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Improving the Efficiency of Fertilizer Utilization in Sierra Leone

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Abstract

Sierra Leone soils are not naturally fertile enough to sustain prolonged crop production and productivity. Without soil fertility improvement, investments in other yield-enhancing technologies are not likely to bear much fruit. Therefore, agricultural intensification that is supported by substantial additions of fertilizer is a necessity for Sierra Leone to attain food security. Fertilizer use is on the increase but there are concerns that fertilizer use is not as efficient as it should be. The quality of fertilizers, use of wrong fertilizers, sub-optimal use levels, and bad cultural practices are some of the factors. The farmers rely on blanket fertilizer recommendations from the government or from trial and error on-farm fertilizer applications. Soil testing for fertilizer recommendation is rarely practiced by the farmers.In addressing the key concerns such as food security, profitability in agriculture, and environmental quality, improving the efficiency, effectiveness and sustainability of fertilizer use is the fundamental challenge for Sierra Leone. In this article, fertilizer use-efficiency in Sierra Leone is examined together with the various terminologies used to determine efficiency of fertilizer use, and recommendations are made on the way forward within the global 4R criteria for efficient fertilizer utilization.

Keywords:*Fertilizer, Sierra Leone, Use-efficiency, 4R, Soil Testing*

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I. Introduction

Sierra Leone is a tropical country in West Africa with a hot and humid climate. There are two main seasons: The rainy season, spanning from May to October, and the dry season, which lasts from November to April (Frausin*et al.*, 2014). The rainy season brings 3,000 - 5,000 mm rain per year to the coastal areas, and 2,000 -2,500 mm of rain per year to the inland areas (Frausin*et al*., 2014). Agriculture is the mainstay of Sierra Leone's economy, and many systemic and deeply rooted challenges exist within the sector.

Sierra Leone is currently facing an urgent need to improve agricultural production and productivity in order to satisfy the food security requirements of its rapidly growing population. Small-scale producers, operating on farm sizes averaging 1.63 ha, dominate farming operations. Crop yields remain low, at about a third of their potential productivity levels. This is the most critical factor affecting profitability and competitiveness, and ultimately the growth of this sector, as low yields and cost inefficiency invariably affect the net returns to agriculture.

The most widespread cropping system in Sierra Leone is that of shifting cultivation. Under this system, the vegetation is cleared by partial felling of trees, burning, and planting of crops for a specific period of one or two years. The nutrients available from the ash provide a rapid, initially lushgrowth of crop plants. After harvesting, the land is left to fallowfor natural regeneration. In the case of Sierra Leone, the fallow period has been continuously decreasing (SaraviaMatus and Gomez y Paloma, 2014). The reduction in fallow period is more severe on lands that are closer to towns and major roads (Kamara*et al*., 2016; Jalloh, 2006).Consequently, the soil fertility is not fully restored, contributing to the decline in yields.

The most predominant soil types in Sierra Leone are the Oxisols and Ultisols (Odell *et al*. 1974). These soils are generally poor butrich in iron oxide and prone to heavy leaching (Rhodes, 1988; Amara *et al*., 2013). The soils are highly weathered, well-drained, and are acidic with low base status and available phosphorus (P). In the report of Rhodes *et al*. (2016), there is variability in soil properties across the country but in general, the soils of Sierra Leone are of low inherent fertility. A variety of soil types can occur within each agro-climatic region depending on parent material, topography and age. An important feature of the landscape of Sierra Leone is a sequence of soils from uplands to lowlands within each agro-climatic region. Uplands soils are generally of lowerfertility (compared to their adjacent lowlands), well drained and have varying textures but are mainly of medium textures (sandy loam to sandy clay loam). Soils of the lowlands (inland valley swamps, riverine grasslands, bolilands and mangrove swamps) are in wetland ecologies. They are poorly drained and waterlogging at the surface is of varying durations ranging from less than 1 month to over 5 months. The mangrove soils are of medium to fine textures and the textures of the soils of the other lowland ecologies are variable ranging from sandy to medium textures. They are deeper than the upland soils (Rhodes *et al.,* 2016).

In their native state, most soils in Sierra Leone have high fertility status as a result of the build-up of soil organic matter over time. However, when these soils are brought into cultivation, the prevailing high temperatures and rainfall induce rapid breakdown of the accumulated soil organic matter, releasing a flush of plant nutrients at a time when crop demands are low. This breakdown of soil organic matter is so rapid that soil fertility declines considerably within two to three cropping seasons. This is the reason for the traditional shifting cultivation or bush fallow system practiced by our farmers for centuries. This system, however, can no longer be sustained given the current population explosion. Furthermore, the predominant low-activity clay minerals present in Sierra Leone soils have low cation exchange capacity (CEC), and this leads to rapid leaching of nutrients not utilized by the previous crop. As a result, Sierra Leone soils are not fertile enough to sustain prolonged crop production and productivity without significant external inputs.

Farmers in Sierra Leone strongly depend on the native soil fertility and do little to maintain or improve soil fertility, thereby degrading the soil to a stage where cropping becomes unprofitable. Consequently, productivity is low resulting in lower incomes to farmers and a vicious cycle of poverty. Without soil fertility improvement, investments in other yield-enhancing technologies are not likely to bear much fruit. Therefore, agricultural intensification that is supported by substantial additions of fertilizer is a necessity for Sierra Leone toattain food security. In recognition of this, and in line with the Abuja Declaration on fertilizers (Africa Union, 2006), the government of Sierra Leone had been embarking on a massive drive to ensure that fertilizer becomes available to our small scale farmers at a reasonable cost.

