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Our First Issue!

PROTECTING AFRICA'S **FOOD SECURITY** AND **BIODIVERSITY**

DOES **REGENERATIVE AGRICULTURE** FIT AFRICA?

SHIFTING TOWARDS **FARMER-CENTRIC** RESEARCH

MORE INSIDE!

ACTIONABLE SCIENTIFIC INFORMATION ON PLANT NUTRITION

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African Plant Nutrition Institute (APNI)
UM6P Experimental Farm, Benguérir 43150, Morocco.
Ph: +212 5 25 07 31 72 | Web: www.apni.net
Enquiries: g.sulewski@apni.net

Director General's Message

Dr. Kaushik Majumdar
Director General | k.majumdar@apni.net

Knowledge is a critical input in modern agriculture. Farmers make numerous decisions during a cropping season on crop management, navigating the weather, input and output markets, and so on. When such decisions are grounded on evidence-based knowledge the likelihood of success improves, productivity and profitability of farming increases, management decisions foster sustainable outcomes, and croplands stay healthy to feed future generations.

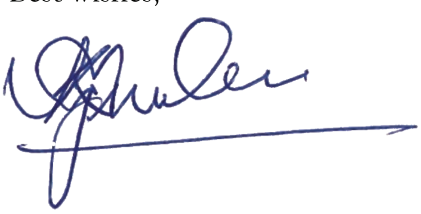
Since the inception of the African Plant Nutrition Institute (APNI), and as our on-farm research began to generate new information, we have mulled over the question…*how do we package information into worthwhile actionable knowledge and deliver it to practitioners?* This brand new publication ***"Growing Africa"*** has evolved out of a consensus that access to useful and pragmatic knowledge on crop management, and particularly on plant nutrition management, is limited in Africa. Therefore, bridging this knowledge gap would be a crucial contribution that APNI can make to African agricultural development.

The concept of *Growing Africa* has received overwhelming encouragement from our partners and collaborators, our Scientific Advisory Committee, and the Board of Directors. We expect this publication to be a critical supporting cog in achieving APNI's mission of *enhanced plant nutrition for a resilient and food-secure Africa*.

So here we are with the first issue of *Growing Africa*, enriched by articles from experts who have spent years understanding crop nutrition in the diverse and complex contexts of African agriculture. The articles that follow span a range of issues that are connected by a common thread – adoption of improved plant nutrition practices that are co-developed with farmers creates economic, social and environmental benefits.

We hope you enjoy reading the first issue. Do send us your comments to help us improve, and we look forward to your support in nurturing this publication into a powerful medium of knowledge dissemination.

Best wishes,



Dr. Kaushik Majumdar
Director General

Editor's Message

Welcome to our first Issue of *Growing Africa*! It's exciting to launch a new digital journal and think about what the future holds for it. As our mission states, we are striving to establish ourselves as a source of actionable scientific information on plant nutrition. In doing so we wish to play a supporting role in helping agricultural practitioners enable agricultural research for development in Africa.

What's inside? You'll find that we are solidly centered on a platform of African-centric agricultural science.

We hope that *Growing Africa's* unique mix of articles, delivered twice a year with an interpretive style, will provide you with many learning opportunities to come. You can look to us to purposely focus the discussion on the practical issues and concepts surrounding improved nutrient management practices within African food production systems.

We also wish to build a forum for you, and this inaugural issue starts that discussion.

As you read through our pages, we invite you to look for opportunities to participate. We are open to receiving brief letters, photos, or you may start a discussion with colleagues via the commenting features provided within our online edition. If you find yourself with the opportunity to contribute an article, we've also provided a link to our Style Guide for potential authors …or you can find out more from our website …www.growingafrica.pub.

Best wishes,

Gavin Sulewski
Editor, *Growing Africa*

Gavin Sulewski
Communications Lead & Editor
g.sulewski@apni.net

Growing Africa Style Guide
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Used Wisely, Fertilizers Will Feed Africa and Protect its Unique Biodiversity

By Achim Dobermann

The balanced and efficient use of fertilizers is critical for improving food security, reducing malnutrition and protecting biodiversity in Africa. The next Africa Fertilizer Summit must result in concrete targets, commitments and actions by governments and industry to, within the next 10-20 years, at least triple the nutrient input rates on cropland. Otherwise hunger and malnutrition will persist, and more natural ecosystems will be destroyed.

