The Impact of Organic Fertilizer Among Smallholder Farmers in Sub-Saharan Africa

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Executive Summary

The agriculture sector is a key contributor to Africa's economy, but is held back by large yield gaps. These yield gaps have persisted in Africa despite dramatic increases in fertilizer application over the last two decades, driven primarily by the use of imported inorganic fertilizers. There is little evidence that continuing to increase the application of imported inorganic fertilizers alone will generate the desired outcome of increasing yields. At the same time, the increased use of imported inorganic fertilizer has resulted in negative soil-health, environmental, and economic outcomes in Africa.

Application of organic fertilizer, in balance with inorganic fertilizer, is a promising prospective solution to these problems. A renewed call to "triple domestic production and distribution of certified quality organic and inorganic fertilizers by 2034" was recently announced in the Nairobi Declaration of the Africa Fertilizer and Soil Health Summit held May 7–9, 2024 in Nairobi. This declaration includes an increased focus on domestic fertilizer production, the need for a balanced approach between increased productivity and soil health restoration, and the efficient use of organic and inorganic fertilizers, along with other complementary inputs (African Union, 2024).

This study examines the relationship between organic fertilizer usage and its various benefits in the setting of smallholder farmers in sub-Saharan Africa. There is robust agronomic evidence of the impact of organic fertilizer on soil fertility, and agricultural productivity and profitability, and suggestive evidence of the environmental benefits and economic viability of organic fertilizer. Additional rigorous evaluations on organic fertilizers' impacts and cost-effectiveness could be helpful to inform policy recommendations further. The adoption of organic fertilizer remains low because of insufficient local manufacturing capacity, limited knowledge of the benefits of using organic fertilizers, and labor and financial constraints faced by farmers. Commercial organic fertilizers coupled with digital extension services have the potential to overcome some of those adoption barriers, and therefore improve farmers' usages and welfare.

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1. Introduction

Key takeaways:

- Yield gaps persist in Kenya and the region and are correlated with poverty.
- Soil degradation is one of the key challenges in closing the yield gap.
- Many approaches can be used to improve yields: adequate fertilization is an important element to yield improvement.
- Historically policy has focused on inorganic fertilizer. But inorganic fertilizer alone does not counteract long term soil fertility decline.
- Introducing organic fertilizer contributes to improving yields and soil fertility; but there are challenges with homemade organic fertilizer. Commercial organic fertilizer industry is nascent in the LMIC settings.
- This paper assesses the available evidence on the agronomic and economic impact of organic fertilizers and discusses the opportunities and challenges to substantially increase the adoption at scale.

The agriculture sector is the backbone of sub-Saharan Africa's economy. It employs around 60 percent of the labor force, produces approximately 22 percent of the gross domestic product (GDP), and accounts for more than 10 percent of export revenues (Wudil et al., 2022). In Kenya, the agriculture sector employs more than 40 percent of the total population and 70 percent of the rural population, and contributes 33 percent of GDP as the largest contributing sector (U.S. Agency for International Development, 2023).

1.1 Yield gaps

Despite the importance of the agriculture sector in sub-Saharan Africa and in Kenya specifically, many farming systems in the region are characterized by large, persistent yield gaps and stagnating agricultural growth rates (Food and Agriculture Organization [FAO], 2024; Kenya National Bureau of Statistics [KNBS], 2023). A yield gap is the difference between measured or reported actual yields, and the potential yield a crop could achieve in a particular environment (van Ittersum et al., 2013). Though there are various methods of calculating this gap with differing levels of modeling and assumptions, results consistently show a remarkably large yield gap for Kenya and many other countries in the region, with average yields in the range of 70-80 percent of the potential yield for maize, 60-80 percent for beans and sorghum, and 40-60 percent for rice (Grassini et al., 2017; Global Yield Gap Atlas, 2024).

More importantly, agricultural productivity has stagnated in recent years in Kenya, as in many other areas in sub-Saharan Africa. In Kenya, the real agricultural growth rate averaged only 2.4 percent from 2018 to 2022, including negative growth in two of these five years (KNBS, 2023). As a whole, the average annual growth rates of Africa's agricultural value added slowed from 5.4 percent per year in 2002-2011 to 3.5 percent in 2012-2021 (Food and Agriculture Organization [FAO], 2023). The sluggish growth rates make closing the yield gaps even more difficult.

In large part due to these yield gaps, incomes of smallholder farmers in sub-Saharan Africa remain stubbornly low. For example, the median monthly income for smallholder farmers is only USD 16 in Zambia, USD 19 in Tanzania, and USD 28 in Kenya (Karlyn, 2017). These yield gaps also lead to high levels of undernourishment in Africa, with nearly 20 percent of the population undernourished as of 2014 (Giller, 2020). Nearly 70 percent of households in Africa depend on agriculture for part of their livelihoods, and food regularly makes up more than 50 percent of the expenses of many households in Africa (van de Ven et al., 2021), making yield improvements critical to solving nutrition and food security challenges across the continent (Giller, 2020). These concerning trends of yield gaps and stagnated growth demand new innovations and solutions.

1.2 Soil fertility

Several challenges have contributed to the persistent yield gaps, including land fragmentation, soil fertility decline, dated management practices, climate change, and institution- and market-related factors (Birch, 2018; D'Alessandro et al., 2015). Of these challenges, the decline in soil fertility is one of the most significant.[1] Degradation of soil fertility across sub-Saharan Africa is well documented, particularly in terms of soil organic matter (SOM) and nutrient balances, as well as other indicators of soil productivity (Nandwa & Bekunda, 1998). The correlation between the decline in soil fertility and the decline in crop yields is demonstrated in multiple studies (Bekunda et al., 2005; Moebius-Clune et al., 2011; Mutuku et al., 2020; Tittonell & Giller, 2013; Tully et al., 2015). These studies relate soil fertility decline to various parameters, notably SOM or soil organic carbon (SOC), soil nutrient status, soil acidity, and soil physical features.

Farming itself is the major cause of these declines in soil fertility, as many basic agricultural practices have been shown to contribute to soil fertility decline. These practices include disturbing the soil, exporting soil nutrients (in crops), and reducing permanent soil cover (Kimetu et al., 2008, Means et al., 2022). In a meta-analysis of 102 studies, Kopittke et al. (2017) show that converting native vegetation to cropping land results in the depletion of critical soil nutrients, including decreases of 43 percent of carbon (C,) 42 percent of nitrogen (N), 27 percent of phosphorus (P), and 33 percent of sulfur (S). Furthermore, when land is converted to farmland, it becomes more susceptible to erosion, and the increasing levels of soil erosion also contribute to the decline of soil fertility (Kogo et al., 2020).

Continuous agricultural cultivation without adequate replacement of nutrients and organic matter causes negative nutrient balances in soils, and reduces soil fertility through loss of SOM (Moebius-Clune et al., 2011; Nyberg et al., 2012; Tully et al., 2015). Crops extract nutrients from soil, and if more nutrients are extracted than are replaced by natural processes or human intervention, this negative nutrient balance depletes the soil fertility over time, as has been observed across several studies of African farming systems (Chianu et al., 2012; Vanlauwe & Giller, 2006).

Improving the nutrient balance can be achieved by increasing input of nutrients, which has an immediate effect on crop growth and yield. However, improving SOM and the physical properties of soils requires not only nutrient inputs, but management of organic resources, including by external addition of organic amendments (Kihara et al., 2016; Roobroeck et al., 2021). SOM (or the closely related SOC) can be defined as organic materials found in soils; these materials originate from living organisms, especially plants and microbes (Chenu et al., 2024). The level of SOM in soils is an essen-

1 Appendix A provides a detailed discussion on soil fertility and soil organic matter.

tial component of soil fertility, and it contributes to crop productivity (Lal, 2006; Manlay, Feller & Swift, 2007). Many studies across sub-Saharan Africa and the rest of the world show the strong relationship between crop yields and SOM (Lal, 2006). Both nutrient management and organic matter management practices offer significant potential for improvement in soil fertility (Gicheru, 2012; Tittonell & Giller, 2013).

1.3 The role of fertilizer in agricultural productivity

One generally accepted policy recommendation to close the yield gap has been to increase fertilizer application. For example, in the Abuja Declaration on Fertilizer for the Africa Green Revolution, announced in June 2006, the African Union member states resolved to increase fertilizer use from 8 kilograms per hectare (kg/Ha) in 2006 to an average of at least 50 kg/Ha by 2015, including both inorganic and organic fertilizers (African Union, 2006).

1.3.1 Inorganic fertilizer

Inorganic fertilizer is defined as "a nutrient-rich fertilizer produced industrially by chemical processes or mineral extraction" by the Food and Agriculture Organization (FAO) Committee on Agriculture and has various types, such as synthetic, mineral, or chemical fertilizers (Food and Agriculture Organization [FAO], 2018). This paper uses the generalized term "inorganic fertilizer" and does not differentiate among those specific types (including urea).

On one hand, various studies have shown that the application of inorganic fertilizer is an important factor in maintaining and increasing crop yields (Giller, 2020; Lassaletta et al., 2014; Stewart et al., 2005). However, on the other hand, despite the near tripling of fertilizer application rates in Africa since the Abuja Declaration, to 22 kg/Ha in 2022 (Malpass, 2022), a proportional decrease in the yield gap has not been observed (Dimkpa et al., 2023; Jayne et al., 2018). For example, in countries such as Kenya, where fertilizer application rates have achieved the Abuja Declaration targets of 50 kg/Ha, yields have continued to stagnate (Ng'ang'a, 2024). The application of inorganic fertilizer without adequate management of organic amendments could result in soil fertility decline that could lead to reduced yields in the long term, especially when inorganic fertilizer applications are interrupted (Tittonell & Giller, 2013). There is little evidence suggesting that continuing to increase the application of inorganic fertilizers alone will generate the desired outcome of increasing yields.

Moreover, the dramatic increase in fertilizer use in Kenya and many other parts of Africa has been driven primarily by an increase in imported inorganic fertilizers (Ariga & Jayne, 2011), with less than one percent of fertilizer use coming from commercial organic fertilizers in Kenya in 2022 (Commercial Agriculture for Smallholders and Agribusiness [CASA], 2023b). According to this business report, the heavy reliance on inorganic fertilizer compared to organic fertilizer, and on imported fertilizer compared to locally produced fertilizer, has contributed to several additional problems, including soil degradation through acidification and nutrient mining; increased greenhouse gas emissions from fertilizer transportation; and macroeconomic shocks due to the rising price of fertilizer imports, especially following Russia's invasion of Ukraine and the subsequent global food and fertilizer crisis (Commercial Agriculture for Smallholders and Agribusiness [CASA], 2023a).

