Nutrient Stewardship and Sustainable Fertilizer Use in sub-Sahara Africa: An Interplay between the Public and Private sector

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Abstract

Fertilizer use is a key factor in increasing crop productivity, yet fertilizer application in SSA is low. In addition, farms are small, plots are non-contiguous and public extension capacity is rather weak. While management practices encapsulated in the 4R Nutrient Stewardship has been critical for targeting sustainable fertilizer use in Canada, there is potential for a sustainable scale up of 4R practices in SSA.

This desktop study reviews project reports, discussion papers, and journal articles, and identifies potential entry points for policy and programming that may stimulate private initiatives and ultimately, enhance 4R uptake in SSA.

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1 Introduction

While the continued use of fertilizer is required to sustain food production, inefficient or excessive fertilizer use can pose serious threats to the environment (Palliser et al., 2019; Wiedmann, 2018) — from the eutrophication of freshwater and the leaching of nutrients into groundwater to an increase in greenhouse gas emissions.

Through research and farmers' experiences, the 4R Nutrient Stewardship guidelines (referred to as 4R practices in this report) has been developed as a solution to increase farm production while protecting the environment (Boateng et al., 2023). 4R practices are a collection of management practices that have been identified to be more productive, profitable, environmentally friendly, and socially acceptable (Fertilizer Canada, 2017). It provides a framework for using the right nutrient source, applied at the right rate, at the right time, in the right place, to achieve improved sustainability (Ibid, 2017). It is currently being adapted in many countries including Canada. Canada has set the standard of sustainable production in the world with a nitrogen use efficiency of 64% (FAO, 2021).[1] This is higher than the World average of 55% (FAO, 2022). Currently in Canada, about 70% of crop acres are operating under the basic principle of 4R (Fertilizer Canada, 2020).

Fertilizer use and 4R uptake is however very different in sub-Saharan Africa (SSA) (Boateng et al., 2023). Fertilizer is rather underused and the uptake of 4R is low. The low 4R uptake has been attributed to the following four factors. First, farmers' knowledge on fertilizer usage is low and their use of fertilizer is liquidity-constrained (ibid 2023). Second, sources of agricultural information pertaining to farmers' practices are often limited (Boateng et al., 2023). Extension officers are unable to reach most farmers given sparse distribution of farmlands and low extension-farmer ratio[2]. In addition, information from extension officers is rather unspecific. For example, given land management practices, extension officers do not have information on the appropriate fertilizer for the specific soil of individual farmers (Ekbom and Sterner, 2009). Third, farmers are unaware of the effect of their actions on the environment, specifically related to inappropriate applications of fertilizers (Boateng et al., 2023). Finally, limited public investment in areas such as laboratory diagnosis of soils through soil testing and infrastructure in terms of transportation and storage decelerate the uptake of any agricultural intervention.

The comparatively high adoption rate in developed countries compared to SSA can be linked to the different roles played by the private and the public sector. The Canadian public sector, for example, has invested in public goods such as infrastructure and provided funds for research. In addition, it has created an enabling environment through policies that encourage 4R uptake (Fertilizer Canada 2020). The Canadian private sector has also featured strongly in disseminating the 4R Nutrient Stewardship. 56% of Canadian farmers rely on agri-retailers for advice on 4R practices (Fertilizer Canada, 2020). In light of these factors, it can be concluded

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[1] Nitrogen use efficiency is a measure of how nitrogen in harvested crop produce compares to nitrogen inputs.
[2] Extension agent farmer ratio various across African countries. In Nigeria, it is 1:5000(Davis et al., 2019) Ghana 1:1500 (https://tiemendo.com/why-do-farmers-need-the-service-of-an-extension-officer/)

that the successful adoption of the 4R Nutrient Stewardship in SSA would require the involvement of both the public and private sectors.