In the 1960s, yields of cereals and other staple crops were similar in sub-Saharan Africa (SSA) and Asia. Since then, crop yields in most African countries have risen, albeit far slower than Asia or other world regions, causing the land area under cultivation to more than double in size (**Fig. 1**). But we also observe that African countries that have made stronger efforts to increase fertilizer use (e.g., Ethiopia) have also been more successful in raising crop yields (**Fig. 1**).

Over 100 million (M) ha of grasslands, savannahs and forests have been converted to cropland in Africa since the early 1960s. Between 2010 and 2022, Africa had the largest annual rate of net forest loss of 3.9 M ha yr^{-1}, much of that due to shifting cultivation (FAO, 2020). Hence, besides general concerns about food security and malnutrition, cropland expansion due to low-input, low-yield agriculture also leads to massive biodiversity loss due to habitat destruction, soil degradation or siltation of waters, and it increases human conflicts (IBPES, 2018; Scientific Panel on Responsible Plant Nutrition, 2021). Overexploitation and land degradation could result in the loss of 50% of Africa's bird and mammal species, and 20-30% of lake productivity by the end of the century (IBPES, 2018). Besides destroying biodiversity, matching the future food demand in Africa through more conversion of forests and grasslands to arable crops would also result in much higher greenhouse gas emissions than if crop production was intensified on existing land (van Loon et al., 2019). Hence, protecting natural ecosystems is now a top priority for the continent and agriculture should become one of the most important means of achieving it.

But this requires a different kind of agriculture than what prevails today. In the 1980s, annual nutrient losses in SSA were estimated at 22 kg N, 2.5 kg P, and 15 kg K ha^{-1} of arable land, and losses were up to double that in East Africa (Stoorvogel et al., 1993). Although fertilizer use has increased somewhat since then (**Fig. 2**), crop yields have

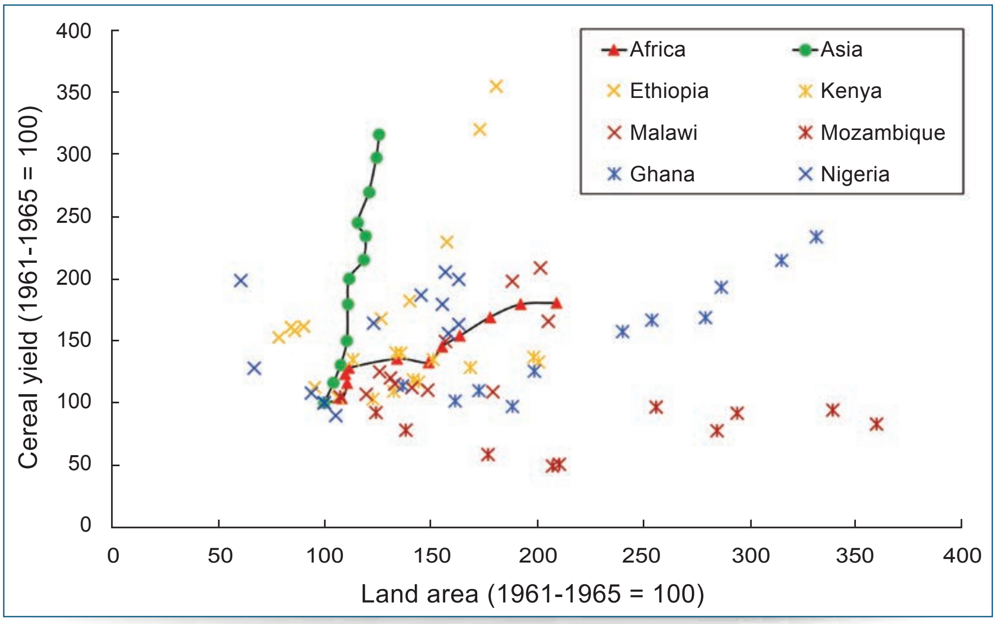

Figure 1. Relative changes in grain yield and land area used for growing cereals (rice, wheat, maize, barley, sorghum, millet) in Asia and Africa, and in selected countries of sub-Saharan Africa. Data shown are 5-year averages for 1961-2015 and a 3-year average for the period 2016-2018. The average of 1961-1965 was set as 100. Source: B. Vanlauwe, IITA, presented at an AGRF meeting in Rwanda, 2018 (based on FAO statistics, https://www.fao.org/faostat/).

increased too. Hence, for the continent as a whole, nutrient input-output balances have not improved at all, resulting in persistent nutrient deficits and soil nutrient depletion that must be overcome to improve food security and environmental sustainability within the next few decades (van Ittersum et al., 2016; Berge et al., 2019). Of course, continental or national averages mask a huge amount of variation. At the continental scale, such data are somewhat skewed by a few countries with relatively high fertilizer consumption, for example Egypt. Despite the lack of reliable information at national and sub-national scales, data on current rates of fertilizer application suggest wide variation among crops and farmers.