The Abuja Declarationwas issued as a result of the Africa Fertilizer Summit, held in Abuja, Nigeria, in June2006. The Declaration included the following objectives(Africa Union, 2006):

- Increase the level of use of fertilizer nutrients from the current average of 8 kg/ha to an average of at least 50 kg/ha by 2015.
- Reduce the cost of fertilizer procurement at national and regional levels.
- Improve farmers' access to fertilizers by developing and scaling up input dealers and community-based networks across rural areas.
- Address the fertilizer needs of farmers, especially women, and develop and strengthen the capacity of youth, farmers' associations, civil society organizations and the private sector.
- Improve farmers' access to fertilizer by granting targeted subsidies in favour of the fertilizer sector, with special attention to poor farmers.

Notwithstanding efforts by the government of Sierra Leone to meet these targets, the efficiency and effectiveness of the entire process has left much to be desired. Around May 2017, the then Minister of Agriculture told pressmen at the Ministry's conference room in Freetown that his Ministry had secured one hundred and sixty thousand (160,000) bags of fertilizer, each weighing 50 kg, to be supplied to farmers (Exclusive Newspaper, 2017; Margai, 2017). "This is the highest number of fertilizers ever purchased by this ministry for farmers. The highest we have had before was forty thousand (40,000) bags of fifty kilograms (50kg) of fertilizers," the Minister had said.The mode of distribution of these fertilizers and the rationale for selection of beneficiaries had left several questions unanswered. Are these fertilizer materials distributed on a blanket basis to recipient Farmer-Based Organizations (FBOs)? Was there any knowledge of soil fertility status of FBO farms before distribution of fertilizers? Was the distribution accompanied by instructions on how, when and how much fertilizer to apply? Did the distributed fertilizer result in any yield increases and/or economic benefit to the farmers? Did the extra benefit, if any, arising from these fertilizers compensate for the cost of these fertilizers? These, and many other questions, need to be examined in efforts to improve the efficiency of fertilizer utilization in Sierra Leone.

There exists enough evidence that fertilizer use is not as effective as it should have been in Sierra Leone for many reasons. The quality of fertilizers, use of wrong fertilizers, sub-optimal use levels, absence of complementary inputs such as improved seed varieties, bad cultural practices and near absence of soil testing are some of the factors (Tarawallie, 2016). The farmers rely onblanket fertilizer recommendation from the government (MAFFS/FAO, 2005) or from on-farm trial and error fertilizer applications. Soil testing for fertilizer recommendation is rarely practiced by the farmers possibly due to insufficient laboratories and the lack of awareness about the relevance of soil testing. This often leads to an imbalance in nutrients and soil fertility depletionwhere the nutrients are under-applied. On the other hand, over-application of fertilizer results in lower profit to farmers and causes environmental pollution. This is not only an environmental hazard but also a substantial economic loss because fertilizers are expensive. Reducing nutrient losses is a critical step toward improving soil fertility and agricultural productivity for the poor farmers. Thus improving the efficiency of fertilizer use is of paramount importance and needs particular attention in Sierra Leone.

Priority on the national agricultural agenda should be given to developing nutrient management practices in which all nutrient sources are judiciously integrated and losses to the environment are minimized. Thus in order to address the key concerns such as food security, profitability in agriculture, and environmental quality, improving the efficiency, effectiveness and sustainability of fertilizer use is the fundamental challenge for Sierra Leone. In this article, fertilizer use in Sierra Leone is examined together with the various terminologies used to determine efficiency of fertilizer use, and recommendations are proffered on the way forward within the global 4R criteria for efficient fertilizer utilization.

II. Fertilizer Use In Sierra Leone

The population of 7.5 million in Sierra Leone is projected to reach 10.3 million by 2030 with the rural population decreasing only slightly from the current 59 % to 52 % by 2030 (SSL 2015; Tilen LLC, 2019). Most farms are small-scale with average farm size of 1.63 ha and very low fertilizer use (Figure 1). A few large-scale farms account for the majority of agricultural input consumption, with one oil palm producer importing and applying 40 % of the country's fertilizer imports (Tilen LLC, 2019). By one estimate, only 3.8 % of farmers use inorganic fertilizers and 9.7 % use organic fertilizers (MAFFS, 2015).

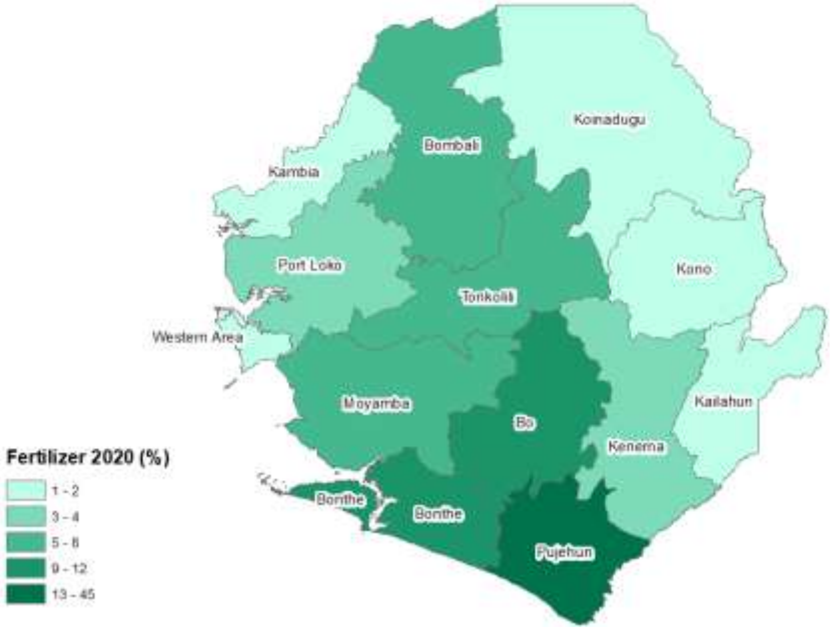

Figure 1: Estimate of Fertilizer Demand (MT) by District in Sierra Leone 2019. Source: Tilen LLC (2019).

