is still limited availability of these products in the Northern region of Ghana. Farmerline has run field trials of organic and inorganic fertilizer blends to encourage farmers to adopt these more sustainable practices on their own farms, which will improve soil health in the long term, as well as productivity.

Lessons learned: the company's perspective

Though it is too early to fully assess the programme's impact, the initial results show that targeted, soil-specific input recommendations can inform more sustainable and effective farming practices. The central challenge to address remains the high costs of inputs, which limit farmers' ability to implement recommended strategies across their entire farms. The solution has been for the training to encourage farmers to apply the right input, at the right time, with the correct frequency, to a smaller plot, as a trial.

Key lessons from this early stage include the need for a multifaceted approach to promoting sustainable farming. While soil testing and input optimization provide valuable data for improving farming practices, issues such as cost can limit adoption rates. Therefore, repeated, timely messaging and potential financial interventions may be necessary to bolster adoption. This case study underscores the need for comprehensive solutions that address both the scientific and economic aspects of sustainable farming.

[80] https://farmerline.co/

4. Challenges and opportunities

This section draws together challenges and opportunities for donors, government policymakers, investors, and the private sector, in relation to supporting the large-scale adoption of alternative products and improving fertilizer use efficiencies.

Despite the diversity of the solutions presented in the case studies, several shared themes emerge. These include the following: the need to build awareness of alternative products and strategies; the importance of product quality; the need to invest in local production and distribution; the need to establish the business case for serving the smallholder farmer segment; the need to build stronger linkages between the R&D of new products and pathways to commercialization; and the importance of developing more supportive policies and regulations. Figure 3 summarizes the opportunities, while further detail is provided below.

1 Influencing farming practices

- Agribusinesses leverage outgrower schemes to promote alternative products and practices
- Governments (with donor support if required) promote low- and high-tech solutions in parallel
- Donors and firms explore market-based incentives for long-term soil health

2 Promoting higher quality alternative products

- Donors, governments and investors make product quality a key criterion for support
- Standards bodies develop/scale certifications (e.g. ISO) for Biological Products
- Biological Products firms with donor support invest in R&D on more robust products, including local strains

3 Investing in local green ammonia production

- DFIs and impact investors invest in modular technologies
- Donors support R&D on smallholder-friendly products
- Firms, donors and associations link renewable energy developers and modular green ammonia plants
- Governments incentivise adoption e.g. tax incentives

4 Improving the business case for serving the smallholder segment

- Donors and investors co-finance production infrastructure for smallholder products e.g. automating packaging
- Startups and donors test locally-scalable waste-to-fertiliser models
- Investors and donors support technology with the potential to lower cost-per-user for fertiliser information

5 Supporting links between R&D and investment

- Investors (supported by concessional capital from donors and foundations) explore early-stage opportunities in Biological Products and green ammonia
- Investors support mature businesses to broaden/deepen offers
- Governments, industry bodies and donors support collaboration between researchers and commercial actors

6 Developing supportive policies and regulations

- Governments update policies to support alternatives
- Governments redesign subsidies to promote soil health
- Governments, firms and donors support regional coordination bodies
- Industry bodies promote standards on Biological Products

Cross-cutting Priorities: Promoting site-specific fertiliser strategies at scale | Supporting long-term soil health | Addressing the needs of smallholder farmers

Figure 3: Summary of opportunities

1. Influencing longstanding farming practices

Several companies highlighted the challenges of influencing longstanding farming practices in the smallholder farmer segment. One key factor was limited awareness of alternative products and technologies, and limited knowledge of their benefits, creating a bottleneck to large-scale uptake. In addition, information can be complex and difficult for first-time users to act on, particularly when presented in the context of an integrated approach to soil health.

The incentives for testing new fertilizer strategies are also not straightforward. Reducing or increasing fertilizer use, and the adoption of unfamiliar products and processes, presents additional risks, both real and perceived. Because the use of alternative products is still limited, there are also few reference cases for farmers to consider: for example, a neighbouring farmer seeing increased yields after using alternative products. Finally, the business case for smallholder farmers to improve long-term soil health – for example, through the application of organic products – is not always compelling, given their immediate needs and limited budgets. Efforts to introduce alternative products need to be grounded in a deep understanding of the risks facing farmers in each specific context. Care should be taken to avoid putting additional risks on smallholders with limited income, tight margins, and few safety nets.