1.3.2 Organic fertilizer

By contrast, organic fertilizers are derived from organic materials, primarily plant residues and livestock manures. The specific use of the term organic fertilizer lacks consistency (Vanlauwe and Giller, 2006). The International Standards Organization defines organic fertilizer broadly as "material containing carbon or one or more elements other than hydrogen and oxygen mainly of plant and/or animal origin added either directly to the plant or to the soil" (ISO, 2022). National standards for the composition of organic fertilizers are in place to regulate commercial organic fertilizers in the formal market, but do not necessarily extend to informal, farm-sourced organic fertilizers. For example, the Kenya KS 2290: 2023 organic fertilizer standard includes compositional requirements such as C:N ratio <20, moisture content <40 percent, N content >1 percent, organic matter content >20 percent, and the total combined N, P, and potassium (K) content >3.5 percent [2] (Kenya Bureau of Standards [KEBS], 2023). These standards also include labeling requirements, and maximum levels of contaminants and pathogens. For ease of comparison with commercial organic fertilizers, when referring to non-commercial organic fertilizer, this paper focuses on composted material and manure, and excludes the discussion on uncomposted plant residues (e.g., green manures, crop residue, cover crops) and other soil conditioners (e.g., biochar).

Organic fertilizer not only contributes to increases in crop yields in the short term, but also contributes to soil fertility improvements in the long term by increasing SOM, which improves many soil physical and chemical properties (Kopittke et al., 2020; Lal, 2006). These improvements in soil fertility lead to further impacts on crop yields in the long term, and also increase certain nutritional parameters of crops.

In the short term, the usage of organic fertilizer leads to direct improvements in yield. This is due to direct increases in nutrient supply to the crops as well as from improved nutrient availability from soil, after organic fertilizer application. These higher yields contribute directly to an improvement in farmer incomes. The usage of organic fertilizer also often reduces the cost of production by improving efficiency of inorganic fertilizers when used in combination. The application of organic fertilizer allows farmers to apply less inorganic fertilizer and get higher yields per unit of both organic and inorganic fertilizers when they are applied together. These two effects of higher yields and lower costs contribute to farmers achieving higher profits. Moreover, the improved efficiency of input usage, particularly in the use of inorganic fertilizer, contributes to reduced negative environmental impacts. These include reduction in the potential for nutrient leaching and gaseous losses, which can harm ecosystems and human health.

In the long term, the usage of organic fertilizers increases the levels of SOM. The level of SOM affects many soil features, including soil structure, cation exchange capacity, available water-holding capacity, pH level, organo-mineral complex formation, and microbial diversity (Adekiya et al., 2020; Franzluebbers, 2002; Kimetu et al., 2008; Kopittke et al., 2020; Lal, 2006; Manlay et al., 2007; Nelson & Su, 2010). Thus, the improvement in SOM levels creates a positive feedback loop for producing higher agricultural yields. It is worth noting that changes in SOM status are long-term outcomes, often the result of repeated applications of organic fertilizer over time.

Combining organic and inorganic fertilizer is one of the key features of the Integrated Soil Fertility Management (ISFM) approach. It has been shown to result in improved soil health, agricultural yields, and input efficiency of both types of fertilizers by a large set of scientific literature (Vanlauwe, 2003; Vanlauwe & Giller, 2006). Table 1 provides a brief summary of the characteristics of inorganic and organic fertilizer.

2 Percent content by mass.

1.4. Outline of the paper

This paper aims to present detailed evidence of the relationship between the application of organic fertilizer and its agronomic, economic, and environmental benefits. Increasing the application of organic fertilizers is expected to have multiple positive impacts for smallholder farmers in both the short and long term. This paper shows the agronomic impact of organic fertilizers without differentiating whether they are commercially produced or not, as these share the same objectives and impact mechanisms, while discussing the economic benefits and adoption barriers of commercial and non-commercial organic fertilizer separately. The specific impact mechanisms are summarized in Figure 1.

The remainder of this paper is organized as follows. Section 2 describes the empirical evidence for how organic fertilizers improve soil fertility, yields, and other agronomic outcomes. Section 3 describes the heterogeneity in this evidence. Section 4 describes the evidence for the impact of organic fertilizers on environmental outcomes. Section 5 describes the evidence for the impact of organic fertilizers on farmer revenue, profitability, and other economic outcomes, in agronomic trials and real-world settings. Section 6 discusses the cost effectiveness of organic fertilizers. Section 7 provides details on the current adoption of organic fertilizers in sub-Saharan Africa. Section 8 briefly discusses additional macro perspectives of the growth of the commercial organic fertilizer sector. Section 9 concludes. Appendix A provides a detailed discussion on soil fertility and soil organic matter. A case study of one specific commercial organic fertilizer – Evergrow – is presented in Appendix B.

2. The impact of organic fertilizer on agronomic outcomes

Key takeaways:

- Organic fertilizers improve soil structure and physical properties.
- Organic fertilizers increase soil nutrient retention and availability.
- Organic fertilizers may promote soil biological activity.
- Organic fertilizers can improve the efficiency and responsiveness of crops to inorganic fertilizers.

2.1 The impact of organic fertilizers on soil fertility

Soil degradation influences soil fertility and agricultural productivity. There is robust evidence from agronomic trials across multiple settings showing that the use of organic fertilizers mitigates soil degradation by improving soil quality through various mechanisms, which in turn boosts yields. Organic fertilizers: enhance the physical structure and biochemical activity of soil, leading to the gradual decomposition of SOM and long-term improvements in soil quality and fertility (Li et al., 2017; Oyetunde-Usman et al., 2021); improve soil water content (Bhanwaria et al., 2022; Lin et al., 2023); augment soil enzyme function (Lazcano et al., 2021); increase water and nutrient retention in the soil (Wang et al., 2020); and stimulate the transformation of soil nutrients and improve the accessibility of nutrients within the soil (Ahmad et al., 2016). Apart from these direct benefits, the improvement in soil's physical and biological properties also improves soil's responsiveness to inorganic fertilizers (Kearney et al., 2012; Marenya & Barrett, 2009b), and could encourage the use of inorganic fertilizers when market conditions permit (Marenya & Barrett, 2009a).

The use of organic fertilizers improves N, P and K levels in the soil. In their meta-analysis, Fan et al. (2023) find that, relative to chemical fertilizers, organic fertilizers increase total N by 32.79 percent, total P by 23.97 percent, total K by 44.91 percent, available P by 14.46 percent, and available K by 16.21 percent. The use of organic fertilizers has also been shown to improve plant P nutrition in tropical soils, not only by affecting the physicochemical availability of P but also by stimulating microbial activity, which in turn boosts the biological cycling of P (Kearney et al., 2012; Nest et al., 2014). The ability of organic fertilizer to elevate soil pH also decreases the adsorption capacity of elements like aluminum, thereby releasing P back into the soil for plant use.

Tovihoudji et al. (2018) report changes in soil properties after four years of maize cropping using 6 tonnes per hectare (t/ha) of manure, with or without inorganic N combinations, in Benin. They find a doubling of SOC content after four years of manure application, which increases with higher inorganic N applications. Synthetic N applications without manure increase SOC content slightly. The authors also find a very strong correlation between SOC and grain yields, with an R^2 of 0.71. Similar responses are seen in manure-treated soils for available P.

Organic fertilizers improve the physical properties of soil, and foster the growth of beneficial micro-organisms (Lazcano et al., 2021; Leroy, 2008; Lori et al., 2017; Moeskops et al., 2012) by increasing SOM and nutrient availability (Lazcano et al., 2021). Organic fertilizers also increase the activity of microarthropods and larger organisms, such as earthworms and springtails (Forge et al., 2003; Leroy et al., 2008; Mäder et al., 2002; Pfotzer & Schüler, 1997). These organisms facilitate N release, promote soil aggregate stability, and suppress diseases. In a meta-analysis of 56 studies, Lori et al. (2017) find that, when compared with conventional farming systems, organic farming systems (rather than just the use of organic fertilizers) have between 32 percent and 84 percent greater microbial biomass C, microbial biomass N, and total phospholipid fatty acids, and dehydrogenase, urease and protease activities, which indicate higher microbial activity. In another meta-analysis of 124 studies evaluating the impact of organic and inorganic fertilizers on soil properties and tomato production, Fan et al. (2023) find that organic fertilizers increase soil bacteria by 5.94 percent, urease by 22.32 percent, and catalase by 17.68 percent, when compared with inorganic fertilizers. In addition, increasing organic C improves soil aggregation (Kay & Angers, 2001) and can reduce soil penetration resistance, thereby facilitating better root growth and water infiltration (Kay et al., 1997). Enhanced soil structure is also pivotal for improving water retention and reducing erosion (Lynch & Bragg, 1985; Tisdall & Oades, 1982).

The evidence above demonstrates the impact of organic fertilizers on soil fertility. However, when considering organic fertilizers versus inorganic fertilizers, it is important to note that organic fertilizers generally release nutrients slowly, thus improving the soil's nutrient-holding capacity and offering a sustained supply of nutrients over time. Inorganic fertilizers, on the other hand, can make nutrients immediately available, which is particularly necessary during the peak growth stages of crops. Thus combining organic fertilizer with inorganic fertilizer not only addresses the immediate nutrient demands of crops, but also contributes to the maintenance of SOM and the overall biological functioning of soils. There may be a trade off in organic fertilizer quality and the interaction effect of organic and inorganic fertilizers, with lower yield response to inorganic fertilizers when combined with higher quality organic fertilizers (Kimetu et al., 2008). Some studies cite higher quality organic fertilizers may contribute less to SOM formation, others show no influence of organic amendment quality, and others find effects of quality on specific pools of carbon in soils, but there is generally an imperfect understanding of how organic amendment quality affects SOM accumulation (Fonte et al., 2009; Kimetu et al., 2008; Sonsri et al, 2022). The strategic use of organic inputs alongside inorganic fertilizers can enhance nutrient cycling, mitigate nutrient losses, and correct minor nutrient imbalances, thereby alleviating crop growth limitations more effectively than either type of fertilizer used alone (Kearney et al., 2012).

2.2 The impact of organic fertilizer on crops: yields, nutrient content, and efficiency of fertilizers

In addition to the broad effects discussed above, organic fertilizers also affect crop yield and may improve crop quality (in terms of crop nutritional content). Evidence from agronomic trials conducted across sub-Saharan Africa demonstrates improvements in yield and crop quality following the use of organic fertilizer (Anyega et al., 2021; Beesigamukama, Mochoge, Korir & Fiaboe, 2020; Beesigamukama, Mochoge, Korir & Musyoka, 2020; Chivenge et al., 2021; Fan et al., 2023; Gram et al., 2020; Houben et al., 2020; Kearney et al., 2012; Nsoanya & Nweke, 2015; Vanlauwe et al., 2011). While some studies compare using organic fertilizer with not using fertilizer, others compare organic with inorganic fertilizers, and still others compare using a combination of organic and inorganic fertilizers with using no fertilizer, or with using either organic or inorganic fertilizers. These findings are discussed below.