The widespread and unsustainable levels of plant nutrient deficits in many parts of SSA, and consequent destruction of natural ecosystems, has been known for a very long time. Critical questions arise: (i) why then has nobody done more about it? and (ii) why is it that we seem to even stagnate in our efforts to overcome that?

In 2006, the first Africa Fertilizer Summit held in Abuja declared, that "*Given the strategic importance of fertilizer in achieving the African Green Revolution to end hunger, the African Union Member States resolve to increase the level of use of fertilizer from the current average of 8 kg ha^{-1} [nutrients] to an average of at least 50 kg ha^{-1} by 2015*." We note, however, that the private sector was largely absent from

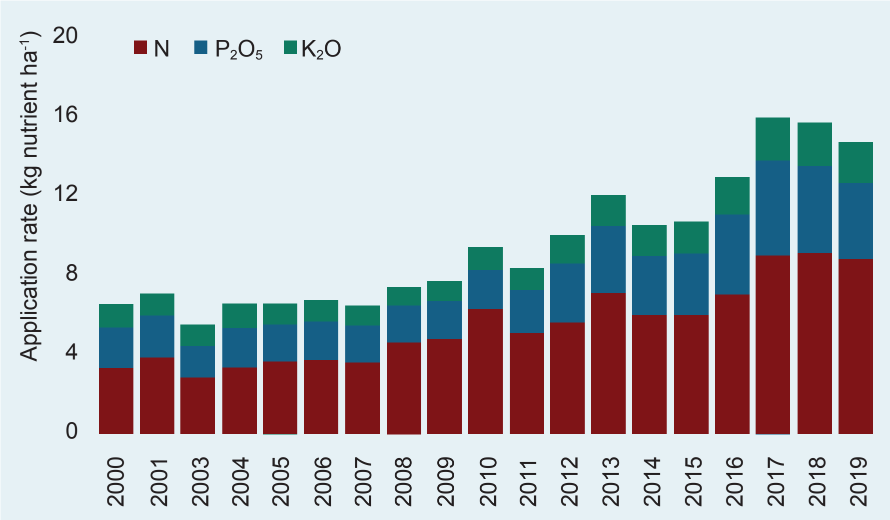

Figure 2. Average rates of fertilizer-nutrient application to cropland in SSA, excluding South Africa. Source: International Fertilizer Association (IFA) 2021, using IFA fertilizer consumption and fertilizer use by crops statistics and FAO cropland statistics.

that summit. Looking at the available statistics on nutrient amounts applied, the average NPK amount reached about 16 kg ha^{-1} by 2017 but has declined slightly since then (**Fig. 2**). The Abuja target was only reached in a few countries (e.g., Kenya, Botswana, Mauritius and South Africa), while several others (e.g., Benin, Ethiopia, Malawi, Mali, Zambia and Zimbabwe) reached average values between 30 and 50 kg ha^{-1} in 2019. Clearly, that is a disappointing and unacceptable outcome for which there are many reasons. Moreover, it has also been demonstrated, that even if the Abuja scenario would be achieved the proposed nutrient rates would still be far too low for food sufficiency and optimized nutrient use efficiency, including avoiding soil mining (Berge et al., 2019; Winnie et al., 2022).

But not all has been bad. Since 2006, we have seen improvements in fertilizer delivery infrastructure and formal markets, more investment in local fertilizer production and blending facilities, greater recognition of soil health, progress in novel ways of soil testing, digital soil mapping (Hengl et al., 2021) or site-specific nutrient management (Chivenge et al., 2022). There has also been a change in mindset in the scientific community, towards a greater recognition of fertilizers as a top priority (Vanlauwe and Dobermann, 2020). Yet, progress is still too slow and the African fertilizer sector is fragile in terms of resilience to external shocks such as the recent Covid-19 pandemic, geopolitics and rising world market prices.