In SSA, public investment in agriculture is low (Mink, 2016). Yet, the adoption of 4R practices for the sustainable use of fertilizer is resource intensive. Hence, small-scale and resource-poor farmers in SSA, including women who are well represented in agriculture (40% of labor force) and face various challenges in accessing and controlling resources (Palacious-Lopez et al 2017), may not be able to adopt 4R practices.

This study explores lessons that can be learned from the Canadian agricultural context, including the role of the private and public sectors in promoting the adoption of 4R practices in SSA. An understanding of these roles is important to serve as a signpost for agribusinesses and retailers on how they can function to promote sustainable use of fertilizer in SSA. Overall, this may also contribute to the achievement of Sustainable Development Goals such as no poverty (SDG1), zero hunger (SDG2), gender equality (SDG5), responsible consumption and production (SDG12) and climate action (SDG13), among others.

The remainder of this study is organized as follows. The next section explains the 4R Nutrient Stewardship in more detail, while Section 3 gives a brief overview of the agricultural systems in Canada and SSA. Section 4 examines the determinants of agricultural technology adoption with emphasis on fertilizer adoption. The last section makes recommendations on how the interplay between the public and private sector can be improved to accelerate the uptake of 4R practices in SSA.

2 The 4R Nutrient Stewardship: On-farm practices that ensure sustainable production

The concept of agricultural best management practices (BMPs) is not new and can best be defined as “practices which have been proven in research and tested through farmer implementation to give optimum production potential, input efficiency and environmental protection” (Johnston and Bruulsema, 2014). The goal of fertilizer BMPs is to match nutrient supply with crop requirements to optimize yield while minimizing nutrient losses from fields (Reetz Jr. et al., 2015). Selection of BMPs varies by location, and those that work best for a given farm will meet local soil and weather conditions, crop type, management system, and other site-specific factors (Boateng et al., 2023). The 4R Nutrient Stewardship is the implementation of BMPs that is site and crop specific and optimizes fertilizer use efficiency by reducing nutrient loss to the environment while increasing profitability (Vollmer-Sanders et al., 2016). The underpinning principles of the 4R practices is to “apply the right type of nutrient in the right quantity needed (rate), at the right time, and at the right place”.

The **right type** refers to the selection of the right source of nutrients for the soil to ensure a balanced supply of essential plant nutrients (Nalivata et al., 2017). In practice, it is not easy to identify the limiting soil nutrients to incorporate into the soil (Johnston and Bruulsema, 2014). The decision to apply the right source of nutrient depends on a laboratory soil diagnosis test and the availability of the nutrient on the market (Ibid, 2014). A laboratory analysis of the limiting nutrient is costly and serves as a constraint to resource poor farmers.

Right rate is the application of an adequate quantity of all limiting nutrients in the soil to meet plant requirements in relation to yield and quality goals. It is the most important 4R component for profitability and environmental consequences (Nalivata et al., 2022). It is done via accounting for the nutrients already in the soil to avoid under- or over- application of fertilizer. While under-application of fertilizer is the main cause of low productivity and profitability, over-application results in nutrient loss with subsequent environmental effects. Thus, too much or too little nutrient application will decrease economic profitability (Reetz Jr. et al., 2015). The right rate of fertilizer to be applied to a crop can be determined using a variety of tools, which include own farm test which matches rates of fertilizer application to farmers' own management practices. Other approaches include rate controllers and yield monitors often used in conjunction with soil test, plant analysis, crop sensors and field scouting (Reetz Jr. et al., 2015). In addition, a web-based decision support tool can be employed. Buresh et al. (2019) use this approach to estimate the field specific nutrient need of a rice farm. Soil testing is a common means of assessing the quantity of limiting fertilizer to be applied (Johnston and Bruulsema 2014). However, as has already been discussed above, this has financial implications, which restricts poor smallholder farmers from analyzing their soils. The plant-based approach is the most common and less expensive method used in detecting field specific nutrient needs. It entails for example, an assessment of the color of leaf or the biomass production of the crop. However, it is difficult to carry out, and in many cases it addresses fewer possible deficiencies. (Nalivata et al., 2017; Johnston and Bruulsema, 2014).