Fan et al. (2023) analyze data from 124 agronomic studies conducted across the world in their meta-analysis of the impact of organic fertilizers on tomato yield and quality, relative to control groups where only inorganic fertilizers are applied. Their analysis of the impact of organic fertilizers on soil properties and soil fertility is discussed in section 2.1. When it comes to tomato nutrient content, Fan et al. (2023) find that organic fertilizer reduces fruit nitrate by 12.66 percent, and increases fruit sugar by 4.79 percent, fruit lycopene by 4.80 percent, and fruit protein by 13.82 percent. In addition, they find that organic fertilizer increases the yield by 3.48 percent compared with a control group where only inorganic fertilizer was applied. In a study focusing on maize in Kenya, Beesigamukama, Mochoge, Korir & Fiaboe (2020) compare N (from urea) replacement values between two organic fertilizer (black soldier fly frass and a commercial organic fertilizer), each combined with inorganic P and K. They find that there were small increases in yields with increasing N-equivalent rates of commercial organic fertilizer (in one season out of two) but not frass, whereas N replacement equivalents tended to be higher for frass.

When it comes to plant uptake of N, Beesigamukama, Mochoge, Korir & Musyoka (2020) find that the release of N in soils treated with organic fertilizers was slow during early-stage maize growth, leading to insufficient N availability relative to the amount of N required by plants (N synchrony). This lack of N synchrony was less pronounced with frass than with the commercial organic fertilizer, but suggests that the N in inorganic fertilizer might be a necessary supplement to organic fertilizer. However, there is probably variability in this, based on the type of organic fertilizer and its nutrient content.

A number of agronomic trials that use a combination of organic and inorganic fertilizers find that this combination leads to better outcomes than either fertilizer type alone. In a study with cabbage in Uganda, Kearney et al. (2012) find that a combination of organic (with 7.1 percent organic matter and 0.34 percent N) and inorganic fertilizer produces 26 percent significantly higher biomass than inorganic fertilizer alone produces. Anyega et al. (2021) study the impact of different organic fertilizers (frass, spent grain, commercial organic fertilizer), inorganic fertilizers, their combination, and not using fertilizer on tomato, kale, and French beans in agronomic trials in both greenhouse and open-field conditions over two cropping seasons in Kenya. They find that vegetable yields achieved from a combination of organic fertilizer (frass) and inorganic fertilizer are significantly higher than from both the control condition and inorganic fertilizers alone. The combination gives both higher agronomic N-use efficiency (increase in yield per unit of N fertilizer applied) and vegetables with the highest crude protein and ash concentrations. This suggests that the combination of organic and inorganic fertilizers boosts the yield and nutritional quality of vegetable crops.

Multiple studies (Anyega et al., 2021; Beesigamukama, Mochoge, Korir & Fiaboe, 2020; Beesigamukama, Mochoge, Korir & Musyoka, 2020) and meta-analyses conducted with maize in sub-Saharan Africa (Chivenge et al., 2021; Gram et al., 2020; Vanlauwe et al., 2011), demonstrate that the combined use of organic fertilizers with inorganic fertilizers increases maize yields and the agronomic efficiency (increase in yield per unit of fertilizer nutrient applied) of applied nutrients, relative to inorganic fertilizers alone, and relative to organic fertilizers alone in certain cases.

Tovihoudji et al. (2018) find some evidence for higher N agronomic efficiency for manure without combination with inorganic N, though this changes significantly from year to year, and the relationships between organic fertilizer and the agronomic efficiency of P and K are not clear. Laub et al. (2023) analyze long-term trials of organic amendments that include manure, in combination with inorganic N sources. They find that over a long time horizon of 16 years, applications of manure or inorganic N alone result in declining yields, whereas the annual applications of a combination of manure and 120 kg/ha of inorganic fertilizer prevent yield decline, although there are some differences in the trend at different sites. This indicates the potential for organic fertilizers to prevent yield decline when used in combination with inorganic fertilizer.

Organic fertilizers contribute to improving soil health, but their nutrient release is slower compared to inorganic fertilizers. Combining organic and inorganic fertilizers generally results in higher yields and better nutrient content than using either type alone, as demonstrated by multiple studies. This integrated approach also helps maintain long-term soil fertility and crop productivity.

3. Heterogeneity in the impact of organic fertilizer on agronomic outcomes

Key takeaways:

- The effectiveness of organic fertilizers varies with soil fertility, type, management history, temperature, and precipitation.
- Different crops, varieties, and intercropping systems respond differently to organic fertilizers.
- The impact of organic fertilizers depends on the quantity and combination with inorganic fertilizers.
- The type and quality of organic fertilizers significantly influence their effectiveness on crop productivity and soil health.
- Higher quality organic fertilizers are more associated with short term yield improvements.

While substantial evidence demonstrates a positive impact of organic fertilizer (used individually or in combination with inorganic fertilizers) on nutrient quality, biomass and yields, the variability in outcomes highlights a need for context-specific recommendations for the usage of organic fertilizers, especially in application combined with inorganic fertilizers. This section discusses how the impact of organic fertilizers varies by agroecological conditions, crops and growing patterns, application rates, and organic fertilizer type and quality. Understanding these factors is crucial for creating localized recommendations that optimize the benefits of organic fertilizers.

3.1 Agroecological conditions

Organic fertilizers improve soil quality by feeding nutrients to the soil, and their effectiveness depends on the baseline soil fertility, which is influenced by soil type and the plot's management history (Chivenge et al., 2011; Zingore et al., 2007). In addition, the efficiency of nutrient use, which comprises capture efficiency and conversion efficiency, varies with soil characteristics (Tittonell et al., 2008), and so applying the same amount of organic fertilizer to soils that have different nutrient levels could generate a variety of responses. Severely degraded soils may require multi-purpose solutions over multiple years to restore productivity, as seen in studies from Zimbabwe (Zingore et al., 2007, 2015). In a three-year study across plots of varying fertility, Zingore et al. (2007) found that application of inorganic fertilizers alone improves yields in the more fertile fields (by soil type and better past management) in the first year, but does not do so in less fertile fields. Application of organic fertilizer in the less fertile fields does not yield any impacts in the first two years, but results in significant increases in yields in the third year. They recommend targeted application of organic and inorganic fertilizers according to soil type and prior field management to improve crop yields and nutrient use efficiencies.

In addition to soil fertility, other agro-climatic factors, such as water availability and temperature, also play critical roles in the impact of organic fertilizers. For instance, a meta-analysis of 464 trials across 168 studies in China shows that temperature and precipitation affect the impact that organic fertilizers have on soil organic carbon content (Wang et al., 2024). They find that the impact of organic fertilizer on soil organic carbon is indistinguishable from that of inorganic fertilizer at high temperatures, but significantly higher in middle and low temperatures—this improvement effect of organic fertilizer is twice that of inorganic fertilizer in low-temperature areas, and 1.3 times in medium-temperature areas. Comparing organic fertilizer impact levels across temperatures also indicates that improvements in soil organic carbon are highest in the low-temperature regions, and lowest in the high-temperature regions. When it comes to precipitation, the authors find that the impact of organic fertilizer on soil organic carbon is 10.2 times higher than that of inorganic fertilizer at the lower rainfall regions (< 400 mm rainfall annually), 0.9 times higher than that of inorganic fertilizer in regions with between 400 mm and 800 mm rainfall annually, and 6.6 times higher in regions with more than 800 mm of rainfall annually.

Field studies also indicate that organic fertilizers, alone or combined with inorganic fertilizers, enhance yields under varying irrigation conditions. Examining the effect of crop production factors, namely water and N, Wang et al. (2020) run a three-year field study in China, and find that organic fertilizers alone lead to higher annual grain yields in the farming schemes without irrigation, while the combination of inorganic fertilizers and organic fertilizers lead to higher annual grain yields in the farming schemes with irrigation. To control the crop growing conditions even more closely, Anyega et al. (2021), a study mentioned above, investigate the performance of fertilizers under greenhouse and open-field conditions in Kenya. They find that adding organic fertilizer (i.e., frass) to inorganic fertilizer leads to significantly higher kale yields in the greenhouse setting. At the same time, they observe no statistical difference between different fertilizer applications in open-field conditions, highlighting the importance of controlled growing conditions.

3.2 Crops and growing patterns

Different crops have distinct nutrient requirements and respond differently to fertilizers. For instance, a study applying fertilizers to French beans, tomatoes, and kale shows that yields improve significantly with organic fertilizer, though the degree of improvement varies by crop (Anyega et al., 2021). The researchers apply as much fertilizer on each experimental plot as would supply 100 percent of the N required, i.e., 371 kg/ha across crops and plots, and find that yields in fertilized soils are consistently higher for all crops compared with yields in unfertilized soils, but to different extents across crops. The application of one type of organic fertilizer (i.e., frass) improves the yield by 63–71 percent and 52–65 percent for tomato and French beans, respectively, compared with other fertilizer treatments. Cereal crops, like sorghum and maize, also respond differently to organic and inorganic fertilizers, with sorghum showing better results in some cases. In Amujoyegbe et al., (2007), the authors assess the effect of organic and inorganic fertilizer in a field trial in Nigeria and find that sorghum responds significantly better to the nutrient provision compared to maize. Wortmann et al. (2017) find some disparities in yield response to organic fertilizers in a global meta-analysis, with leafy crops showing the highest response and root/tuber crops showing the lowest response after a single application of organic fertilizer.

Even within the same crop, different varieties can have varied responses. Islam et al. (2017) conduct field trials in Bangladesh to examine the impact of fertilizers on two varieties of tomato. They find that, compared to the control plots where no fertilizer is applied, yields in treatment plots where a combination of organic and inorganic fertilizer is applied increase slightly from 8.47 t/ha to 9.94 t/ha for one variety (i.e., BARI 15) and almost double from 10.45 th/ha to 20.84 t/ha for another variety (i.e., Roma VF).

Intercropping patterns also influence the performance of organic fertilizers. For example, maize yields in combination with common beans or soybeans improve significantly when both organic and inorganic fertilizers are used, though the magnitude of improvement varies by intercropping system (Chichongue et al., 2020). The authors record that, compared to the control plots, maize yields in plots treated with a combination of organic fertilizer (manure) and inorganic fertilizer (NPK) increase to 5.42 t/ha from 3.67 t/ha, and to 5.41 t/ha from 1.60 t/ha for maize-common bean and maize-soybean intercropping systems, respectively.

3.3 Application rates

The quantity of fertilizer applied per unit of land is another factor contributing to the heterogeneity of organic fertilizer impacts. Optimal application rates depend on specific conditions, including soil type, crop, and yield targets; and so when farmers make different choices about application rates, whether to combine organic and inorganic fertilizers, etc., the impact of applied organic fertilizers on crop performance could be highly heterogeneous.

Studies with multiple fertilizer treatments generally find that a combination of organic and inorganic fertilizers yields the best results in terms of improved yields, or improved soil properties such as organic C and N content, soil sucrose, etc. (Kearney et al., 2012; Tovihoudji et al., 2018; Zhou et al., 2022). The treatment arms within these studies generally share the same level of nutrient inputs (i.e., N, P, K inputs), but these inputs are supplied by different fertilizer types and application amounts, such as pure organic fertilizer, pure inorganic fertilizer, 75 percent organic fertilizer and 25 percent inorganic fertilizer, 50 percent organic fertilizer and 50 percent inorganic fertilizer, 25 percent organic fertilizer and 75 percent inorganic fertilizer.