The case studies confirm that influencing longstanding farming practices takes time and ongoing, hands-on effort. To be more widely adopted, biofertilizers need to be actively promoted to smallholder farmers in conjunction with a phased approach to training on their use so that farmers see the benefits of making the transition without experiencing a reduction in yield, combined with after-sales support and regular follow-ups. Technology-based solutions, such as soil testing kits and remote sensing to provide information on soil conditions, can be an important part of an integrated approach, but soil health information needs to be combined with interpretation of results, ongoing customer education, and regular monitoring.

Opportunity 1.1: Agribusinesses running smallholder outgrower schemes have an opportunity to promote and distribute alternative products and support initial and ongoing use, in conjunction with soil analysis and other technology-based solutions: for example, as part of an integrated soil health management service. Donor programmes should identify and support these initiatives, both on a standalone basis and as part of existing programming.

Opportunity 1.2: Governments (with donor support if required) should lead programmes that promote high- and lower-tech solutions in parallel, supported by ongoing education and monitoring. Tools such as portable soil sensors and soil management apps can provide valuable data on soil health and fertilizer needs. The initial cost of deployment can be mitigated by working through co-operatives, nucleus farms, and other established farmer groups, and technology firms can engage with local financial institutions to explore financing options. Lower-tech tools – for example, soil health cards based on qualitative information (e.g. soil life, visible salts, smell, and workability)[81] – can offer a lower-cost, more accessible alternative for smallholder farmers. Both groups of solutions have the potential to influence fertilizer use when combined with ongoing training and support (particularly through in-person visits, with lower-cost options like call centres also showing a positive impact)[82].

Opportunity 1.3: Donors and private firms should explore market-based incentives that promote long-term soil health: for example, working with agri-insurance providers[83] to

[81] Testen, A., Mamiro, D., Nahson, J., Amuri, N., Culman, S., & Miller, S. (2018). *Farmer-Focused Tools to Improve Soil Health Monitoring on Smallholder Farms in the Morogoro Region of Tanzania*. Plant Health Progress, 19, 56-63.
[82] Kishore, A., Alvi, M., & Krupnik, T. J. (2019). *Development of balanced nutrient management innovations in South Asia: Lessons from Bangladesh, India, Nepal, and Sri Lanka* (CSISA Project Notes 14). International Food Policy Research Institute (IFPRI).
[83] For example, https://www.pula-advisors.com/

develop crop insurance products that monitor and incentivize efforts to achieve long-term soil health. Governments have an opportunity to subsidize insurance schemes (and provide other forms of compensation) that protect farmers transitioning to alternative products from lower yields over the short term[84]. Opportunities to influence farming practices via public subsidies are presented under *6. Developing supportive policies and regulations,* below.

2. Promoting higher-quality alternative products

The quality of Biological Products and organic fertilizers significantly influences their effectiveness. Lower-quality products diminish potential yields and fail to provide the full benefit in terms of soil health. In addition to these "direct" issues, negative customer experiences with inferior-quality products are likely to discourage repeat use.

At the production stage, the quality of Biological Products is influenced by the selection of suitable microbial strains, the use of appropriate carrier materials, proper sterilization techniques, and an adequate supply of nutrients for microbial growth. The quality of organic fertilizers is determined by the source of organic matter, the composting or fermentation process, and the content and balance of nutrients it supplies. While most organic products are robust, Biological Products can be compromised by factors like temperature extremes, moisture levels, and inappropriate storage conditions – all common challenges when distributing these products to last-mile customers.

There are some examples of production in Africa and South Asia; however, there are also significant gaps – for example, in terms of funding to procure high-quality production equipment and establish sterile facilities.

Opportunity 2.1: **Donors and governments should make product quality a key criterion when providing support to companies in the space** (e.g. via a startup incubator, challenge fund, or other incentive scheme), and investors should assess product quality as part of any commercial or concessional investments in the sector. Financial support should also be combined with specialist technical assistance on production, handling, storage, and distribution to maximize product quality.

Opportunity 2.2: Standards bodies, with donor support where required, should scale up the use of certifications (e.g. International Organization for Standardization standards) and quality testing in the production of Biological Products. Donors and governments should build awareness of the importance of Biological Product and organic product quality among "scale agents": for example, government extension services, product distributors, agricultural associations, and farmer co-operatives.