Most farmers in Sierra Leone are illiterate and depend on personal interaction with Extension Workers provided by the government or through various donor funded projects to build their knowledge about fertilizer use. According to plans by the Ministry of Agriculture and Forestry (MAF), 608 Extension Workers are required to cover the country, but the Director of Extension services confirmed that less than 200 are currently employed. As a result, farmers do not receive appropriate technical instructions on fertilizer application methods, timing, and dosages. Current fertilizer recommendations used by Extension Workers are outdated blanket recommendations (MAFFS/FAO, 2005) not based on soil fertility status.

The timely availability of adequate and appropriate quantities of fertilizers to the farmers is constrained by inefficient distribution systems. Even if fertilizer is available on time at reasonable price, the farmers have to worry about its quality. The application of adulterated fertilizers reduces crop yields significantly because of their low nutrient contents. While the government has developed a promising strategy, the National Fertilizer Regulatory Agency is not yet operational, leaving aspects of the regulatory environment unresolved. Critically, as part of this new strategy, the Ministry of Agriculture and Forestry (MAF) promised to end government importation and distribution of fertilizers after 2019. While this liberalization creates an opportunity for the private sector, the transition from subsidized fertilizer to full private sector distribution will increase fertilizer prices for farmers, but currently the government's strategy for supporting smallholder farmers during the transition is not immediately clear (Tilen LLC, 2019).

Over the past 3 years, MAF has spent about Le 12 billion per year (USD 1.3 million) buying fertilizers (MoF, 2019). Though government's strategy is to end government imports of fertilizer, the budget allocation for this line item doubled in 2019 and is projected to double again in 2020, sending a mixed signal about the role of the government in importation and distribution of fertilizer (MoF, 2018).

Currently the government does not require a license to import or distribute fertilizers; however importers and distributors are expected to be registered with MAF. In this regard, the government attempts to track import and distribution activities without becoming involved in monitoring and controlling the quality of product delivery. Labeling is also not regulated; agro-dealers and retailers can re-package fertilizers in smaller sizes without appropriate labeling or fear of inspection. Farmers cannot be certain whether these new and smaller packages contain the appropriate ingredients at the weights advertised. Quality control issues like these decrease trust between agro-dealers and farmers further undermining fertilizers adoption among farmers.

Corporate farms import fertilizer for application on their own farms, and Government imports for programs to support local rice production. The majority of fertilizer imports in 2018 were Urea and various NPK blends. Urea comprised 41 % of all types of fertilizer while NPK 4-5-50 and NPK 10-10-30, both of which are used for Oil Palm production, comprised 25 % each. Eight different NPK blends were imported by port in 2018. "Other NPK" include 15-15-15 and 17-17-17 commonly used for rice and vegetables as well as specialized blends like 18-8-15, 20-0-20, and 11-29-15 (Tilen LLC, 2019).

The primary sources of fertilizer imported into Sierra Leone are companies based in Europe and Morocco. Excluding imports from Guinea via road, only 1,300 MT (2.6 %) was imported from other African countries in the past five years, and these imports are primarily Rock Phosphate and organic materials. Nearly 85 % of all Urea imported in 2018, for example, was purchased from the government from Iran, which is offering Urea at heavily discounted prices due to pressure from international sanctions (Thapliyal. 2019). Most fertilizer is imported directly by owners of corporate farms who then transport the fertilizer to their own warehouses and apply it directly on their own farms. Fertilizer imported by Government is transported to District level warehouses, mostly in the capital cities of each district, and then transported to smaller warehouses at Agricultural Business Centers (ABCs) owned by Farmer Based Organizations (FBOs).

Sierra Leone soils are highly acidic, and acidic soils significantly reduce the efficiency of fertilizer use by crops (Conteh *et al.*, 2017). Soil acidity and its effect on nutrient availability can be ameliorated by lime application. However, there is little awareness about liming materials and their benefit to soil fertility, thus agri-input dealers do not sell agricultural lime in their stores. There is a strong need to include sourcing and distribution of lime as a pre-condition to any effort in increasing the use of fertilizer in Sierra Leone. The government must ensure that agricultural lime, an essential commodity, be exempted from custom duty and sales tax. Lime should be included as a subsidized product for distribution in the proposed E-voucher subsidy program for rice production.

The bulk of the fertilizers distributed by the Ministry of Agriculture in Sierra Leone are for rice, the nation's staple crop. It has been observed on several occasions that fertilizers and seed rice are supplied to farmers simultaneously. However, unlike seed rice, fertilizers are hazardous chemicals that can affect not only the environment, but also human beings and the very plants whose performance they are supposed to improve. It is worth noting that some fertilizers are toxic and some (e.g. ammonium nitrate) can be explosive and must be handled with care. The practice of distributing fertilizers to farmers without the associated activities, such as soil testing and training, is counterproductive and needs to be examined.

Many input dealers are poorly informed about what they sell, so cannot advise farmers appropriately. Farmers end up applying the wrong chemicals at the wrong time, wrong rates, and harvest low yields as a consequence. This lowers their trust in the potential of fertilizers and in the people who sell them.