Some experiments find that the specific nutrient sources (i.e., the division between organic fertilizer and inorganic fertilizer) do not significantly affect the crop outcomes, and could be determined by fertilizer prices and budget constraints (Kearney et al., 2012; Tovihoudji et al., 2018). On the other hand, some experiments find that nutrient input choices matter. Zhou et al. (2022) show that, compared with recommended inorganic fertilizer application, maize yields are higher only when inorganic fertilizer is coupled with a large amount of organic fertilizer (i.e., 45 t/ha). If the amount of organic fertilizer is a small (i.e., 15 t/ha) or medium (i.e., 30 t/ha) quantity, there is no significant difference in yields.

3.4 Organic fertilizer type and quality

Organic fertilizers could be produced commercially or in the farmyard, and commonly come in the form of vermicompost, compost, and manure. The type and quality of organic fertilizers significantly influence their impact on crop productivity and soil health.

Different types of organic fertilizers are shown to affect these soil properties differently. Adekiya et al. (2020) observe that different types of manures applied to okra result in significantly different soil parameters, including organic matter (OM), N, P, K, and magnesium, within one- and two-year horizons after application. More rapidly mineralizable manures, such as poultry manure, raise soil nutrient status more, whereas manures that are higher in lignin and those with higher C:N ratios raise OM more. Nevertheless, Mahmood et al. (2017) find that manures with higher C:N may stimulate a priming effect, which refers to added organic material leading to the loss of SOM previously existing in the soil. This is thought to be due to an increase in microbial populations caused by adding an organic substrate, which leads to a bigger population able to decompose the previously existing OM in the soil (Fontaine et al., 2004). However, even with the potential priming effect of higher C:N manures, SOM status is improved more by these treatments than by treatments without organic materials.

Looking at the impact of different organic fertilizers on downstream agricultural outcomes, Mahmood et al. (2017) compare the impact of three types of manure—farmyard manure, poultry manure (PM), and sheep manure—and conclude that PM is more effective at improving maize growth and yield than the other two types of manures. Masarirambi et al. (2010) evaluate the impact of chicken manure, cattle manure, and composted chicken manure on the growth of red lettuce. They, too, find that the type of fertilizer applied has a significant influence on crop growth. Chicken manure leads to better productivity, such as a higher number of leaves, higher leaf dry mass, larger plant height, and more yield, while composted chicken manure generates higher nutrient content in the plants, such as higher calcium, iron (Fe), and zinc (Zn) contents. A global meta-analysis by Wortman et al. (2017) similarly finds poultry manure having the highest average yield response, as compared to cattle or swine manure, or plant composts. Anyega et al. (2021) compare the impact of black soldier fly frass fertilizer (BSFFF), conventionally composted brewer's spent grain, and commercial organic fertilizer on the growth of vegetable crops, and discover that BSFFF has a better performance than the other two fertilizers. Islam et al. (2017) compare two types of organic fertilizers—vermicompost and compost—and do not find a significant difference in their impact on tomato growth.

Beyond the type of organic fertilizer, the quality of the fertilizer is a crucial determinant of the response of crops to the fertilizer application. Ogunlela et al., (2005) clearly state that the optimal amount of manure would vary depending on the quality of the manure. Only with organic fertilizers of intermediate quality (i.e., those consisting of manure, compost or organic materials with high N, high polyphenols or high lignins, as defined in Palm et al. (2001), do Vanlauwe et al. (2011) find an increase in maize yield and the agronomic efficiency of applied nutrients, on plots treated with a combination of organic and inorganic fertilizer relative to plots treated with inorganic fertilizer alone. Chivenge et al. (2011) find a general increase in yield with increased quality and increased N-content of organic fertilizer, when the organic fertilizer is used both alone and in combination with inorganic fertilizers.

Relying on linear mixed effect modeling in their meta-analysis, Gram et al. (2020) find that the significant positive effects on maize yields and on the agronomic efficiency of applied nutrients are more pronounced at higher N rates and for high-quality organic fertilizers, when combining organic and inorganic fertilizers. Their findings suggest that, when compared to low-quality organic fertilizer (low N, high lignins), high quality organic fertilizer not only increases yield and agronomic efficiency, but also results in a slower decline of agronomic efficiency with the N rate, a decreased inter-seasonal yield variability, and an increased SOC.

4. The impact of organic fertilizer on environmental outcomes

Key takeaways:

- Partial replacement of inorganic fertilizers with organic fertilizers reduces inorganic fertilizer application, which could decrease environmental pollution and health risks from nutrient runoff and leaching.
- Organic fertilizers could contribute to carbon sequestration, aiding climate change mitigation.
- Substituting imported inorganic fertilizer with locally-produced organic fertilizer could reduce GHG emissions through decreased international transportation and better management of local organic waste.

4.1 Impacts due to reduction in inorganic fertilizer use

A combination of organic and inorganic fertilizers not only has the greatest agronomic impact, leading to improved soil as well as providing accessible nutrients during plant growth, but also allows farmers to reduce the quantity of inorganic fertilizers used without necessarily experiencing a reduction in yield. Inorganic fertilizers contribute to various forms of environmental degradation, and their use sometimes leads to pollution that is harmful to human health.

Nitrogen and phosphate leaching and runoff contribute to eutrophication, and nitrates that often leach into groundwater are a human health hazard, leading to methemoglobina-related diseases, and have potential links to various other health effects (Lubkowski, 2016). This is largely due to the solubility of inorganic fertilizers, which are designed to allow for rapid uptake by plants during periods of rapid growth that require high nutrient availability in soils. However, this high solubility results in rapid loss through leaching in the case of N, whereas fixation of P in soils leads to loss through erosion into waterways (Sileshi et al., 2019). Reducing the rate of release of soluble forms of N and P into soils is one approach to reducing these environmental losses (Lubkowski, 2016). Organic fertilizers contribute to reaching this goal of reducing environmental losses associated with fertilization.

Although nitrate leaching is not known as a major problem in sub-Saharan Africa at the moment, there are examples of higher groundwater nitrate levels in more heavily fertilized fields. Regardless of the current level of nitrate leaching in the region, improved nutrient recovery by crops provides both environmental benefits as well as benefits to farmers (Kihara et al., 2020). Some studies show that leaching is reduced when manures and inorganic fertilizers are applied together (Murwira, 1994; Nyamangara et al., 2003). This reduced leaching is thought to be due to the greater synchrony of nutrient-uptake by crops under management that uses combined organic and inorganic amendments (Kihara et al., 2022). However, in a review paper on the potential for organic farming systems to reduce N leaching, Kirchmann and Bergström (2001) find no significant difference in leaching per unit of N applied in organic farming systems when compared to conventional farming systems.

4.2 Impacts due to organic fertilizer use

As previously discussed, one of the impacts of organic fertilizer on soil is improving its water retention capacity (Lynch & Bragg, 1985; Tisdall & Oades, 1982). This helps communities adapt to floods, by absorbing water and preventing the runoff of pollutants, and to droughts, by holding water for longer (Bondi et al., 2022; United States Environmental Protection Agency [EPA], 2024). In addition, increasing soil C content through the addition of organic fertilizers contributes to carbon sequestration in the soil, reducing CO_2 in the atmosphere, and contributing to climate change mitigation efforts (EPA, 2024; Villat & Nicholas, 2024; Wong et al., 2023).

However, if organic fertilizers, especially those derived from animal manure or waste, are not treated or composted properly, they may introduce pathogens into the soil. This could contaminate crops and water supplies, and pose a risk to human and animal health (Adegoke et al., 2016). These risks can be mitigated by careful composting, or the use of commercial organic fertilizers which employ advanced, standardized techniques (Ramos et al., 2021; Singh, 2012). Compared with less processed manures of similar feedstocks, certain commercially processed organic fertilizers reduce ammonia losses—for instance, Assefa & Tadesse (2019) find that pelleted manure has 97.8 percent lower ammonia emissions relative to unprocessed manure. This reduces environmental impacts such as eutrophication and acidification of aquatic environments that are caused by ammonia (Wyer et al., 2022), and represents a major N saving (Assefa & Tadesse, 2019).

Another aspect to consider in the environmental impacts of fertilizer use in agriculture is the resulting emission of greenhouse gasses (GHGs) such as methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2), which are major contributors to climate change (Shakoor et al., 2020; Shakoor et al., 2021). The use of organic fertilizers supports methane oxidation under aerobic conditions, thus lowering methane emissions, but stimulates methane production under anaerobic conditions, thus increasing methane emissions (Conrad, 2007). For instance, in a field trial in a wheat-corn cropping system in China, Gong et al. (2022) find that the use of organic fertilizers (microbial fertilizers) reduces N_2O and CH_4 fluxes and reduces CO_2 emissions by 6.9–18.9 percent compared to inorganic fertilizers, by conserving soil heat and moisture during the corn season. In a field trial with maize in Zimbabwe across soil types and seasons, Mapanda et al. (2011) compare organic fertilizer (composted manure) with inorganic fertilizer and a control group, and find that organic fertilizer significantly reduces N_2O emissions compared to the impact of inorganic fertilizers, especially during the wet season. However, the results for CH_4 and CO_2 fluxes were variable and dependent on soil water content. Similarly, in a global meta-analysis of 48 studies, Shakoor et al. (2021) show that the type of organic fertilizer, application rate, soil texture, climate zone, and crop type have an impact on the extent of GHG emissions. This suggests that the use of organic fertilizers does have the potential to reduce GHG emissions in the agricultural sector, although reducing GHG emissions from agricultural practices depends on management practices and use conditions.

4.3 Impacts due to production of organic fertilizers

The improper disposal of organic wastes in landfills or unmanaged environments leads to anaerobic decomposition, releasing substantial amounts of methane, a GHG (EPA, 2024). Composting organic waste instead of landfilling can significantly lower methane emissions, as organic materials decompose aerobically rather than anaerobically, thus minimizing methane production (Brown et al., 2008;

Zhang et al., 2019; Li et al., 2023). Composting can also be responsive to local waste streams, further enhancing sustainability. Commercial production of organic fertilizer provides further opportunity for organic waste conversion into organic fertilizer for crop production, which could potentially reduce negative environmental impacts from existing waste management practices (Bidzakin et al., 2023).

The production and transportation of inorganic fertilizers are energy-intensive and release significant amounts of CO_2, N_2O, and CH_4 (Wood & Cowie, 2004; Smith et al., 2014). For instance, estimates indicate that the production and use of nitrogen fertilizers account for approximately five percent of global GHG emissions (Gao & Serrenho, 2023), while the synthesis of ammonia from which fertilizers are produced directly accounts for 10 percent of global GHG emissions and two percent of global energy (Gao & Serrenho, 2023). In Kenya, the use of inorganic fertilizers is responsible for one percent of Kenyan GHG emissions (0.6 Mt), and, in addition, the import of inorganic fertilizer causes further GHG emissions (3.4 Mt) upstream in countries where it is produced (Commercial Agriculture for Smallholders and Agribusiness [CASA], 2023b). Substituting imported inorganic fertilizer with locally-produced organic fertilizer could reduce GHG emissions occurred during transportation. Local production of organic fertilizers could also potentially reduce GHG emissions through treating organic wastes properly, as discussed above.