Right time is the timely application of nutrients given the interactions of crop uptake, soil supply, environmental risks, and field operation logistics (Reetz et al., 2015). Application of nutrients at the right time ensures optimum uptake of nutrient during peak and critical growth stages. In addition, it supplies nutrients to crops when demand is high and thus reduces nutrient loss to water bodies and the environment. Research has shown that split application[3] of nitrogen fertilizer results in higher yield and increases nutrient use efficiency (Johnston and Bruulsema 2014). Therefore, an annual or seasonal nutrient management plan helps to ensure that nutrients are applied at the right season or right time of the season. In Canada, for instance, application of fertilizer during spring reduces emission by 20% (Fertilizer Canada 2022). The local environment, site-specific characteristics and the management capabilities of the grower influence the right timing of fertilizer application. (Ibid, 2022)

Finally, **right place** entails putting fertilizer at the right location or depth to take advantage of the root-soil dynamics considering nutrient movement, spatial variability within the field, and potential to minimize nutrient losses from the field (Boateng et al., 2023). Nutrients are placed below the soil surface where they are taken up by roots and are far enough from waterways. Placing fertilizer at the right depth plays an important role in nutrient uptake. For cereals for

[3] Split application refers to the application of fertilizer at two different periods within the growing season.

example, early season access to nutrient is important, and thus, placement of nutrients near the seed row can have a major impact on crop growth in terms of increased branching.

The next section introduces the characteristics of the Canadian and sub-Saharan agricultural sector.

3 The agricultural sector in Canada and SSA

3.1 Agriculture in Canada

Agriculture in Canada is an important industry and provides employment to 1 in 9 people (Agriculture Canada, 2022). The Agri-food sector contributes 6.8% to Gross Domestic Product (GDP) (Ibid, 2022) and contributes significantly to global food production. 80% of Canadian farmers produce for the export market (Montel 2016) amounting to more than 60 billion USD in 2016 (Poulin, 2022).

As of 2021, 62.2 million hectares of land was allotted to agricultural production of which 37.9 million hectares was used as a cropland (Statistics Canada, 2022). Of the total cropland, less than 1 million is currently under irrigation although, there is potential for 1.9 million hectares (Statistics Canada, 2018). This indicates that majority of the land under cultivation in Canada is rain-fed. 82% of the cropland is concentrated across the Canadian Prairies, namely Alberta, Saskatchewan and Manitoba (Poulin 2022). Other farming areas are in Quebec and Southern Ontario. Farming in Canada is diverse and keeps changing. Most farming activities are still traditional (Poulin, 2022), but there is also greenhouse production of crops such as cannabis, mushrooms, and flowers. The average land size of growers has increased over the years with a reduction in the number of farmers signaling a significant change in the structure of agriculture over the last five decades. The average farm size increased from 187.37ha in 1971 to 327.39ha in 2021 (Statistics Canada, 2022), while the number of farmers decreased from 366,110 to 189,874.

Agriculture in Canada is also among the most sophisticated and technologically advanced in the world. Farmers use scientific methods, soil analysis and state-of-the-art equipment. According to Poulin (2022), as at 1996, more than 25% of farmers were using computers in managing crops and livestock. Farming in Canada is intensively carried out by means of fertilizers and crop protection. Fertilizer application rate for 2020 growing season was 142kg per hectare (FAO, 2021).

The agricultural sector is heavily supported by both the federal and provincial government. The funds received from the government are used to support agricultural research and trade. In addition, the funds are used to promote the adoption of new technologies and practices geared towards reducing environmental impact as well as increasing efficiency of farming activities (Fertilizer Canada, 2020). Given the support provided by government and other stakeholders, the nitrogen use efficiency in Canada is high (64%) and exceeds the world average (55%) (FAO, 2021). Further, yields per ha has been on a gradual rise over the years, with the exception of 2021, where there was incidence of drought (Statistics Canada, 2022) This also reinforces farmers' dependency on rains for production activities.