In a recent consolidated verification report on the distribution of Seeds and Fertilizer by the Ministry of Agriculture, Forestry and Food Security (MAFFS, April 3, 2017), several pertinent observations were made:

i. The distribution of seeds and fertilizers did not reach all the farmers of FBOs. Rather, it was the FBO contact person that benefited as an individual.
ii. Fertilizers were supplied without instructions on other associated practices, such as weed control. This further negatively impacted on yield and the farmers can't pay back their loans.
iii. Farmers complained that the repayment terms for the fertilizers were high. The Ministry is asking for 2 bushels (approximately 50 kg) of seed rice for 1 bag of fertilizer. This was viewed by the farmers as being too expensive to them.
iv. There was a huge communication gap between the farmers, the Ministry and the FBO contact persons. Most FBO contact persons do not have direct link with the farmers and were never around the community, so proper communication did not filter down to the farmers.
v. There was a lack of engagement and lack of information-sharing across all stakeholders involved. The process totally eliminated local authorities, thus accounting for low collection and increased bad debts.
vi. There was a need for technical training on the application of fertilizers.
vii. Some farmers made better yield by applying the fertilizer supplied to them by MAFFS but it was not technically done as some farmers applied it 5 times before the harvest. No economic analysis was done so it was not clear if there was any profit.

In December 2016, a survey of Inland Valley Swamp (IVS) farmers around the country was conducted to solicit their perspective on fertilizer support from MAFFS (Conteh*et al*., 2017). Most of the farmers interviewed claimed to have received government support in the form of fertilizers and some improved varieties of rice. The fertilizers received by farmers from MAFFS were mainly urea and NPK (15-15-15).However, none of the farmers claimed to have received instructions on how the fertilizers were to be applied to their swamps. A good number of the farmers claimed that the fertilizer was received very late, when the rice crop was already past the panicle initiation stage, so they believed the fertilizer would be useless at that stage and thus did not apply it. Those who did apply fertilizer explained that the first application was made during land preparation before transplanting and then another dose two weeks after transplanting. The farmers explained that at each application stage, they mixed the urea and the NPK. No farmer could give an exact figure on how much fertilizer was applied at each of these stages. All the farmers agreed and emphasized that fertilizer is a vital yield-enhancing factor.

There is a serious need to provide information that will assist the Government of Sierra Leone to improve the cost-effectiveness and ecological sustainability of fertilizer use in Sierra Leone. Such information will be useful to:

i. Maximize the crop nutrient uptake and economic efficiency of fertilizer use.
ii. Maintain or enhance soil nutrient levels using fertilizers in the context of integrated smallholder agriculture methods to enhance agricultural productivity.
iii. Minimize environment degradation, including from run-off or leaching into water resources.
iv. Minimize potential negative human health impacts.

Yield gains obtained through expanded use of fertilizer and other complementary inputs can enhance household food security and increase rural incomes, which in turn will allow for investments in human capital and technologies to maintain the long-term quality of the soil.

III. Fertilizer Use-Efficiency

Fertilizer nutrients applied to the soil are either taken up by the crop,retained in the soil as soil nutrient stocks, or lost from the soil through erosion and leaching, and other processes of nutrient loss.To use fertilizer more efficiently and in a sustainable manner, management practices must aim at maximizing the amount of nutrientsthat are taken up by the crop and minimizing the amount of nutrients that are lost from the soil.

Reviews on fertilizer/nutrient use efficiency abound in the literature. The term fertilizer use efficiency is defined by Barber (1976, as cited in Baligar and Bennet, 1986) as "the amount of increase in yield of the harvested portion of the crop per unit of fertilizer nutrient applied where high yields are obtained." Other excellent reviews of fertilizer/nutrient use efficiency measurements and calculations can be found in Dobermann (2007), Chianu*et al*. (2012), Fixen*et al*. (2014), and Norton (2017). These reviews described various metrics used to describe fertilizer use efficiency (Table 1.)

Table 1: Fertilizer Use Efficiency Measurements

Term	Calculation*	Question addressed	Typical use
Partial factor productivity (PFP)	PFP = Y/F	How productive is this cropping system in comparison to its nutrient input?	As a long-term indicator of trends.
Agronomic Efficiency (AE)	AE = $(Y-Y_0)/F$	How much productivity improvement was gained by use of nutrient input?	As a short-term indicator of the impact of applied nutrients on productivity. Also used as input data for nutrient recommendations based on omission plot yields.
Partial nutrient Balance (PNB)	PNB = U_H/F	How much nutrient is being taken out of the system in relation to how much is applied?	As a long-term indicator of trends; most useful when combined with soil fertility information.
Apparent recovery efficiency by difference** (RE)	RE = $(U-U_0)/F$	How much of the nutrient applied did the plant take up?	As an indicator of the potential for nutrient loss from the cropping system and to access the efficiency of management practices.
Internal utilization efficiency (IE)	IE = Y/U	What is the ability of the plant to transform nutrients acquired from all sources into economic yield (grain, etc.)?	To evaluate genotypes in breeding programs; values of 30-90 are common for N in cereals and 55-65 considered optimal.
Physiological efficiency** (PE)	PE = $(Y-Y_0)/(U-U_0)$	What is the ability of the plant to transform nutrients acquired from the source applied into economic yield?	Research evaluating NUE among cultivars and other cultural practices; values of 40-60 are common.