5. The impact of organic fertilizer on economic outcomes

Key takeaways:

- Organic fertilizers lead to increase in income and profits, supported by evidence in the experimental settings from agronomic trials and in the real-life setting from survey data.
- There are differences in the impact levels of organic fertilizer observed in the experimental setting and in the real-life setting. Those discrepancies in productivity could go in either direction. Possible reasons include variations in soil characteristics and behavioral choices.

This section provides evidence of the economic benefits accrued from the application of organic fertilizers. The use of organic fertilizers, both alone and in combination with inorganic fertilizers, results in better soil health, increased yield, and higher nutritional quality of crops as shown in Section 2, and improved environmental benefits as shown in Section 4. Moving along the theory of change, this section investigates whether adoption of organic fertilizers could generate positive gains on smallholder farmers' livelihood, such as increasing income, profits, and food consumption, using both insights from agronomic trials and learnings in real-life settings.

5.1. Economic impact in agronomic trials

Testing the potential of organic fertilizers, Kearney et al. (2012) conduct field trials on cabbage in Uganda. They find that, compared with control plots, the market value of cabbage heads, estimated by a group of local produce retailers, is increased in all treatment plots that use various fertilizer applications. The increase in economic benefit is 98 percent in the pure organic fertilizer (manure) treatment and 162-186 percent in the combination of organic and inorganic fertilizer treatment. Based on average land that farmers cultivate cabbage on in the region, the authors estimate that using a combination of organic and inorganic fertilizers translates into an increase in farmers' incomes by USD 114.68 per growing season, compared with using either an organic or an inorganic fertilizer alone. Exploring the benefits of partially substituting the chemical fertilizer with organic fertilizer, Zhai et al. (2022) conduct field trials on wheat in China, and observe increases in the net benefit by USD 336/ha and USD 208/ha for 15 percent and 30 percent substitution, respectively.

In terms of gross margin, Tovihoudji et al. (2018) examine the impact of organic fertilizer in combination with inorganic fertilizer on maize farming in Benin over a four-year period. The authors find that the gross margin increases 26-96 percent from applying manure, compared with not applying manure. Dada and Ewulo (2015) study maize farming in Nigeria, and find improved gross margins (i.e., USD 954) from combining poultry manure with superphosphate and urea, compared to no nutrient amendment (i.e., USD 245).

5.2. Economic impact in a real-world setting

To reveal the impact in the real-world setting, another strand of studies conducts surveys with smallholder farmers, and estimates the yield differences between adopters and non-adopters of organic fertilizer, using quasi-experimental methods. Mwaura et al. (2021) interview 137 maize producers in Kenya and find that farmers who use either organic fertilizers (animal manure) solely or organic combined with inorganic fertilizers report higher gross margins, compared to farmers who use inorganic fertilizers solely. Those differences are statistically significant, and in the range of 16–80 percent higher for sole organic fertilizer users and 42–55 percent higher for combined inorganic and organic fertilizer users. Wainaina et al. (2018) conduct a representative survey with 1,344 maize farmers over all six agroecological zones in Kenya, to examine the impact of agricultural technology on household incomes. They observe that adopting organic fertilizer (manure) increases farm household income by 14 percent (USD 360) and per capita income by 20 percent (USD 99), compared to not adopting the organic fertilizer. By interviewing 300 farmers across three regions in Ghana, Bidzakin et al. (2023) find that organic fertilizer adoption increases yields by 57 percent, farm income by 53 percent, and farm gross margins by 63 percent.

Expanding the scope to the national level by comparing adopters and non-adopters in the sixth wave of the Ghana Living Standard Survey, Martey (2018) demonstrates that organic fertilizer (green and animal manure) increases crop productivity 1.43 times, increases crop income by USD 132, reduces total household expenditure by USD 174, reduces food expenditure by USD 58, and reduces poverty by 8 percent. In a similar study that uses data from the 2018/2019 Nigeria General Household Survey, Oyetunde-Usman et al. (2021) show that households that use organic fertilizer (green manure, compost, crop residue, and animal manure) increase their per capita asset value, per capita total house expenditure, and per capita food expenditure by USD 1,925, USD 407, and USD 236, respectively, compared to non-adopters. In the context of Ethiopia, Gelgo et al. (2017) collect survey data from 368 farmers in Shashemene district, and find that adoption of organic fertilizers increases farm income per hectare by USD 111–124, compared to non-adopters.

While those studies present significantly positive results, it is worth noting that the sample sizes used in some studies are small. More importantly, the economic analysis methods adopted, such as propensity score matching, rely on using statistical techniques to construct an artificial control group. More rigorous examinations on organic fertilizer in the real-world setting are needed to show its causal impacts.

5.3. Factors contributing to the differences in productivity between agronomic trials and real-world settings

When an agricultural input is adopted under real-life conditions, the benefit realized by smallholder farmers may differ from the gains observed in agronomic trials (Abate et al., 2018; Dar et al., 2013; Laajaj et al., 2020). The discrepancy in productivity could go in either direction. Possible reasons for the lower outcomes in the real-farm settings include differences in soil characteristics, and in farmers' behavioral choices and characteristics. A possible reason for higher outcomes in the real-farm settings is the crowding in of additional investment.

Among the field trials that examine the impact of organic fertilizer, baseline soil properties are commonly measured, and the rate of organic fertilizer application is determined so as to supply the required nutrient content to that specific soil. On the other hand, in the real-life setting, smallholder farmers rarely conduct soil tests on their plots (Olwande, 2019; Wawire et al., 2021), and usually choose the application rate based on past experience or on general advisory suited for the aggregate location. These approximated rates may not be the optimal application rates of the farmers' particular cropland, and would thus decrease the potential impact of inputs. The issue is amplified when farmers choose to apply organic fertilizer based on the soil conditions, such as applying organic fertilizer to less fertile areas that would require additional nutrient supplement compared to the standard application rate.

Furthermore, smallholder farmers may face financial and logistical constraints when deciding about the application of a fertilizer. Bidzakin et al. (2023) show that the adoption of organic fertilizer is correlated with farmers' organization membership status and access to organic fertilizer, and with transportation costs in Ghana. Given those external constraints, farmers may adopt organic fertilizer at a suboptimal level even when they know the optimal rate.

Farmers' behavioral choices, such as in farming management and implementation, are also pivotal reasons for the disparity between experimental trials and real-world settings. One aspect centers on the correct adoption of organic fertilizer, such as when to apply and how to apply the organic fertilizer, in addition to the application rate discussed in section 3. Other aspects relate to other complementary agricultural practices, such as the type of seeds used, planting time, frequency of weeding, and usage of irrigation. Tittonell et al. (2008) show that there is a significant yield gap between farmer- and researcher-managed fields, due to differences in agronomic management and disparities in resource-use efficiencies. Because of the importance of appropriate management, supporting farmers with digital extension service, which could provide customized, timely, actionable advisory on both appropriate usage of organic fertilizer and other complementary practices, is an effective policy action that helps farmers reach their yield potential.

On the other hand, the application of organic fertilizers improves soil physicochemical and biological properties. The increased soil health results in higher efficiency and marginal returns of other input applications, such as improved seeds and inorganic fertilizer. As a consequence, farmers may crowd in additional investment on their farming, which in turn increases agricultural yield and income further (Boucher et al., 2021; Emerick et al., 2016).

6. Cost-effectiveness of organic fertilizer

Key takeaways:

- There is suggestive evidence indicating that the application of organic fertilizer is an economically viable choice, having a benefit-cost ratio that is bigger than 1. More rigorous insights are needed to provide further and complete affirmation, especially for commercial organic fertilizer.
- To maximize farmers' return of investment, it is also important to assess which organic fertilizer application offers the highest cost effectiveness.

The ultimate assessment of organic fertilizer is its cost-effectiveness for smallholder farmers. The inherent impact level of organic fertilizers on agricultural productivity is a key determinant of organic fertilizer's benefit-cost ratio. External market factors also play a crucial role. The benefit levels vary with the market value of the harvest. Given a fixed amount of harvest, if the market price of output is high, the total gross income farmers received would be large. In parallel, the cost levels vary with the input prices, which are affected by the availability and source of the organic fertilizer, be it commercially produced, or home-made compost, or manure.

Table 2 summarizes benefit-cost (b-c) ratios of the application of organic fertilizers or the combination of organic and inorganic fertilizers from seven studies. Benefit-cost ratios of organic fertilizers are defined as additional net income incurred from the organic fertilizer application divided by the additional cost of the organic fertilizer application. Benefit-cost ratios equaling one stand as a break-even scenario, the additional benefit being the same as the cost. If the b-c ratio is larger than one, it indicates that organic fertilizer is a cost-effective agricultural input. The few existing empirical studies generally demonstrate a benefit-cost ratio that is larger than one.

Focusing on non-commercially produced vermicompost and manure first, Kearney et al. (2012) perform a simple cost-benefit analysis on cabbage growing in Uganda. The authors calculate the benefit based on the market value of cabbage, and calculate the cost based on survey information for manure, and on the market price for inorganic fertilizer. They find that the combined use of organic and inorganic fertilizers results in net benefits that are 61 percent higher than use of inorganic fertilizer alone, and 39 percent higher than use of organic fertilizer alone. Tovihoudji et al. (2017) study the cost-effectiveness of maize farming in Benin, and how the benefit-cost ratios vary with the fluctuation of output and input prices. They observe that the benefit-cost ratios are always bigger than one (ranging between two and ten) in all experimental arms that have some amount of nutrient amendment, either manure or fertilizer or a combination of them. Even when there is a significant drop in the output price, i.e., decreasing the maize price by 25 percent, the application of organic fertilizer still remains financially attractive with b-c ratios bigger than two. Similarly, Jjagwe et al. (2020) estimate that the benefit-cost ratios for various manure usages on maize in Uganda are all bigger than one, ranging from 3 to 168, under the average interest rate (13.9 percent) assumption.

Regarding commercial organic fertilizer, there is a clear gap in the available evidence of its cost effectiveness. Commercial Agriculture for Smallholders and Agribusiness (CASA) report highlights the lack of scientific evidence on commercial products, and advocates for building a strong evidence base from large-scale trials (Commercial Agriculture for Smallholders and Agribusiness [CASA], 2023b). Based on a few proprietary reports from a commercial organic fertilizer company, the benefit-cost ratios of one commercial organic fertilizer (i.e., Evergrow) are shown to be 3.35 for usage on French beans and bigger than 1 for various crops. In theory, the commercial processing of organic fertilizers can have greater cost effectiveness than less processed forms. Assefa and Tadesse (2019) find that the use of pelleted manures results in higher cost effectiveness per unit of nutrient applied, relative to similar unprocessed feedstocks, largely due to reduced N losses.