Collective action of farmers by means of cooperatives has helped to optimize their production and distribution activities. This became all the more important with the change in farm structure, i.e., reduction in the number of famers and increase in farm sizes. Farmers organized themselves in cooperatives with economic intent (Goddard, 2002). Hence, they are able to collectively resist low prices offered for farm produce and obtain better access to input prices. The collective action gives them the market power they need to bargain in their favor. Agricultural cooperatives started as farm associations where homogenous farmers organized themselves to access input as well as aggregated their commodity for collective sale after which the proceeds were shared among participating farmers based on production shares and quality differential. Cooperatives are of diverse types, some perform only marketing functions, which aggregates, processes and sells all farm commodities on behalf of their members. Other cooperatives provide inputs for their members and others do both. Major challenges faced by agricultural cooperatives in Canada are limited access to capital (Doyon, 2002) and they cope by merging with other cooperatives with similar interest (Richard and Manfredo, 2001).

3.2 Agriculture in SSA

In SSA, more than half (58.8%) of the population is engaged in agriculture (Cordingley et al., 2015). Agriculture is therefore an important sector for sustaining growth and reducing poverty. The food and agricultural sector contributes approximately 17% to GDP (Statista 2023). Therefore, its growth and development are important for the overall process of socioeconomic development in the region.

Agriculture in SSA is characterized by small landholdings often less than 1 hectare of size[4] and mainly managed via manual labour and rudimentary tools such as hoes and cutlasses. Landholdings often consists of parcels that are non-contiguous. Women play a central and critical role in SSA agriculture. Approximately 40% of farmers in SSA are women, though the number varies across countries[5] (Palacious-Lopez et al, 2017). In addition, there is ample empirical evidence for the existence of a considerable productivity gap between men and women ranging between 8% to 30% (Mugisha et al, 2019; Rodgers and Akram-Lodhi 2019) attributable to gender differences in access to, and control of inputs, resources, and services (Croppenstedt et al., 2013).

Further, climate change has reduced agricultural productivity in SSA more than in any other region, i.e., by 34% since 1961. There is high confidence that future warming will shorten growing seasons and increase water stress which in turn will negatively affect food production

[4] Other studies such as Samberg et al., (2016), for example, reports land size of 2-5 ha with an average of less than 2ha contrary to the figure presented. The main reason for the different values is due to the fact that Samberg's study considered both grazing and cropping lands where as Gillers et al (2021) used only crop land.

[5] For example, the percentage of women farmers is slightly above 50% in Malawi, Tanzania, and Uganda, and substantially lower in Nigeria (37%), Ethiopia (29%), and Niger (24%) (Palacious-Lopez et al, 2017)

from crops, livestock, and fisheries (Adelekan et al. 2022). At the same time, the extent of irrigation or other technologies is very low compared to other continents (Lal et al. 2015). Only 7% of cropland on the entire continent is irrigated, and only 3.8% in SSA. (Lal et al., 2015).

Fertilizer usage, albeit increasing since 2005, is still low in comparison to other nations such as Canada. Figure 1 shows that the average application rate in SSA is 22kg/ha/year and below the Abuja Declaration[6] of 50kg/ha (AfDB, 2019). There is, however, heterogeneity in the use of inorganic fertilizer among countries and even within countries in SSA. For example, fertilizer adoption rates range from 3.2% in Uganda to 64.3% in Nigeria, while the average nutrient application rates in the same countries range from 0.7kg/ha to 64.3kg/ha, respectively (Sheahan & Barrett 2017). In Canada, the application rate is 142kg/ha (FAO, 2022). The low fertilizer application rate in Africa can be linked to high retail prices, lack of farmer knowledge and extension, limited access to finance, and limited market access among others (Boateng et al., 2023). Approximately 90% of fertilizer used in SSA is imported from outside the continent (AfDB, 2019; World Bank, 2022). Poor infrastructure, high transportation cost and handling result in high retail prices.