* Y = yield of harvested portion of crop with nutrient application; Y_0 = yield of harvested portion of crop without nutrientapplication; F = amount of nutrient applied; U_H = nutrient content of harvested portion of the crop; U = total nutrient uptake in aboveground crop biomass with nutrientapplication; U_0 = nutrient uptake in

aboveground crop biomass without nutrientapplication; Units are not shown in the table since the expressions are ratios on a mass basis and are therefore unitless in their standard form. P and K can either be expressed on an elemental basis (most common in scientific literature) or on an oxide basis as P_2O_5 or K_2O (most common within industry). Adapted from Fixen*et al*. (2014).
** Short-term omission plots often lead to an underestimation of the long-term AE, RE, or PE due to residual effects of nutrient application.

However, regardless of the metrics employed, the objective of fertilizer use is to increase the overall performance of cropping systems by providing economically optimum nourishment to the crop while minimizing nutrient losses from the field and supporting agricultural system sustainability through contributions to soil fertility or other soil quality components. Maximum profit will occur when the maximum value of outputs is reached for each unit value of all inputs.

Estimates of overall efficiency of applied fertilizers have been about 50 % or lower for N, less than 10 % for P and close to 40 % for K in tropical soils (Baligar and Fageria, 2001). These low efficiencies are due to significant losses of nutrients by leaching, run-off, gaseous emission and fixation by soil. These losses can potentially contribute to degradation of soil, and water quality and eventually lead to overall environmental degradation. The clay fraction of the Ultisols and Oxisolsthat cover extensive areas of Sierra Leone is dominated by iron oxides, gibbsite, kaolinite aluminum chlorite and amorphous oxides of iron and aluminum (Dijkerman, 1969; Dijkermanand Miedema, 1988; Sutton *et al*., 1989; Ojanuga, 2007). These components have the tendency to fix large amounts of applied P making it unavailable to plants. These are compelling reasons for the need to identify strategies that will lead to ~~an increase~~increasein nutrient use efficiency in tropical cropping systems such as exists in Sierra Leone.

In the acid soils that are dominant in most of Sierra Leone, the efficiency of applied nutrients is considerable reduced because acid soils have low cation exchange capacity, which gives them poor retention of added nutrients; thereby, making such nutrients susceptible to loss by leaching. Also, denitrification losses are much higher. Allison (2019) reported that an average of 40 % of the nitrogen fertilizer applied to crops isn't utilized and could be lost. In a normal season, most farmers will achieve a nitrogen use efficiency of somewhere around 60 %. In the tropics, large N losses are attributed to ammonia volatilization, leaching and denitrification. Losses of potassium are mostly by leaching. Although P losses by soil erosion can be significant (Reid*et al.*, 2018), losses of P from tropical soils by leaching are very meager, becauseP is fixed by adsorption on amorphous (non-crystalline) Fe and A1 oxides and hydroxides(Baligar and Fageria, 2001)which prevents them from leaching and also making them immediate unavailability to crops.

In tropical farming, climatic factors like rainfall and temperature play an important role on fertilizeruse efficiency. Rainfall leaches away the soluble nutrients like NO_3^- and K. Water logging of lower areas cause denitrification of NO_3^-, and extensive evaporation during dry spells results in ammonia losses. Since the common practice of N application in these countries is by broadcasting, volatile losses of ammonia from ammonium or ammonium forming fertilizers will result.

IV. The Global "4R" Nutrient Stewardship Framework

Fertilizer Best Management Practices (BMPs) can be aptly described as the application of the right source (or product) at the right rate, right time and right place. Under the Global "4R" Nutrient Stewardship Framework(Bruulsema, 2017), the four "rights" (4R) comprehensively convey how fertilizer applications can be managed to achieve economic, social and environmental goals (Figure 2).

In 2007, the International Fertilizer Industry Association (IFA) initiated a program to define the principles of fertilizer BMPs and develop a strategy to encourage their international adoption. At an IFA workshop held in Brussels in 2007 to define and encourage the adoption of fertilizer BMPs, Fixen (2007)described the idea of a global BMP framework that would be science-based, tested through farmer implementations, adaptable to local conditions and able to change and evolve as the understanding of the system increases(Fixen, 2007). The concept of a global framework for sustainable nutrient management that could be applied on a local level was further developed by IFA and the International Plant Nutrition Institute, and became the Global "4R" Nutrient Stewardship Framework (Bruulsema 2017; Bruulsema*et al*. 2009; Bruulsema*et al*. 2008; IFA 2009).