The evidence for the cost-effectiveness of organic fertilizer, especially commercial organic fertilizer, is sparse and calls for further impact evaluations to provide rigorous affirmation. While the limited available insights indicate the economic viability of organic fertilizer application in general, it is also essential for farmers to assess which organic fertilizer application offers the highest b-c ratio. Is it the home-produced organic fertilizer or commercially produced product, and is it when organic fertilizer is applied alone or when it is applied with inorganic fertilizer? Tovihoudji et al. (2017) find that the benefit-cost ratios of sole manure application rank on the top in three out of four seasons, compared to no fertilizer application and to the combination of manure and inorganic fertilizer. Mwaura et al. (2021) observe that sole animal manure application leads to the highest return in a sub-county in Kenya, while animal manure combined with inorganic fertilizer leads to the highest return in another sub-county. The answer to this optimum choice question would vary by context, depending on the local impact levels and costs.

7. Adoption of organic fertilizer

Key takeaways:

- Adoption of organic fertilizer remains low in Kenya and Africa.
- Several barriers must be addressed for the widespread adoption of organic fertilizer, such as providing information campaigns, extensive service, and financial assistance for farmers, and supporting the growth of the commercial organic fertilizer industry.

The usage of fertilizer has dramatically risen over the past several decades in Kenya, and Africa in general. Sub-Saharan Africa's fertilizer market has been growing at a rate of 8 percent per year since 2008 (Ariga et al., 2019). In Kenya, total fertilizer consumption doubled between 1990/1991 and 2011/2012 (World Bank, 2024) and reached 750,000 metric tons in 2021 (Commercial Agriculture for Smallholders and Agribusiness [CASA], 2023b); this increase was mostly driven by inorganic fertilizer. The adoption rate of organic fertilizer remains low. In most regions of Kenya, less than 50 percent of farmers surveyed in the Tegemeo/MSU panel Household Survey report using organic fertilizers (Kibaara et al., 2008). Using the Living Standard Measurement Study—Integrated Surveys on Agriculture from six African countries (Ethiopia, Malawi, Niger, Nigeria, Tanzania, and Uganda), Sheahan and Barrett (2014) calculate that the proportion of cultivating households using organic fertilizer is only about 29 percent in 2010/2011. The usage of commercial organic fertilizer is even more sparse. According to the CASA report, only 1 percent of total fertilizer consumption is commercial organic products (Commercial Agriculture for Smallholders and Agribusiness [CASA], 2023b).

Several barriers must be addressed for the widespread adoption of organic fertilizer; such barriers include insufficient knowledge, limited labor, financial constraints, and lack of policy support (Chianu et al., 2012). The first major cause of the low usage is inadequate knowledge of the application practices for and the impact of organic fertilizer. While the benefits of inorganic fertilizers—supplying nutrients to crops for improving their growth—have been assimilated, the gains of organic fertilizers are not well understood. Muluneh et al. (2022) and Okuma and Isiorhovoja (2017) highlight the effect of having information and experience about organic fertilizer on increasing its adoption significantly. Transitioning from locally-made manure and composting to commercially-produced organic fertilizer faces further knowledge challenges. In Kenya, manufactured organic fertilizer products are of varying quality, and strong evidence of their yield impact and standard recommendations for using them are not sufficiently generated (Commercial Agriculture for Smallholders and Agribusiness [CASA], 2023b). Without widely recognized efficacy and usage guidelines, farmers are reluctant to adopt the product because of risk averseness and inadequate knowledge. Providing extension service and training agro-dealers could potentially close up those knowledge gaps and, in turn, drive up the adoption of commercially-produced organic fertilizer. In their examination of the organic fertilizer usage in Africa, various papers suggest increasing information campaigns and extension works to raise awareness about the importance of organic fertilizer, and thereby expanding the adoption of it among smallholder farmers (Fasina, 2013; Macharia et al., 2014; Muluneh et al., 2022; Mwaura et al., 2021; Okuma and Isiorhovoja, 2017).

In addition to the low demand from farmers, the supply of organic fertilizer has immediate challenges as well. One pivotal reason is the paucity of available organic resources (Bidzakin et al., 2023; Giller et al., 2009; Place et al., 2003). Not every farmer may be able to use their crop residues for composting, or have sufficient animal manure to apply to all their fields. When some raw materials exist, the amount of raw ingredients available are usually smaller than the amount needed to provide the required nutrients, and there are competing uses for these scarce resources, such as livestock feed or fuel (Anyega et al., 2021; Ndambi et al., 2019; Rufino et al., 2011). This barrier is especially salient for manure and home-made composting, which require a sizable application rate, typically thousands of kilograms per hectare. Gizaw and Kalsa (2017) show that increasing the availability of composting material could increase the adoption of organic fertilizer in Ethiopia. Commercial organic fertilizers offer a solution to the issues of insufficient organic resources and long composting time by using improved composting techniques and accessing large aggregated waste sources. But given the nascent commercial organic fertilizer industry in Kenya and sub-Saharan Africa, improvement of the production line (i.e., a more effective biomass supply chain and a higher local manufacturing capacity) and distribution channels is needed to improve the availability of product in all locations and at relevant agricultural timing.

Another vital advantage of commercial organic fertilizer compared to manure or home-made compost is its higher and more stable quality that has a more favorable C:N ratio and a lower risk of pathogens. Nonetheless, the higher quality comes with an inevitable hurdle—a higher cost. While the prices of commercial organic fertilizers are usually lower than the prices of inorganic fertilizers, greater volumes of organic fertilizer are needed when organic fertilizers are used alone. Thus, the price per unit of nutrient is higher with commercial organic fertilizer than with inorganic fertilizer. Also, the bulky nature and high moisture content of organic fertilizer increases its transportation cost. Odhiambo and Magandini (2008) and Aderinoye-Abdulwahab and Salami (2017) underscore that the high transportation costs is one of the prominent limitations to the use of organic fertilizer. Because of the financial constraints that smallholder farmers usually face, and the up-front high cost barriers, interventions such as input subsidies and transportation support could contribute to the spread of smallholder farmers using organic fertilizer. Furthermore, some studies demonstrate the significant yield benefit when adopting organic and inorganic fertilizers together, and small differences in the yield benefit for different combination rates, thereby suggesting that the application ratio between organic and inorganic fertilizers can be based on their prices (Kearney et al., 2012; Tovihoudji et al., 2018).

8. Macro perspective of commercial organic fertilizer sector

Key takeaways:

- The growth of the local commercial organic fertilizer sector has the potential to generate positive impacts on local employment and reduce the economic volatility caused by international shocks.

The Kenyan commercial organic fertilizer industry represents a USD 3 million value in 2022 and is predicted to grow to USD 45–75 million value in 2030 (Commercial Agriculture for Smallholders and Agribusiness [CASA], 2023b). This enormous expansion is expected to generate a diverse set of benefits for the economy. This increased production and usage of commercial organic fertilizers could increase soil health and agricultural productivity, and reduce negative environmental impacts, as discussed in previous sections. Another direct impact from this sector growth is the increase in employment opportunities (Bidzakin et al., 2023). A substantial number of jobs would be created if those organic fertilizers are produced locally. The openings would happen not only in the fertilizer manufacturing sector, but also in the waste management sector and in distribution channels.

Furthermore, almost all inorganic fertilizers in Kenya are imported from a handful of international players. As a result, this heavy reliance on foreign trades makes Kenya's fertilizer market extremely sensitive to international events. For example, a large component of the fertilizer retail price is the Free on Board (FOB) price, and FOB increased by 100 percent after the outbreak of the war in Ukraine because the supply was suddenly reduced (Commercial Agriculture for Smallholders and Agribusiness [CASA], 2023b). The Kenyan inorganic fertilizer market experienced both a skyrocketed fertilizer price and a hiatus in the supply chain. World Food Programme & Boston Consulting Group (2022) estimates that fertilizer prices have risen by approximately 70 percent from 2021 to 2022. Substituting some inorganic fertilizers with commercial organic fertilizers applications, and producing those commercial organic fertilizers within the country, would alleviate the Kenyan fertilizer market's vulnerability to foreign shocks, such as international trade disruption and exchange rate fluctuations.

These macro perspectives are mainly drawn from one study conducted by Commercial Agriculture for Smallholders and Agribusiness using 60 in-country interviews and desk research and analysis to assess the fertilizer sector in Kenya (Commercial Agriculture for Smallholders and Agribusiness [CASA], 2023b). Additional empirical evidence is called for understanding the full impact of sector growth.

9. Conclusion

Even though the agriculture sector is one of the main contributors in the economies of sub-Saharan Africa, the sector still faces a significant yield gap. Declining soil fertility and low productivity in current cropping systems are two key challenges. This study focuses on examining one potential solution that is often neglected—the use of organic fertilizer.

Applying organic fertilizer can result in increased SOM and an improved nutrient status of soil, and contributes to reducing soil degradation. There is strong evidence that, by improving the physical and chemical features of soil, organic fertilizer also improves the efficiency of other nutrient applications. Existing studies provide rigorous evidence that organic fertilizer application leads to significant benefits. Applying organic fertilizer increases agricultural productivity, profitability, and the nutrient values of the harvest. Additionally, organic fertilizer application is beneficial in avoiding the environmental losses that are common with inorganic fertilizer application, such as leaching, gaseous losses, and runoff. Moreover, the improved productivity and efficiency in resource use could crowd in additional agricultural investments, which increase yield and profit further. It is also important to note that the impact of organic fertilizer could vary substantially across different circumstances. Specifically, agroecological conditions, target crops and growing patterns, fertilizer application rates, and the type and quality of the organic fertilizer all influence the performance of organic fertilizers.

Despite the well-documented agronomic gains of organic fertilizer application, its adoption level remains low in Africa. Crucial barriers are the scarcity of raw organic material, local manufacturing capacity, and insufficient awareness of the benefits of organic fertilizer. Commercial organic fertilizer presents an opportunity to improve the usage of organic fertilizers significantly. Commercial production addresses the issues of insufficient organic resources and long composting time that home-made production commonly experiences. Using commercial organic fertilizer also has the potential to reduce negative environmental impacts through avoiding the environmental issues associated with utilizing inorganic fertilizer and organic waste.

Nevertheless, the additional costs associated with using commercial organic fertilizer, compared to using home-made compost or manure, are new challenges to be solved. Encouraging investment into commercial production of organic fertilizer could increase the supply of organic fertilizer and reduce the costs, thereby increasing farmers' access. Expanding the market provision could also reduce transportation costs, as products become available even in remote areas. Finally, coupling the sale of organic fertilizer with digital extension services could provide farmers with knowledge of the appropriate application, and therefore increase the yield and profit gain for farmers, making the adoption more cost effective. For an innovation to spread widely, agronomic gains are not sufficient—it has to be cost-effective for farmers. While there is suggestive evidence that indicates organic fertilizers are cost-effective, future impact evaluations that provide rigorous proof of the cost-effectiveness of commercial organic fertilizer are needed.