A lot will depend on how smallholder farming in Africa will become structurally transformed in the next 10-20 years, as it has happened in other world regions long before. In many parts of SSA, land is so constraining that even with the best agronomic efforts and closed yield gaps, households would remain food-insecure and without a decent income and livelihood (Giller et al., 2021). It is probably inevitable that land markets will accelerate further (Jayne et al., 2021) and more people will migrate out of rural areas or seek off-farm employment. Although this has numerous social consequences that need to be managed carefully by governments, it also provides an opportunity for accelerating balanced and efficient use of fertilizers to the benefit of farmers, the whole society and the environment.

Whatever term is preferred, ‘sustainable intensification’, ‘regenerative agriculture’, ‘climate-smart agriculture’ or ‘nature-positive farming’ cannot happen in Africa without the use of more fertilizer, along with other locally available nutrient sources. Scientists have called that Integrated Soil Fertility Management (ISFM), which focuses on the systematic co-deployment of fertilizer and other amendments and agronomic practices to maximize the use efficiency of external inputs. The principles of ISFM have been well established (Vanlauwe et al., 2010) and many scientific papers have been written about it in recent years. What is now needed are concrete, scalable forms of implementing it in millions of farms and fields across Africa. To achieve that, I wish to propose the following as some of the priorities to tackle:

Agriculture can be one of the most important means of protecting natural ecosystems in Africa. Anja Koeberle/istock

(1) **Stop spreading myths and misinformation about fertilizers that seem to have prevailed in SSA for a long time** (Vanlauwe and Giller, 2006). Fertilizer use continues to face considerable controversy in SSA, although the scientific evidence is clear: when chosen and applied correctly, the benefits of fertilizer use outweigh the cost, and soils on which there is no response to fertilizer application are quite rare (Nziguheba et al., 2021). Fertilizers do not damage the soil, and they are also not a major cause of eutrophication of waters in Africa. The reality is also that organic inputs alone cannot overcome the current nutrient deficits. They need to be grown first, so hardly represent a net nutrient addition to the whole system.

(2) **Develop and scale robust advisory solutions for farmers.** Research has demonstrated that well-tailored nutrient management recommendations increase crop yields, profitability, and nutrient use efficiency in crops such as maize, rice and cassava in SSA, even without access to more sophisticated services and technologies such as soil testing and precision farming (Chivenge et al., 2022). We now also have numerous new data resources and computational tools available that should make it easier to scale things up towards robust business solutions, including a unique digital map of soil properties for all of Africa at 30-m resolution (Hengl et al., 2021). The main challenge is to systematically fuse a multitude of geospatial data with readily obtainable local information and scientific knowledge into decision support services that are not only scientifically sound and robust in performance, but also easily usable by farmers and advisors. My hope is that we may even be able to move towards self-learning fertilizer recommendation solutions, i.e., data-driven applications that iteratively fine-tune advice at any scale through learning by doing, but hide all that complexity from the actual users. Farmers should not be given ‘prescriptions’, but solid choices that also consider the available capital and uncertainties.

(3) **Investment in fertilizer needs to be combined with other agronomic improvements to increase fertilizer use efficiency and economic benefits.** Access to quality seeds is already improving, but three other

measures will be critical for success: *liming, mechanization* and *irrigation*. On acid soils, it is imperative to find ways to lift soil pH to levels required for achieving high fertilizer efficiency, but liming is only cost-effective when it is combined with proper fertilizer application (Hijbeek et al., 2021). Growing a successful crop typically involves about 10-20 concrete actions by farmers. If many of them rely on manual labor, the risk is high that they cannot be done at the right time, or with the right quality. Labor cost and availability will rise in SSA, just as they have all over the world. Hence, now is the time to sustainably mechanize smallholder farming in SSA, first through small-scale machinery and also by overcoming some of the myths surrounding it (Daum and Birner, 2020). A lot of valuable experience has been gained for that, also in other world regions (van Loon et al., 2020). Likewise, much greater efforts are needed to capture and use water for increasing crop yields and cropping intensity, and reducing the risk of crop failure. More than 10 years ago, an IFPRI study concluded that there was a profitable irrigation expansion potential of 24 M ha over the next 50 years, compared to the then existing area of 13 M ha, which is just 6% of the total cultivated area (You et al., 2011). There are many forms of water management that can be adapted to local farming systems (Shah et al., 2020).