Opportunity 2.3: Biological Product manufacturers can reduce supply chain risks by developing more robust products: for example, by investing in a) R&D to create formulations that are more resilient to temperature extremes and storage conditions, and b) research on indigenous micro-organisms that may be better adapted to local conditions than imported strains. There is an opportunity for **development partners** to co-fund this research. Supporting improved logistics can avoid product loss or deterioration – for example, by experimenting with different packaging solutions and building the knowledge of logistics partners on optimal storage and transportation methods. Building the capacity of local distributors to ensure efficient delivery and apply suitable quality control measures will also add value.

3. Investing in local green ammonia production

Investing in smaller-scale, localized green ammonia production presents various opportunities, particularly in areas that face challenges accessing traditional mineral fertilizer

[84] Hazell, P., Sberro-Kessler, R., & Varangis, P. (2017). *When and How Should Agricultural Insurance Be Subsidized?: Issues and Good Practices*. http://hdl.handle.net/10986/31438

supply chains. Modular production has the potential to lower entry barriers for developers and offers more consistent, affordable ammonia supply via shortened supply chains, lower logistics costs, and reduced transport emissions. The technology is particularly suited to contexts with renewable energy potential (e.g. solar or wind) and access to water.

The key challenges are developing forms of ammonia that are useable by smallholder farmers, high capital costs for production infrastructure, and the need for affordable and reliable renewable energy. Opportunities for overcoming these barriers include the following:

Opportunity 3.1: Donors and investors should support piloting and scale-up of smaller-scale, modular green ammonia production in areas where there is low or inefficient fertilizer use. There is an opportunity for DFIs and impact investors to provide lower-cost capital and risk guarantees to project developers, which is a key element considering the significant costs associated with infrastructure assets.

Opportunity 3.2: Donors should support the development of smallholder farmer-friendly products. There is an immediate opportunity to (co)fund feasibility studies for smallholder pilot projects: for example, on the potential to convert anhydrous ammonia into ammonium sulphate. There is also an opportunity for donors and research institutions to assess the most cost-effective methods for producing granular fertilizers, beyond traditional options like urea. Finally, there is an opportunity for firms and donors to research new carrier materials (e.g. biochar) and build partnerships between green ammonia plants and biochar producers.

Opportunity 3.3: Industry leaders, associations, and donors should build partnerships between green ammonia producers and renewable energy providers to accelerate pilots and scale-up. Modular green ammonia production depends on access to renewable power, while small-scale renewable energy projects stand to benefit from "anchor" commercial offtakers like modular green ammonia producers. Areas where mini-grids are most needed are also likely to be areas with low fertilizer use, offering a win-win opportunity.

Opportunity 3.4: Governments, with donor support if needed, should develop policies and incentives that stimulate the adoption of green ammonia among smallholder farmers, including subsidies for initial adoption, tax breaks for producers[85], and support for research into smallholder farmer-friendly production and application methods.

4. Improving the business case for serving the smallholder segment

The business case for targeting the smallholder farmer segment is still being established across most businesses profiled in the case studies. The central challenge is that making products and services attractive and relevant to smallholder customers often drives up unit costs beyond the ability to pay. This is because there are no one-size-fits all solutions when it comes to promoting alternative fertilizer strategies, and the more specific the solution, the more it tends to cost. There is also a lack of price premiums for organic foods in Africa, which further disincentivizes farmer uptake.

For biofertilizers, the largest customer segment is large commercial farms in Europe, the United States, and other developed economies, while smallholder farmers in Sub-Saharan Africa and South Asia remain a nascent customer group[86]. Larger customers tend to buy higher volumes over fewer transactions and tend to operate in markets where these products are increasingly well established. In addition, demand for Biological Products in these markets is growing quickly, offering a "path of least resistance" for commercial product manufacturers. Creating financially viable business models targeting smallholder farmers

[85] Tax incentives offered to US-based green ammonia products via the Inflation Reduction Act have had a significant impact on the US green ammonia market.
[86] Adekunle, R., Roopnarain, A., & Adeleke, R. (2021) *Biofertilizer production in Africa: Current status, factors impeding adoption and strategies for success*. Scientific African, 11.

can be more challenging, due to the need to invest in new production equipment (e.g. automated packaging for smaller pack sizes), building distribution partnerships that require hands-on technical support, and navigating supply chain risks.