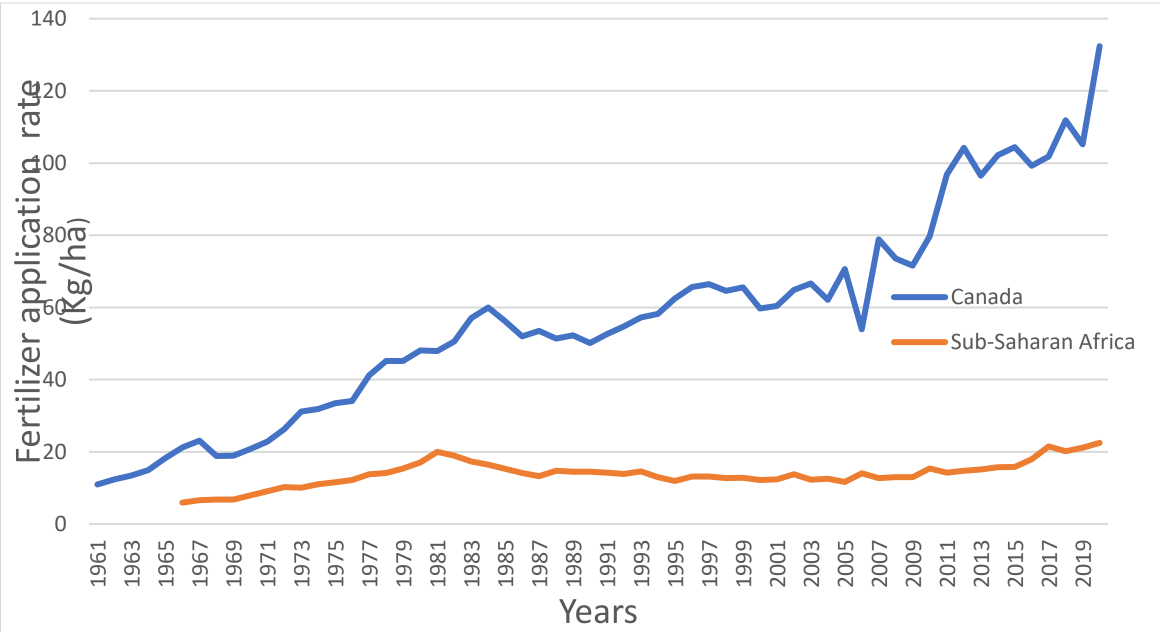

Figure 1: Comparison of fertilizer application rate between SSA and Canada
Source: FAO 2020

Against this backdrop, there is a high degree of soil nutrient mining which easily degrades farmlands. In addition, soils in SSA are inherently infertile (Otter et al., 2007). This together with recurring droughts and other adverse weather events related to climate change negatively affect crop yields (Cairns et al., 2013). Yields are, hence, low, on average less than 20% of its biological potential (www.yieldgap.org). It is also worth noting that the small landholding

[6] In 2006, the Abuja declaration brought together states of the African Union to collectively recommend an increase in fertilizer nitrogen (N) use from 8 kg ha^{-1} to 50 kg ha^{-1} by 2015 to help enable sub-Saharan Africa (SSA) to achieve food sufficiency and eradicate poverty while improving the soil fertility (Ntinyari et al., 2022)

system causes a wide variation in soil fertility across and within farmlands attributable to management practices (Chikowo et al, 2014).