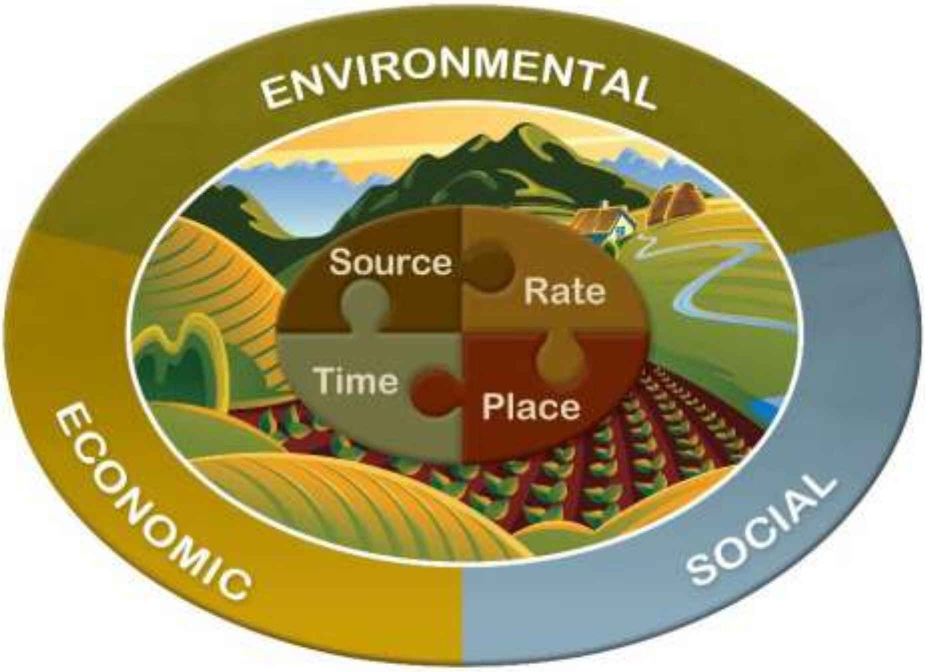

Figure 2: The 4R nutrient stewardship concept defines the right source, rate, time, and place for plant nutrient application as those producing the economic, social, and environmental outcomes desired by all stakeholders to the soil-plant ecosystem.Credit: http://www.ipni.net/ipniweb/portal/4r.nsf/article/communicationsguide

The initiative focuses on applying the right nutrient source or product at the right rate, right time and right place to achieve sustainability goals. Farmers may focus on the agronomic and economic aspects of production as well as stewardship of their land (Johnston and Bruulsema, 2014). The public may be more concerned with safe, nutritious and affordable food, clean air and water, and habitat preservation. Policy makers may focus on food security and addressing the evolving needs of both current and future generations. Balancing the varying concerns of the different stakeholders is a major challenge and the “right” choices will depend on the environmental, economic and societal conditions of each situation (Figure 3).

***Right Rate* -** Choosing the right rate means matching the fertilizer applied to the crop demand. Accurate assessment of nutrient supply is a first step to selection of the right rate. Optimum rate will reflect the balance between crop demand and soil supply.

***Right Source* -** Using the right source means using a form that is suitable to the crop being grown, the management practices used and the environmental conditions occurring in the field. Source selection will be affected by balance and interaction with other nutrients and the presence of other nutrients or contaminants in the fertilizer material.

***Right Place* –** Applying fertilizer in the right place means that the nutrient must be in a position where the crop can access it when needed and where it will not be lost from the system. Root geometry is an important factor in selecting proper placement.

***Right Time* -** Applying fertilizer at the right time means making nutrients available to the crop when they are needed. Nutrient use efficiency can be increased significantly when availability is synchronized with crop demand. Timing of application may also influence risk of off-site movement of P by runoff.

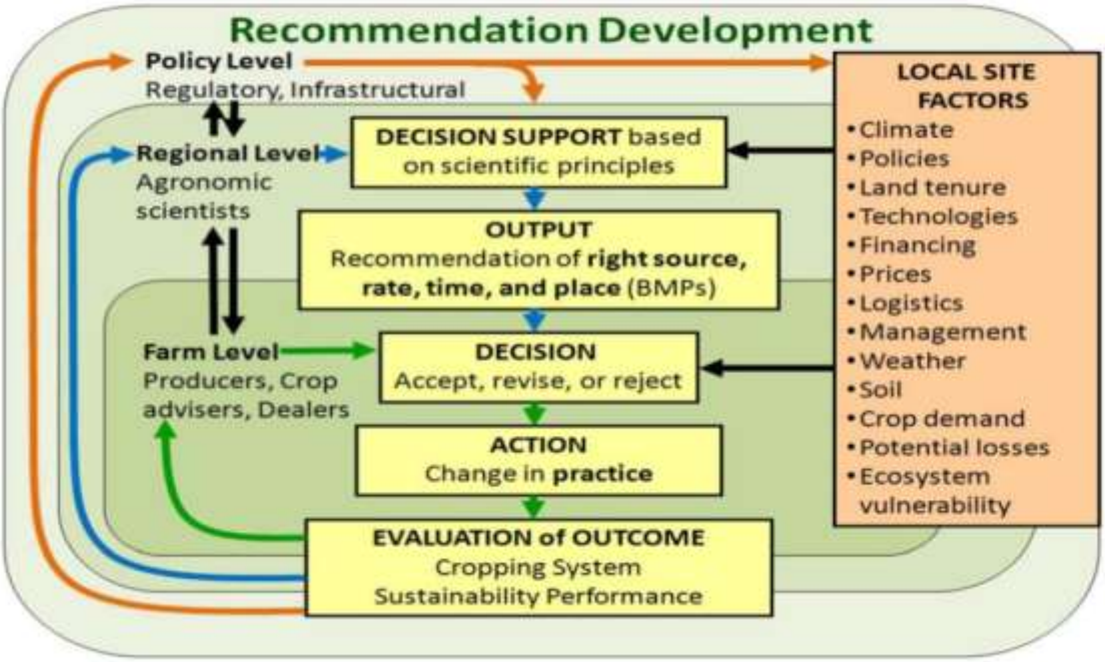

Figure 3: The 4R nutrient stewardship concept requires evaluation of sustainability performance, whether applied on-farm by producers and advisers, in recommendation development by agronomic scientists, or in consideration at the policy level. Practical decisions depend on close attention being paid to the full range of local site factors (Johnston and Bruulsema, 2014).