10. Figure and Tables

Figure 1: Framework for impact pathways of organic fertilizer

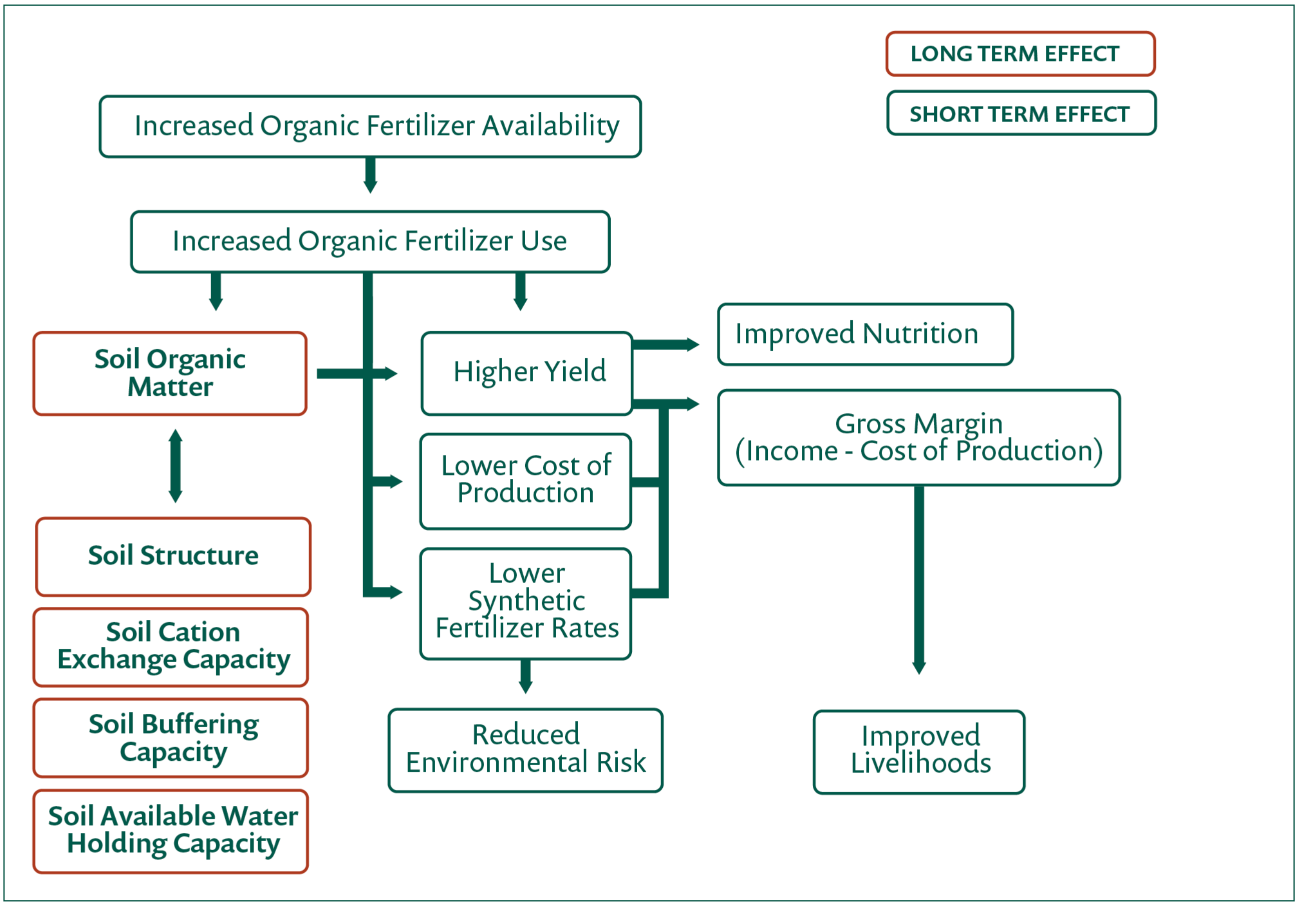

Table 1: Summary of various fertilizers

	Inorganic Fertilizer	**Organic Fertilizer**
Main Purpose	Provide essential nutrients to crops; improve crop yield immediately	Provide essential nutrients to crops; provide carbon-based material to soils; improve long-term soil fertility
Application Rates	Typically tens to hundreds of kilograms per hectare	Typically thousands of kilograms per hectare
Common Sources	Synthesized from air; processed from mined minerals	Animal manures; composted plant residues; animal byproducts
Environmental / Health Concerns	Leaching into groundwater; airborne particulates; eutrophication	Potential source of pathogens
Challenges with Adoption	High cost; availability; need for technical knowledge to select ideal type and rate	Insufficient knowledge; lack of sufficient quantities; tradeoffs in use of plant materials; financial constraints

Table 2: Cost-effectiveness of organic fertilizer

Study	Study Location	Study Crop	Study Year	Treatment	Benefit-Cost Ratio
Panel A: Manure and compost (farm trial data)					
Jjagwe et al. (2020)	Uganda	maize	2018	manure with various storage methods [1]	3.00-168.00
				vermicompost	102.00
Kearney et al. (2012)	Uganda	cabbage	2010	manure	4.59
Tovihoudji et al. (2017)	Benin	maize	2012-2015	manure with various application rates [2]	2.00-10.00
Panel B: Manure (collected survey data)					
Mwaura et al. (2021)	Kenya - Gatanga	maize	2018	sole animal manure	2.69
	Kenya - Meru South			sole animal manure	1.63
Panel C: Commercial organic fertilizer (proprietary farm trial data)					
FarmStar report	Kenya	French beans	2014	commercial organic fertilizer (Evergrow) + inorganic fertilizer	3.35
SGS report	Kenya	tomato	2024	commercial organic fertilizer (Evergrow) + inorganic fertilizer	>1
CropNuts report	Kenya	various crops [3]	2023	commercial organic fertilizer (Evergrow) + inorganic fertilizer	>1

Note:
1. Various storage methods refer to storing under a shade, storing in the open, and storing in a biogas digester.
2. Various application rates refer to 3 Mg/ha and 6 Mg/ha.
3. Various crops include maize, rice, potato, onion, cabbage, and black nightshade.

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Appendix A: Soil fertility and soil organic matter

A.1 Definition of soil fertility and soil organic matter

Soil fertility refers to a soil's ability to provide essential plant nutrients, and to maintain the necessary chemical, physical, and biological properties to sustain plant growth (Food and Agriculture Organization [FAO], 2022). Soil chemical properties are those properties, such as pH or cation exchange capacity, that influence the availability of nutrients; soil physical properties relate to soil structure, which drives the flow of gas, water, and nutrients through soil; and soil biological properties allow the continuity of nitrogen and phosphorus cycles, which provide usable forms of these nutrients for plants. Plants typically require large quantities of macronutrients, namely nitrogen (N), phosphorus (P) and potassium (K), and smaller quantities of micronutrients, such as iron (Fe), manganese, and zinc (Zn). All these elements are made available to plants through biological cycles, and chemical and physical processes, through the mineralization of soil organic matter, or through addition as inputs (Food and Agriculture Organization [FAO], 2022).

Soil organic matter (SOM) (or the closely related soil organic carbon—SOC) can be defined as organic materials found in soils; these materials originate from living organisms, primarily plants and microbes (Chenu et al., 2024). The level of SOM in soils is an essential component of soil fertility, and it contributes to crop productivity (Lal, 2006; Manlay et al., 2007). Many studies across sub-Saharan Africa and the rest of the world show the strong relationship between crop yields and SOM (Lal, 2006). SOM confers many benefits: It contains essential plant nutrients which are mineralized and become available for plant uptake (Kimetu et al., 2008); it provides cation exchange sites which are critical for retaining plant nutrients in soils (Kimetu et al., 2008); it increases the water-holding capacity of soils (Kimetu et al., 2008); it improves soil structure and aggregation, leading to better infiltration (Franzluebbers, 2002); and it contributes to the pH buffering capacity of the soil (Nelson & Su, 2010; Adekiya et al., 2020).

SOM content is determined by a dynamic process of gains and losses of organic carbon (C). Organic material may be added to soils naturally as C assimilated by plants as they grow, and it may be brought to the field from external sources (Tittonell & Giller, 2013). On the other hand, organic material is lost from soil when crops are harvested, when other biomass is removed from fields, when crop residues are burnt or grazed, when carbon-rich topsoil is eroded, and when organic material is degraded by microbes into carbon dioxide (CO_2) (Ölinger, 1996). In addition, SOM is also reduced by agricultural practices such as repeated soil disturbance or the dominance of annual crops (Means, Crews & Souza, 2002). As a result, maintaining and improving SOM is a persistent challenge for smallholder farmers (Willy et al., 2019). Furthermore, a net depletion of SOM could potentially lead to a vicious cycle where a reduction in SOM leads to soils losing productive capacity, which in turn reduces biomass production, which in turn leads to a further reduction in SOM (Kimetu et al., 2008).

A.2. Methods that increase soil organic matter

There are many mechanisms through which farmers can increase the SOM content of their soils and in turn improve soil fertility. Each method has its advantages and disadvantages.

SOM may be improved by traditional fallowing, by which farmers periodically leave a portion of their land unmanaged for one or more seasons, which allows vegetation to grow and improves soil fertility through lower mineralization rates, higher retention of N deposited from the atmosphere, higher uptake of N by deeper rooting plants, higher biological N fixation, and higher input of more recalcitrant organic matter (Giller et al., 1997). However, with fallowing, gains in SOM rapidly decrease once the soil is cultivated again, and fallowing land may not be feasible for smallholders, who have limited areas of land and urgent income needs.

Intercropping with trees and other beneficial plants is another way to improve the N and C content of soil. Intercropping with grain legumes increases biological N fixation, and some grain legumes also provide direct N additions to the soil. Increased N in the soil can support subsequent C assimilation by other higher biomass crops. However, intercropping by itself is unlikely to reverse soil fertility decline without additional measures; inter-crops also compete with crops for sunlight, nutrients and water (Giller et al., 1997).

Planting N-fixing or high biomass plants, known as cover crops, can rapidly improve N content, and plant residue and C accumulation (Giller et al., 1997). However, this requires sufficient land and water, which could otherwise be used for crops themselves. Again, for smallholders with limited resources, growing a crop with no direct monetary or nutritional benefit is a challenge (Tittonell et al., 2008; Giller et al., 1997).

SOM may also be improved through better management of crop residues, which are the plant materials that are left on the field after the removal of the harvested portion. This can be achieved by reducing both the burning of crop residue and the export of crop residues from fields after the growing season, such as for livestock feed. These crop residues are an important source of organic matter which can be returned to the soil for nutrient recycling, and improved crop residue management is shown to support improvements in SOM and soil fertility. Higher levels of SOM improve the soil's physical, chemical, and biological properties (Kumar & Goh, 2000). However, on its own crop residue management cannot reverse declines caused by negative nutrient balances and related reinforcement loops that reduce biomass production. In addition, a competing use for crop residues is as livestock feed, and thus crop residues may not be available for soil fertility management (Lal, 2006).

Organic fertilizers accessible to farmers in their farmyards include animal manures, and composted or vermicomposted crop residues or farmyard waste. The main benefits of on-farm compost or manure is its low cost, nutrient cycling and waste management within the farm (Waqas et al., 2023). However, the availability of organic material or on-farm manure is often limited (Tittonell et al., 2008), and their nutrient content is highly variable.

Lastly, farmers may purchase commercial organic fertilizers, which are produced at large-scale using improved composting or vermicomposting techniques. This allows the standardization of nutrient content and control over the process. However, large-scale production could be resource intensive, and purchases of commercial organic fertilizers imply that farmers face additional costs.