(4) **Better data.** By and large, for most countries in Africa, we currently rely on poor data on actual fertilizer use by different crops and regions, as well as other data that are needed to properly assess and target nutrient use, nutrient use efficiency, nutrient gaps and economic responses to fertilizer application. This also severely constrains the use of geospatial 'big-data' approaches that could allow us to assess, for example, how fertilizer and grain prices constrain food production in SSA, and what is needed to overcome that (Bonilla-Cedrez et al., 2021). Increasingly, such data is also needed at sub-national scales in order to guide better practices, new investments and appropriate policies. No organization alone will be capable of overcoming this data gap. Both public and private sector will need to work together on collecting and sharing more and better data, which should be in everyone's own interest. The Consortium for Precision Crop Nutrition (https://www.precisioncropnutrition.net) has begun to work on the first pilots for creating and governing open, thematic databases related to soil and crop nutrients. Far more is needed to extend such progressive data sharing principles and mechanisms to other data areas of wide applicability. Collecting and reporting agricultural statistics for different purposes must be upgraded with modern tools and data sources, including crowd sourcing, rapid field surveys, digital supply chain monitoring and remote sensing.

(5) **Micronutrient fortification of fertilizers.** Hidden hunger, particularly the forms of it that are caused by deficiencies of mineral elements such as zinc, iron, iodine or selenium, remains widespread in many parts of SSA. Fertilizers enriched with specific mineral elements can be a very efficient intervention to increase grain nutrient concentrations (Chilimba et al., 2012), and through that directly improve human health (Joy et al., 2021), particularly in rural areas where people consume much of the food grown. The challenge is how to deploy such solutions in a targeted manner across the whole continent. Besides identifying the right target area, crops and fertilizer formulations, a key question to resolve is that of who should pay for such a direct health benefit. The fertilizer industry can play a leading role in making more direct contributions to improving human nutrition, but only if there is also a shift in public policy making towards more support for concrete solutions that advance nutrition-sensitive agriculture.

Besides these more fertilizer-use related challenges, enabling greater and responsible use of fertilizers by millions of farmers requires improving the whole policy environment for fertilizers in Africa. The continent requires more investment, innovative financing schemes, and suitable buffers against price risks. Initiatives that can enforce high quality standards throughout the supply chain, and expanding the capacity and skillsets in applied research and extension, both in public and private sector. The international fertilizer industry has recently stated an ambition to *Double nutrient application rates in SSA by 2030 and triple them by*

2040 to close the large nutrient and yield gaps and eliminate hunger by:

- improving access, availability and affordability of plant nutrients;
- becoming a key partner in designing policy and regulatory frameworks and supporting business strategies for national nutrition roadmaps, including possible reallocation of government subsidies for improved access to trade finance and targeted nutritional interventions; and
- designing nutrition-focused product solutions and setting up suitable business models that help create value propositions for the entire agri-food value chain, from farm to fork.

This can be achieved or even exceeded, and the upcoming second Africa Fertilizer and Soil Health Summit must provide a platform to set things in motion, at a faster pace than ever before. ■

Summary

The balanced and efficient use of fertilizers is critical for improving food security, reducing malnutrition and protecting biodiversity in Africa. The next Africa Fertilizer Summit must result in concrete targets, commitments and actions by governments and industry to, within the next 10-20 years, at least triple the nutrient input rates on cropland. Otherwise hunger and malnutrition will persist, and more natural ecosystems will be destroyed.

Dr. Dobermann is the Chief Scientist of the International Fertilizer Association (IFA), Paris, France, and a member of the Scientific Advisory Committee of the African Plant Nutrition Institute. e-mail: adobermann@fertilizer.org.

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Soil Organic Matter Regulates Maize Productivity and Fertilizer Response in Maize Production

By Shamie Zingore and Samuel Njoroge

Resource-constrained systems need strategies that focus on striking a balance between maintaining SOC above a critical value to ensure high agronomic fertilizer use efficiency and avoiding accumulation of nutrients to levels that prevent viable nutrient use efficiency.

Large agricultural areas in sub-Saharan Africa (SSA) are covered by inherently poor soils that have been subjected to soil fertility depletion and land degradation for many decades due to poor management, including low nutrient and organic matter application (Van der Velde et al., 2014). It is estimated that more than 60% of the arable land in SSA is degraded, with critically low contents of soil organic matter (SOM) (Bationo and Fening, 2018). Under these conditions, increased use and judicious management of fertilizer and organic nutrient resources are essential to optimize crop productivity and fertilizer use efficiency.