Businesses that have made inroads into the smallholder farming segment note the importance of building partnerships with local “scale agents” like extension services and commercial farms running outgrower schemes, to support cost-effective outreach to larger numbers of smallholder farmers.

It can also be challenging to make the business and investment case for organic fertilizers. One reason for this is the natural limit on scale due to the bulky, low-value nature of these products. Longer supply chains translate into higher unit costs, which undermine financial viability, as well as increasing transport-based emissions. Secondly, farmers often need to apply organic matter over long periods of time to see results in improved soil quality, which can disincentivize use. In-situ production of organics – for example, on-farm composting – offers benefits in terms of more straightforward, lower-emission logistics[87], but also faces natural limits on scalability.

Soil testing and remote sensing technologies continue to evolve and improve. These technologies can provide site-specific information to support tailored fertilizer strategies; however, the added costs of “wraparound” supporting services – for example, training and after-sales support – can increase per-user costs significantly.

The business case for green ammonia relies on being able to offer the product at the same, or lower, cost as compared to traditional alternatives, finding anchor customers with the ability to reach large numbers of smallholder farmers cost-effectively, and developing products that this segment can use safely and effectively.

Opportunity 4.1: Donors and investors should (co)finance production infrastructure – for example, automated packaging equipment – to lower unit costs. Biological Product producers should work more intensively with distributors (e.g. agro dealers) to develop cost-effective marketing and distribution strategies.

Opportunity 4.2: Entrepreneurs and donors should test locally scalable models for organic fertilizers, particularly waste-to-fertilizer solutions. Associations and donor programmes should broker partnerships between organic fertilizer producers and large-scale offtakers (e.g. commercial agribusinesses for use across an outgrower network, or green ammonia producers if the use case for biochar as a carrier can be proven); between producers and organizations with the capacity to test quality and recommend improvements; and between producers and integrated soil health technology providers looking for local suppliers of organic products.

Opportunity 4.3: Investors and donors should support technologies with the potential to decrease cost-per-user fertilizer information. There are also opportunities to support linkages between technology providers and actors with access to large smallholder farmer networks: for example, government extension services, input suppliers with large distribution networks, and commercial outgrower schemes.

5. Supporting links between R&D and investment

Several of the profiled businesses received grant funding to support initial research and product development. Beyond this initial phase, access to external financial and non-financial support was mixed. Two key points of transition were identified as particularly

[87] Vanlauwe, B., Amede, T., Bationo, A., Bindraban, P., Breman, H., Cardinael, R., Couedel, A., Chivenge, P., Corbeels, M., Dobermann, A., Falconnier, G., Fatunbi, W., Giller, K., Harawa, R., Kamau, M., Merckx, R., Palm, C., Powlson, D., Rusinamhodzi, L., Six, J., Singh, U., Stewart, Z., van Ittersum, M., Witt, C., Zingore, S., & Groot, R. (2023) *Fertilizer and Soil Health in Africa: The Role of Fertilizer in Building Soil Health to Sustain Farming and Address Climate Change.* IFDC.

challenging: shifting from initial product development to early commercialization, and scaling from early commercialization to large-scale operations.

A key consideration for investors is the effectiveness of Biological Products. Interviews indicated a perception that the development of these products is sometimes rushed, without proper field testing. In addition, inadequate mutual awareness between investors, development partners, and new ventures poses a challenge. Furthermore, making a persuasive argument for products in the early stages of development that have not yet achieved commercial viability can be difficult, especially when the founding team's skills are more focused on technical and scientific aspects than on business.

From the sample of businesses, it appears that technology-based solutions – for example, soil testing technology – may be more inherently attractive to external investors due to the fact that their results are more understandable and there is a clearer pathway to scale.

Opportunity 5.1: Impact investors and DFIs should engage more actively with businesses related to fertilizer alternatives. There is a spectrum of opportunities which fit the range of financial instruments which these investors can deploy (e.g. equity, debt, repayable grants), from early-stage ventures in Biological Products and fertilizer use technologies through to larger-scale projects supporting green ammonia production, particularly modular technology. **Donors and foundations** should provide concessional capital to help crowd private investment into this nascent market. There is also an opportunity to provide technical assistance alongside funding: for example, market analysis focusing on the potential of the smallholder farmer segment, and feasibility studies for new production infrastructure.