Appendix B: A case study of a specific commercial organic fertilizer

B.1 Introduction

Evergrow is a commercial organic fertilizer locally manufactured by Regen Organics in Kenya. Regen Organics sold an estimated 3,600 metric tons of Evergrow to farmers in 2022, which represents a market share of more than 50 percent by quantity sold in Kenya (Commercial Agriculture for Smallholders and Agribusiness [CASA], 2023b). Given its majority share of the commercial organic fertilizer market in Kenya, and the availability of information on its use and impacts from the manufacturer, we focus on Evergrow to understand adoption, impact, and benefits and challenges relating to commercial organic fertilizers. In this case study, we summarize the insights learned from three sets of surveys and three sets of farm trials that were conducted in Kenya by multiple organizations.[3]

Evergrow is made of residual organic materials from agricultural, animal, and municipal sources. These residual organics are composted using thermophilic aerated windrow composting. This is a common composting process that breaks down organic raw materials and eliminates pathogens. The resulting organic fertilizer contains 1.5–3 percent N, 1 percent P, 1 percent K and 20:1 C:N ratio (Commercial Agriculture for Smallholders and Agribusiness [CASA], 2023b). As indicated in this paper, organic fertilizers help increase soil carbon, leading to multiple improvements in soil productivity, such as microbial activity, improved water retention, and improved nutrient holding capacity. Many studies have shown the application of organic fertilizers can improve the efficiency of inorganic fertilizers, and complement the use of inorganic fertilizers to improve soil fertility, while providing crops with essential nutrients. Consistent with this, Evergrow is positioned by Regen Organics as a complement to inorganic fertilizers: Evergrow may maintain yield by replacing up to 50 percent of inorganic fertilizer used on farms (Commercial Agriculture for Smallholders and Agribusiness [CASA], 2023b).

Regen Organics indicates that Evergrow is designed for use on any crop, and they particularly recommend its use on horticultural crops such as tomatoes, capsicum, onions, French beans, and flowers, and high-value seasonal crops like coffee, tea, rice, and wheat. Evergrow is compliant with requirements set by the Kenya Bureau of Standards (KEBS) (Commercial Agriculture for Smallholders and Agribusiness [CASA], 2023b).[4]

B.2 Farmer awareness, adoption, and perceptions of Evergrow

Strathmore Business School (SBS) and Boston Consulting Group (BCG) conducted surveys with 671 farmers and 584 agrovets (resellers of farm inputs) across six counties in Kenya (Boston Consulting Group, 2023). Farmer respondents include 74 percent and 26 percent of male and female farmers, respectively. Maize was the most commonly grown crop (68 percent of farmers), followed by beans (31 percent of farmers). Among all farmer respondents, 85 percent had heard of specific commercial

3 The specific studies included are a survey with farmers and agrovets conducted by Strathmore Business School (SBS) and Boston Consulting Group (BCG), a survey with farmers conducted by 60 Decibels, a survey with farmers conducted by Kearney, a field trial conducted by Farm Star, a field trial conducted by SGS Kenya Limited, and a set of field trials conducted by Crop Nuts.

4 Evergrow Gold meets EcoCert export standards (Commercial Agriculture for Smallholders and Agribusiness [CASA] , 2023b).

organic fertilizers. Of those farmers who were able to name brands, 43 percent had heard of Evergrow, making it the best-known brand in this sample. While 70 percent of all farmer respondents had considered buying commercial organic fertilizer, 49 percent of farmers bought it at some point, and 43 percent of farmers bought it in the past 12 months. Evergrow was bought by 26 percent of farmers in the past 12 months, indicating that it also was the most bought brand with this sample of farmers. Of farmers who had not considered purchasing commercial organic fertilizer, 72 percent indicated that they used their own manure or compost, and 25 percent indicated that commercial organic fertilizer was unavailable in their area.

The majority of farmer respondents (94 percent) applied fertilizer in the last season. Among them, 72 percent used synthetic fertilizer, 54 percent used manure or compost, and 26 percent used commercial organic fertilizer. In terms of application rate, compared to what farmers perceived to be correct rates, farmers thought that they applied 109 percent less commercial organic fertilizer and 20 percent less synthetic fertilizer than they should, while applying 31 percent more manure or compost than what is needed. Farmers perceived the main benefits of organic fertilizers as increasing soil productivity and leading to higher crop yield, while the principal disadvantage was affordability. Similarly, agrovets considered that commercial organic fertilizers had the same yield and soil health benefits as in-house manure or compost, but at a higher cost, making it difficult to compete price-wise against in-house manure or compost. These responses imply concerns about the value for money of commercial organic fertilizers and indicate insufficient awareness of the difference between commercially produced organic fertilizer and homemade manure and composts.

Across all farmer respondents, commercial organic fertilizer had a low Net Promoter Score (NPS) of -22, comparable to synthetic fertilizer (NPS of -23), with more farmers preferring to recommend in-house manure or compost (NPS of 22). However, among Evergrow users, the product had an NPS of 36, higher than for in-house manure or compost (NPS of 21) and general commercial organic fertilizer (NPS of 23). These ratings indicate that farmers who used Evergrow saw value in it compared to their own manure or homemade compost.

In another survey, conducted by 60 Decibels, 287 Kenyan farmers who had purchased Evergrow before were interviewed (60 Decibels, 2023). This sample of respondents includes 53 and 47 percent of male and female farmers, respectively. Their median cultivation area of last year was 2 acres. 78, 43, and 26 percent of farmers selected maize, beans, and potatoes as their top 3 important crops. The median tenure of using Evergrow fertilizer was 1.5 years. Before starting to use Evergrow fertilizer, 88 percent of farmers only used chemical fertilizers; 84 percent said they had no prior access to a comparable fertilizer, and 88 percent said they could not easily find a good alternative to Evergrow. The NPS for Evergrow reported by farmer respondents was 56, which is in the top quintile of 60 Decibels' East Africa benchmark, and 82 percent of respondents consider Evergrow fertilizer's value for money to be good or very good. Nevertheless, 19 percent of respondents experienced challenges, such as high prices, poor farming outcomes, and unavailability of smaller quantities.

B.3 Impact of Evergrow on yields and revenues

To understand Evergrow fertilizer's impact on yield and revenue, we examine information from both self-report surveys, in which respondents shared their experiences before and after adopting Evergrow, and farm trials that rigorously measure the impact of Evergrow.

In the SBS-BCG survey mentioned above, 545 farmers reported their yields. Conducting ordinary least squares analysis with this sample, we find that adoption of commercial organic fertilizer is associated with 31.7 percent higher yields per acre (statistically significant at $p < 0.05$), when controlling for the type of crop (i.e., fruits, vegetables, rice, cereals, and cash crops) and usage of other fertilizers.

In the 60 Decibels survey mentioned above, comparing their experience before and after using Evergrow fertilizer, 96 percent of farmers reported an increase in their production, and 85 percent of farmers reported an increase in their farm earnings, mostly attributed to an increase in harvest volume sold. Most farmers (90 percent) who experienced increases in total production farmed on the same amount of land, indicating that they achieved higher yields. Moreover, 83 percent of farmers reported reducing the usage of chemical fertilizer because of Evergrow fertilizer, including 42 percent who no longer used inorganic fertilizer at all, and 77 percent of farmers noticed a decrease in the occurrence of crop diseases or pests since they started using Evergrow fertilizer. Overall, 92 percent of farmers reported that their quality of life improved because of using Evergrow fertilizer, due to factors such as increased food availability at home, increased income, and improved ability to pay essential bills and education.

In another survey, conducted by Kearney, agricultural production, cost, and revenue were collected from 81 farmers who purchased Evergrow fertilizer, for both the season before they used Evergrow fertilizer and the season they used it (Kearney, 2023). Conducting ordinary least squares analysis with this sample, we find that farmers' self-reported yields per acre across multiple crops are, on average, 89 percent higher after starting to use Evergrow fertilizer (a median increase of 43 percent), and positively associated with the quantity of Evergrow that they apply per acre, although those two relationships between Evergrow usages and yields are not statistically significant. Furthermore, farmers reported their revenue increased by 217 percent on average (a median increase of 91 percent). 37 percent of this increase in revenue was attributed to Evergrow fertilizer usage, while other reasons, such as better weather conditions and increased price of harvest sales, generated the rest of the increase. The value of the annual income increase per farmer attributable to use of Evergrow Organic Fertiliser was $1,486 and $7,361 for small and large farmers, respectively[5], equivalent to increases of 35 percent and 32 percent respectively as compared to the income reported for the season before adoption of Evergrow. Farmers reported using this increase in income primarily to fund better access to education (mentioned by 78 percent) and increased savings (mentioned by 62 percent) as well as to purchase inputs for the following season (44 percent).

Moving to farm trials, Farm Star conducted a field trial on French beans in Kenya in 2014. Specifically, it performed two treatments side-by-side, in which the control block used chemical fertilizer and the treatment block used both chemical fertilizer and Evergrow organic fertilizer. The trial results show that the yield in the treatment block with Evergrow fertilizer is more than doubled compared to the yield in the control block, 1.9 MT/ha vs. 0.9 MT/ha.

In 2023, SGS Kenya Limited conducted a farm trial on tomatoes, and Crop Nuts conducted a series of farm trials on maize, cabbage, potato, onion, and black nightshade. All those trials experimented with different combinations of chemical fertilizer and Evergrow organic fertilizer in various quantities. Those trial results show that substitution of higher rates of inorganic fertilizers with commercial organic fertilizer results in similar yields, and this finding is consistent across crops. The reduction in inorganic fertilizer application combined with small amounts of commercial organic fertilizer results in the highest benefit-cost ratio, defined as the total crop value minus fertilizer cost divided by the fertilizer cost. Linear regression of the influence of inorganic and organic fertilizers reveals a positive interaction effect of the two, indicating greater efficiency of inorganic fertilizer applications is achieved by applying commercial organic fertilizers in combination with inorganic fertilizers.

5 Small farmers defined as farmers with farm size less than 10 acres, large farmers defined as farmers with farm acreage > 10 acres.

In the field trial on maize, Crop Nuts observed another advantage of Evergrow fertilizer. It reported that "as the season progressed, the site was affected by a prolonged drought which had an impact on the crop. Some plants succumbed to this drought. The plots with the Evergrow products had more plants (higher survival) and taller plants (healthier crop), suggesting that the Evergrow products can be beneficial to provide a better resistance to drought situations."

B.4 Conclusion

Evergrow is a commercially available organic fertilizer with the potential to significantly positively impact the agriculture sector in sub-Saharan Africa. Internal field trials and surveys with Evergrow fertilizer users suggest positive impacts on agricultural yields and smallholder farmer incomes across multiple crops. These findings are promising, and further field trials and impact evaluations could provide more rigorous causal evidence. While farmer awareness and adoption of Evergrow fertilizer is currently low, increased availability and uptake among farmers in Kenya and other areas of sub-Saharan Africa could have large aggregate impacts on improving soil fertility, agricultural productivity, and, ultimately, smallholder farmers' livelihoods.

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