V. The Need For Updated Fertilizer Recommendations In Sierra Leone

As already seen on the 4R, fertilizer recommendations contain several important factors including crop grown, timing of application, fertilizer type, form and source, placement method, and moisture regime. The optimum fertilizer amount is determined from extensive field experimentation conducted at multiple locations, with several varieties, etc. Sierra Leone does not have updated fertilizer recommendations and it is not clear on which data the current fertilizer rates are based. When applying fertilizers, they must be used efficiently to reduce cost, prevent plant injury and to prevent unwanted changes in the environment. Fertilizer application methods, rates, and timing should be matched to the nutritional needs of particular plants and to the nutrient deficiencies of the soil. There are a few basic, fundamental questions that must be addressed when planning fertilization: Is the fertilizer necessary? How much should be applied? What type of fertilizer should be used? When should it be applied? Where and how should it be applied? These questions can only be addressed following anextensive field experimentation backed by a sound soil analysis program. This will involve studies on soil test levels, and crop response trials integrated with fertilizer placement, timing and crop residue management. Calibration of soil tests are urgently needed to assist in tailoring recommendations to particular farms. The need for other nutrients in this more productive environment will also need to be investigated. Thus there is a need to reassess and review fertilizer recommendations in Sierra Leone.

In order to achieve this, thelaboratory analytical capabilities for agricultural materials (e.g. fertilizers and manures) in the Ministry of Agriculture and Forestry ((MAF) and other affiliated institutions must be enhanced. Enhancement of analytical capabilities in MAF or an affiliated institution will provide information that will enhance proper usage of chemical fertilizers in Sierra Leone with a view to improving fertilizer use efficiency, productivity and household food security in Sierra Leone. To accomplish this, there will be a need to:

1. Strengthen soil and plant analytical services in Sierra Leone
2. Identify the primary nutrients limiting crop productivity in Sierra Leone
3. Develop fertilizer recommendations based on soil tests and crop responses in the field
4. Promote the recommended and effective usage of fertilizer materials through educational programs.

VI. Some Guidelines On Using Fertilizers

Before applying fertilizers, it is very helpful to obtain an assessment of soil conditions using soil testing. Indiscriminate use of chemical fertilizers should be avoided. Fertilizer application has to be considered in the context of the overall farming system. This includes the use of organic manure and crop residues, crop rotation and water control. Collectively, these factors influence the efficiency of nutrient use in cropping systems. When fertilizers are used, it is very important to apply the correct amount for the given situation. Excessive application of nutrients over time can cause pollution. Such effects may occur when nutrients are transported by runoff into stream water, or leached through the soil, beyond the root zone, eventually reaching the groundwater, or escape into the atmosphere as volatile gases. The challenge to the farmer is to match as closely as possible the input of nutrients to the nutrient uptake of the crop, thereby minimizing losses. Over-fertilization is both costly (wasteful) and potentially harmful to the environment.

In deciding what fertilizer to use, it is very necessary to understand the different types of fertilizers available, how fertilizers are used by plants, and to choose which type of fertilizer is best for a given situation. The most pressing challenge for cropping systems is to ensure that knowledge of basic principles of integrated nutrient management, rather than 'blanket fertilizer recommendations', is communicated to those that are most in need – our farmers.

There are 16 plant nutrients generally considered necessary for plant development and growth, of which three (carbon, hydrogen, and oxygen) are supplied by air and water. The remaining 13 plant nutrients are typically supplied through the soil from soil reserves or by the application of fertilizer materials. These 13 plant nutrients are commonly categorized into **macronutrients** (required in large amounts) and **micronutrients** (required in small amounts). Macronutrients are typically divided into **primary nutrients** (nitrogen, phosphorus, and potassium) and **secondary nutrients** (calcium, magnesium, and sulfur). The micronutrients are boron, chlorine, copper, iron, manganese, molybdenum, and zinc. A commercial fertilizer is a material containing at least one of the plant nutrients in a form available to plants in known amounts. Most countries express the quantities or percentages of the primary nutrients in fertilizer materials as nitrogen (N), phosphorus pentoxide (P_2O_5), and potassium oxide (K_2O).

Fertilizers can contain a wide range of concentrations of various forms of nutrients. Consistent description of nutrient form and content allows informed decision making. They can also contain impurities from the raw material or manufacturing process. Some of these can present a risk to plant health, human health and food safety. When procuring fertilizers, there should be an indication of the origin of the fertilizer. There must be a mention of bothdate of manufacture andexpiry date, so that it becomes quite clear as to how long this fertilizer has been standing with the supplier before it was shipped to Sierra Leone. A policy is needed to ensure thatno person/dealer distributes fertilizer, agricultural amendment, agricultural mineral or lime products in bulk unless a label in the form of a separate document physically accompanies the shipment and is furnished to the user or purchaser when each separate delivery is made, or when the last delivery from the lot is made.

VII. Commonly Available Fertilizers In Sub Saharan Africa

The nutrient content of the most commonly available fertilizers in sub-Saharan Africa are presented in Table 2. Using the recommended fertilizer rates based on soil test results, it can then be decided on whether to use a straight fertilizer or a compound fertilizer using the nutrient content present in each type of fertilizer (Table 2).

Fertilizer application must be balanced. When only N, P and K are applied, the high yields induced by the application of N, P and K also increase the uptake of other secondary nutrients (Ca, Mg, and S) from the native soil. This means that in a very short time, these secondary nutrients will become limiting. When this happens, no matter how much NPK is applied, yields will only get to what is possible with the limiting nutrients. It is therefore also very important to consider sources of Ca, Mg and S. For example use of SSP provides, in addition to P, Ca and S. As a way of supplying Mg and increasing the pH levels, it is strongly recommended that some amount of Dolomite be available. These should be top priority.