The variation in initial resource allocation as well as marketing failures justify the need for public investment in the agricultural sector (Benin 2015). However, public investment is low and inadequate. Many African countries[7] are unable to meet commitments to the Maputo Declaration (AU, 2014), which advocates an increase in annual spending on agriculture to 10% of the total national expenditure (Benin, 2015). In addition, climate-related research in SSA faces several challenges related to data availability, and inequities in funding and research leadership. Between 1990 and 2019, only 3.8% of global climate-related research funding was allocated to the continent (Adelekan et al. 2022). Therefore, there exists a significant funding gap, which signals inadequacy in the provision of public goods and services, including adequate infrastructures

In the light of inadequate infrastructure and public under-investment in agriculture to help manage market failure and inequality in resource allocation across different groups and members of the society (Benin 2014), agricultural cooperatives have been initiated by government and other non-governmental development agencies. As already mentioned above, the goal of agricultural cooperatives is to raise producers' output and income through the creation of better links with finance, agricultural inputs, information, and output markets (Gebremichael 2014). In addition, a collective voice may enable members to better advocate for their needs. There is, however, overwhelming evidence of failed agricultural cooperatives (Moon and Lee 2020; Zantsi 2021) and only a few success stories, e.g., in Rwanda and Kenya (Wanyama 2008, Gebremichael, 2014). One major obstacle is that unlike Canada, where average landholdings are large and contiguous, SSA farmers often produce on small and fragmented plots on a semi-subsistence basis where farm outputs are self-consumed and the relatively small agricultural surplus is sold directly to farm traders or neighboring consumers instead of cooperatives (Francesconi and Wouterse 2015). Ultimately, cooperatives are unable to sufficiently aggregate and commercialize agricultural surplus from members. Other challenges relate to insufficient managerial capital (Francesconi et al., 2023), lack of communication and participation among members, insufficient or inadequate funds, market access, and inadequate training in terms of extension and educational programs (Moon and Lee, 2020; Zantsi 2021).

The next section summarizes the factors found to be associated with agricultural technology adoption, in particular fertilizer application.

[7] Only 13 countries have achieved or surpassed the 10 percent agriculture expenditure target in any year since 2003, when the Maputo Declaration was signed, with only seven (7) of the countries doing so on a consistent basis (Benin and Yu 2013).

4 Determinants of agricultural technology adoption

In general, a farmer's decision to adopt a technology (or not) depends on complex interactions between different factors including demographics, wealth, agro-ecological conditions, markets, information, social networks, risk and uncertainty.[8] As explained above, there is potential tosustainably scale up 4R practices in SSA (Lotter 2015). To better understand the factors associated with fertilizer application, we resort to Arslan et al's (2022) meta-analysis of farmers' technology adoption in SSA. Table 1 summarizes the vote counting results of the 144 studies on agronomic practices including water, soil, nutrient, and crop management.

While Table 1 speaks to agronomic practices in general, one can identify at least five important factors affecting the fertilizer application decision. First, Arslan et al. (2022) shows that wealth, and wealth-related factors such as assets (including livestock), land size, but also access to credit are consistent positive predictors of fertilizer use. Income, and off-farm income, however, are not among that list.

Second, downside risk is another well-known constraint for fertilizer use. Studies in SSA that investigate the effect of weather anomalies on fertilizer application, find that fertilizer is reduced in times of heightened rainfall variability in Ethiopia (Alem et al. 2010; Dercon & Christiaensen), Zambia (Kusunose et al. 2020), and Kenya (Jagnani et al. 2020). More specifically, Jagnani et al (2020) show that Kenyan maize growers shift investments from productivity-enhancing inputs such as fertilizer to damage control inputs such as pesticides and weeding when exposed to drier and hotter conditions. Under such conditions, fertilizer application can even cause plant damage (Nyssen et al. 2017). In contrast, however, Heisse and Morimoto (2019) indicate a positive relationship between rainfall variability and fertilizer use in Tanzania. The authors of the first four studies conclude that fertilizer is a liquidity-dependent input, whereby – following Arslan et al's (2022) analysis – liquidity seems to be a function of asset-stocks and not necessarily of income-flows.