Opportunity 5.2: Investors and donor programmes should support more mature businesses to broaden and deepen their offers with concessional finance: for example, for improving the efficacy, robustness, or cost of existing products; tailoring existing products to new crops, geographies, or customer groups; and developing new products that leverage existing production infrastructure, market knowledge, supply chains, and customer bases.

Opportunity 5.3: Governments, industry bodies, and donors should support knowledge exchange and collaboration among research institutions, businesses, and investors. There is an opportunity to increase representation from the commercial sector and potential investors in workshops and events relating to fertilizer alternatives, and to facilitate exchanges between these actors and members of the scientific and technical community. This can spur co-investment initiatives, promote the sharing of best practices, and accelerate the development and commercialization of new soil health solutions.

6. Developing supportive policies and regulations

Regulations and standards guiding the development, trade, and use of alternative fertilizers are generally under-developed in the target regions. Countervailing duties, administrative bureaucracy, and customs for various categories of goods obstruct technology acquisition. For example, the registration of new Biological Products can be time-consuming, costly, and difficult to navigate (and is often not factored into developers' timelines and budgets). The use of non-indigenous microbial species strains that must be imported will face a more severe regulatory environment than using indigenous species and strains. Manure management policies in Sub-Saharan Africa countries are often either lacking or incomplete and tend to view animal waste as a health risk instead of as a resource[88].

In addition, blanket fertilizer subsidy programmes have created a range of perverse incentives, encourage indiscriminate use of mineral fertilizers, and have held back the

[88] Asaah, N. O., Pelster, D. E., Owino, J. O., de Buisonjé, F., & Vellinga, T. (2019) *Manure Management Practices and Policies in Sub-Saharan Africa: Implications on Manure Quality as a Fertilizer.* Frontiers in Sustainable Food Systems, 3.

development and adoption of fertilizer alternatives and integrated soil fertility management practices.

Opportunity 6.1: Governments, with donor support if required, should update existing fertilizer strategies[89], policies, and regulations to promote integrated soil health over the long term, including the production, trade, and use of organics and Biological Products.

Opportunity 6.2: Governments should re-design subsidies to incentivize farmers to follow the 4Rs of fertilizer use, and to invest in alternative or supplementary products and practices that improve nutrient use efficiency and restore soil health. Transition subsidies can support the adoption of fertilizer alternatives by offsetting initial yield losses, higher costs, and educational expenses during farmers' adaptation to new practices and products. There is also an opportunity for governments to explore the potential to offer tax incentives for producers of high-quality fertilizer alternatives.

Opportunity 6.3: Governments, firms, and donors should establish or support regional coordinating bodies: for example, the West African Fertilizer Control Committee. Research and private sector players should be included in coordinating bodies to support access to technical and commercial perspectives.

Opportunity 6.4: Industry bodies and standards organizations should implement general standards on the development and use of Biological Products. Despite the benefits, these products are not risk-free: for example, nitrogen-fixing bacteria applied to crops can potentially disturb natural ecosystems if they propagate to non-target species. It is therefore important to ensure risk assessment pre-use and periodic monitoring over the longer term.

[89] For example, World Bank (2023) *Fertilizers and Soil-Health Roadmap for West Africa and the Sahel*. Report from the High-Level Roundtable on Fertilizers: Investing in the Future by Improving Soil Health, Lomé, Togo.

5. Conclusion

The products and technologies profiled in this report have already shown the potential to improve yields and mitigate climate and environmental damage. The challenge is scaling up solutions in the smallholder farmer segment in commercially viable ways. Achieving this will depend on ongoing development of these products for smallholder use, testing new business models, and closing the gap between scientific innovation and investment.

The case studies and wider evidence highlight some principles for future work in this space. First, solutions should be built with long-term soil health as a central aim. Second, models must support fertilizer strategies that are tailored to specific contexts, avoiding one-size-fits-all outcomes. Third, businesses looking to have a positive impact on food security need to position smallholder farmers as a critical customer group, and work to develop the commercial case for serving this segment. And, finally, meaningful change in this sector takes consistent effort over time – including substantial hands-on support – and there are few shortcuts.

With sustained effort, there is the potential to support significant increases in agricultural productivity, and to improve food security and the livelihoods of smallholder farmers, and to do so in ways that mitigate climate and environmental impacts.

Commercial Agriculture for Smallholders and Agribusiness

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