Table 2: Nutrient Content of Fertilizers Commonly Available In Sub Saharan Africa

Name	Nutrient Content (%)						
	Abbrev	N	P_2O_5	K_2O	MgO	CaO	S
Ammonium chloride	AC	25					
Ammonium sulfate	AS	21					24
Calcium nitrate	CN	15				26	
Diammonium phosphate	DAP	18	46				
Mono-ammonium phosphate	MAP	11	55				
Nitrate of potash (potassium nitrate)	KN	13		44			
Muriate of potash (fertilizer-grade potassium chloride)	MOP			60			
Sulfate of potash (fertilizer-grade potassium sulfate)	KS			50			17
Single superphosphate (SSP)	SSP		16			28	11

Triple superphosphate (TSP)	TSP		44			12	1
Urea		46					
Dolomite (Liming)					10	35	
Gypsum (Liming)						22	13
NPK 15–15–15		15	15	15			
NPK 15–15–6+4 (Mg)		15	15	6	4		
NPK 13–13–21		13	13	21			

Adapted fromFairhurst, T. (ed.) (2012).*Handbook for Integrated Soil Fertility Management*. Africa Soil Health Consortium, Nairobi. CAB International 2012.

VIII. Addressing Soil pH

Most of our soils in Sierra Leone are acidic with pH values as low as 4.5. These pH values are not only detrimental to plant growth but severely limit the availability of essential plant nutrients (Table 3). A first step towards improving the efficiency of applied fertilizer is to examine and address the soil pH levels. Most plants suffer visually when soil pH is below 4.8.

For most crops, the most appropriate pH for efficient utilization of nutrients is in the pH range 5.5 - 7.0. By adjusting soil pH to this range, fertilizer use-efficiency will be significantly increased, as illustrated in Table 3. Correcting soil acidity by the use of lime, or liming material such as gypsum or dolomite (see Table 2) is the foundation of a good soil fertility program. Lime does more than just correct soil acidity. It also supplies essential plant nutrients, Ca and Mg, if dolomitic lime is used. Lime makes other essential nutrients more available and prevents elements such as Mn and Al from becomingtoxic to plant growth.

Table 3: Nutrient Use-Efficiency at Various Soil pH Levels

	Fertilizer Use-Efficiency (%)			
Soil pH	**N**	**P**	**K**	**Fertilizer wasted**
< 4.5	30	23	33	71.34
4.5 - 5.0	53	34	52	53.69
5.0 - 5.5	77	45	77	32.69
5.5 - 6.0	89	52	100	19.67
6.0 - 7.0	100	100	100	0.00

The Mosaic Company. 2020. Soil pH. 2020- Nutrient Management | Mosaic Crop Nutrition. https://www.cropnutrition.com/nutrient-management/soil-ph.

IX. General Considerations

No recommendation will be beneficial if it is not directed to the smallholder famers in Sierra Leone. There will be no single fertilization recommendation which will fit all situations. Even with the recommendations provided after soil testing, many farmers will be either unwilling or unable to purchase this amount of fertilizer, and they will end up applying fertilizer at a much lower rate (or not at all). Decreasing the amount of fertilizer will result in more modest yields, but we must not lose sight of the fact that any amount of fertilizer, no matter how small, will help. We must never lose sight of safety considerations. Efforts should be made not to apply fertilizer in swamps from which water is used for drinking, washing, or laundering, unless an alternative water source is available. If farmers are to be taught how to use chemical fertilizers, they should be taught to use them efficiently, safely, and in moderation. Great care should be taken in handling, transporting, and storing chemical fertilizers. Although most inorganic fertilizers are fairly stable when kept dry, many will undergo drastic chemical changes when exposed to rain or even moisture in the air. Under inadequate storage facilities, gases and liquids can be released from fertilizers, which do not only carry off valuable nutrients, but they can cause considerable corrosive damage to cement floors and walls, metal tools, motorcycles, etc.

X. Conclusions

Sierra Leone soils are not naturally fertile enough to sustain prolonged crop production and productivity without significant external inputs. Agricultural intensification must be supported by substantial additions of fertilizers in order for Sierra Leone toattain food security.Without soil fertility improvement, investments in other yield-enhancing technologies are not likely to bear much fruit.

The profitability of using fertilizer can be increased by developing fertilizer management techniques that are appropriate for smallholders and by ensuring that recommendations for fertilizer are better targeted to their circumstances. The practice of distributing fertilizers to farmers without the associated activities, such as soil testing and training, is counterproductive and needs to be examined.

A first step towards improving the efficiency of applied fertilizer is to examine and address the soil pH levels. On acidic soils, fertilizer recommendations must be accompanied with lime recommendations to ensure efficiency of use.

There is a serious need to provide information that will assist the Government of Sierra Leone to improve the cost-effectiveness and ecological sustainability of fertilizer use in Sierra Leone. When applying fertilizers, they must be used efficiently to reduce cost, prevent plant injury and to prevent unwanted changes in the environment. When fertilizers are used, it is very important to apply the correct amount for the given situation.

The advantage of using the 4R framework to make nutrient management decisions is the adaptability to site-specific conditions. Actively making decisions on the right source, at the right rate, at the right time, and in the right place, while considering site-specific characteristics like soil type, soil test concentrations, slope, and edge of field resource concerns, has the greatest potential for reduced environmental impact and improved economic performance. Selecting the right fertilizer rate, right fertilizer source, right fertilizer placement, and right fertilizer timing are important aspects of best management practices. Farmers should consider all the options for each “right” component and select the best combinations for maximizing crop profitability and minimizing negative environmental impacts.

In deciding what fertilizer to use, it is very necessary to understand the different types of fertilizers available, how fertilizers are used by plants, and to choose which type of fertilizer is best for a given situation. Fertilizer application must be balanced. Continuous application of the same nutrients will create a deficiency of other nutrients over time.

There is no single fertilization recommendation that will fit all situations.If farmers are to be taught how to use chemical fertilizers, they should be taught to use them efficiently, safely, and in moderation.

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