Third, gender-differentials in the use of fertilizer seem to play an important role. According to Rodgers and Akram-Lodhi (2019), women in Ethiopia and Tanzania are particularly constrained in terms of access to inorganic fertilizer which needs to be purchased in the marketplace. Women, hence, often resort to organic fertilizer such as manure produced by households' own livestock.

Fourth, access to information through extension services and social learning by observing peers' behavior is another important factor shaping fertilizer use (see Takahashi et al. 2019 for a recent discussion). This is linked to participation in farm groups, where knowledge can be shared and bargaining power of the individual farmer can be strengthened (Arslan et al. 2022).

[8] Arslan et al (2022) provide a comprehensive meta-analysis of the adoption of agricultural technology in SSA.

Table 1 Overview of factors associated with agronomic practices including water, soil, nutrient, and crop management

Factor	N	% - significant	% + significant
Demographics of decision-maker			
Age	289	19.7	17.6
Education	368	7.1	28.0
Female*	273	22.7	8.8
Married	15	20.0	26.7
Socioeconomics			
Wealth	126	4.8	36.5
Farm assets	27	3.7	33.3
Land size	346	16.5	36.1
Livestock assets	231	9.5	25.1
Access to credit	186	11.8	24.7
Labor availability	103	14.6	24.3
Household size	237	11.0	21.1
Dependency ratio	29	13.8	6.9
Farm experience	68	14.7	23.5
Tenure insecurity*	99	28.5	8.9
Land fragmentation	30	43.3	10.0
Information access*	211	5.1	38.2
Social capital	100	10.0	23.0
Farmer group part.	122	4.1	33.6
Access to support (government/NGO)	41	17.1	29.3
Infrastructure			
Distance to plot	105	25.7	14.3
Distance to markets	249	22.9	14.1
Distance to water	22	25.7	11.4
Bio-physical factors			
Soil fertility*	236	22.5	13.1
Plot slope (moderate to steep)	155	12.3	23.2
Pest/diseases	55	14.5	14.5

Source: Arslan et al. 2022 Table S7.

Note: N counts the number of times a respective factor was observed as a coefficient in a multi-variate analysis related to the 144 studies that investigated determinants of agronomic practices as summarized in Table S7 in Arslan et al. (2022). *Indicates factor categories that were aggregated across original categories used by Arslan et al. (2022) as follows: Female decision-maker includes female head and the transformed counts for male head, Tenure insecurity includes transformed counts for secure land and insecure land; Information access includes access to information in general, access to extension, and access to sustainable land management/climate change/climate-smart agriculture specific information; Soil fertility includes plot fertility (moderate-good) and transformed land degradation.

Finally, infrastructure conditions shape the accessibility to fertilizer. Minten et al. (2013), for example, show that transaction and transportation costs increase fertilizer costs by 20% to 50% relative to remoteness in Ethiopia. They also show that remoteness not only increases input prices, but also decreases output prices, which consequently undermines the financial viability of fertilizer.

Overall, it should be noted that, as in any other agricultural management decision, the profitability of fertilizer use needs to be considered (Takahashi et al. 2019). Profitability is mainly a function of the yield response rate. In other words, if one intends to improve fertilizer profitability, one must improve yield response rates, which may ultimately relate to soil health.

The next and final section draws conclusions.

5 Sustainable fertilizer use in SSA: Lessons for consideration

The discussion related to factors affecting fertilizer application in the previous section including the emphasis on profitability, puts the spotlight on best management practices encapsulated in the 4R Nutrient Stewardship. Given the relative high uptake of 4R in Canada and the role played by both the public and private sector, what are potential lessons for the uptake of 4R practices in SSA?

The literature review above, while not exhaustive and highly dependent on the studies' local context, offers several entry points for policy and programming. For example, access to information and farmer group participation calls for public investment in extension services and agricultural R&D that builds knowledge of farm management practices that improve soil health and sustainable yield growth (Burke et al. 2017; 2019).

To complement extension services from public agents, the farmer-to-farmer extension (F2FE) approach, where extension agents train farmer-trainers that are expected to share knowledge and information within their network could be explored. To implement the F2FE approach, one needs to contemplate what type of farmer to select as a farmer-trainer (e.g., an entrepreneurial lead farmer vs. an ordinary farmer) and whether to incentivize the farmer-trainers' efforts (Takahashi et al. 2019). Hereby, the Canadian setup of the extension system as an interplay between government-employed extension officers and those employed by private agribusinesses could serve as a role model[9]. It is important, however, that both are well-trained or even certified in 4R practices.

[9] Government employed agronomist as extension officers are mandated to work closely with farmers guiding them of good management practices. In addition, agribusinesses employ agronomist who are 4R certified to work closely with farmers. This approach can be a win-win situation where farmers are advised or guided on the right type of fertilizer to be applied, at the right rate, in the right place, and at the right time. The agribusinesses on the other hand use is at a medium to advertise their product.

The private sector could also explore agricultural R&D opportunities, possibly supported by initial governmental funding, related to e.g., stress-tolerant seeds, efficient supplemental water management systems, soil tests, early-warning systems of adverse local weather events and related pests and diseases, or other technologies that may help their customers, i.e., farmers, to deal with downside risks, specifically those related to climate change.

Consequently, an active collaboration between public and private research institutions, extension services and farmers could strengthen agronomists'4R technology capacity. The involvement of farmers in the collaboration process directly informs about their local needs and experiences, which is key in ensuring sustainability of any agricultural-centered program.

Public policy and programming can also tackle wealth-related factors and improve farmers' access to credit especially in rural areas either formally through state-owned banks or by supporting micro-financial institutions (MFIs) [10] that can serve those who cannot otherwise obtain loans due to their limited financial resources. At the same time, the involvement of the private sector into MFIs and the development of innovative financial services, including e.g., index-based insurance schemes or mobile/digital money transfers may improve the sustainable access to financial services (Van Rooyen et al. 2012). Ultimately, improved access to financial services may enable an uptake of agricultural technologies, specifically 4R practices.

Another important policy entry point is public investments into infrastructure including roads but also mobile and digital connectivity in remote areas that can lower transportation and transaction costs, and may, hence, decrease costs for fertilizer and other inputs and improve the marketability of farmers' produce (Fabregas et al. 2019; Suri & Jack 2016). Empirical studies of rural road programs in developing countries mostly find positive effects on agricultural and also non-agricultural earnings (e.g., Khandker et al. 2009; Dercon et al. 2009; Mu and van de Walle 2011). Asher and Novosad (2020), however, point out that roads alone may not be sufficient to transform the economy of remote areas.

Finally, policymakers could explore ways to improve land tenure security to encourage specifically sustainable production investments that usually involve long time horizons. Albeit limited evidence, tenure security is also positively related to women's empowerment (Higgins et al. 2018).

In terms of "what should not be done", there is empirical evidence that large-scale input subsidy programs, as promoted by governments since the early 2000s, seem to crowd out private sector initiatives (Mason & Jayne 2013; Ricker-Gilbert et al. 2011). In addition, the costs of such programs undermine public investment in extension services and agricultural R&D, as discussed in the first entry point above as a valuable use of public funds.

[10] The original idea of MFIs goes back to Muhammad Yunus who established the Grameen Bank in Bangladesh in 1976 to provide microloans specifically to women. In 2006, Yunus received the Nobel Peace Price. For an extended literature review on the impact of MFIs in SSA see for example Van Rooyen et al. (2012).

Overall, public investments that improve access to information, markets, credit and other financial services, and land tenure security could potentially unleash private investments along the agricultural value chain from input supply, over processing facilities for higher-value products to (local and online) market outlets. Hereby farm groups such as agricultural cooperatives could play an important role.

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