The status of SOM varies substantially in cropping fields, driven by differences in management practices, soil types, and landscape position (Tittonell et al., 2013; Zingore et al., 2007). Here we examine the critical role of SOM in regulating maize productivity and fertilizer use efficiency in smallholder farming systems, and provide insights for improved targeting of fertilizer resources to optimize maize productivity, based on two case studies in East and Southern Africa.

Fertilizer response and agronomic N use efficiency patterns

Agronomic fertilizer use efficiency is intricately related to soil quality. Conceptually, the relationship between soil organic carbon (SOC), used as a proxy for soil quality, and crop yields and agronomic nitrogen use efficiency (AEN), creates three categories of response that can form the basis of optimizing fertilizer management (Musingizi et al., 2013):

Category 1. Non-responsive degraded soil: At the lower end of the SOC spectrum, low AEN is associated with very low SOC levels due to complex chemical, physical and biological constraints that severely constrain fertilizer response.

Category 2. Responsive soils: At moderate levels of SOC, high AEN are a result of nutrient deficiencies in the absence of other severe constraints.

Category 3. Non-responsive fertile soils: Very high SOC levels

Due to its strong influence on soil biological, chemical and physical properties and crucial soil functions, SOM is an essential indicator of soil quality with direct implications for crop productivity, food security, and human livelihood result in high N mineralization rates and sufficient soil N supply to achieve attainable yields. Soils in the 'non-responsive fertile' category are not common in smallholder farming systems in SSA. They are only found in small hot spots of nutrient accumulation in fields that receive high amounts of organic resources and fertilizer.

For resource-constrained systems, strategies for nutrient management optimization should focus on striking a balance between maintaining SOC above a critical value to ensure high agronomic fertilizer use efficiency while avoiding concentration of nutrient resources to levels that prevent viable nutrient use efficiency. The following case studies illustrate the association of SOC with maize fertilizer response in smallholder farming systems in SSA.

Table 1. Nitrogen and phosphorus agronomic efficiencies as influenced by nutrient management and SOC content, Wedza district, Zimbabwe.

Site	SOC	AEN			AEP		
		NK	NPS	NPKS	NPS	PKS	NPKS
	(g kg^{-1})	kg grain kg^{-1} N applied			kg grain kg^{-1} P applied		
Site 1	3.5	7.0	16.0	17.0	31.5	2.0	35.5
Site 2	5.4	12.1	35.2	31.4	51.8	13.3	51.4
Site 3	8.9	14.1	29.9	36.3	50.5	14.1	52.4

> Critically low SOC levels characterize large areas of agricultural soils in SSA due to the predominance of coarse-textured soils and continuous cultivation with little additions of inorganic and organic nutrient resources.

Case Study 1: Sandy soils in Zimbabwe

The Zimbabwean agricultural landscape is dominated by infertile sandy soils derived from granitic parent material. Steep soil fertility gradients on these sandy soils develop due to differentials in soil fertility management, particularly the variable application of manure. Some soils have degraded to a point where strategic targeting of scarce nutrient resources by smallholder farmers on different field types becomes crucial to ensure viable fertilizer use efficiencies.

To assess fertilization strategies for optimizing crop productivity and NUE in maize production on heterogeneous sandy soils under rain-fed conditions in Zimbabwe, Kurwakumire et al. (2014) established a nutrient omission study during two cropping seasons, across three on-farm sites with SOC ranging from 0.35–0.89%. N and P fertilizer agronomic efficiencies were influenced by both nutrient management and initial soil fertility (**Table 1**). Overall, this study established that fertilizer application was only agronomically and economically viable for soils with SOC > 0.44%.

In a related study under similar soil and agroecological conditions, Kafesu et al. (2017) showed similar trends of yield responses and fertilizer use efficiency. Baseline yields (< 1 t ha^{-1}) and attainable yields (< 2 t ha^{-1}) were low in fields with less than 0.4% SOC (**Fig. 1a, b**), which translated into very low AEN (**Fig. 1c**). Small increases in SOC between 0.4–0.6% resulted in more then 100% increases in baseline yields, attainable yields, and AEN. These results highlight the vital connection between SOC, land degradation, and crop productivity in granitic sandy soils with critical SOC values between 0.4–0.5%.

Case Study 2: Clayey soils in Kenya

On-farm nutrient omission trials conducted over six consecutive cropping seasons in western Kenya allowed the assessment of initial field SOC status on spatial-temporal patterns in yield response to fertilizer N applications (Njoroge et al., 2017).

Fields in this study differed in past manure application history and initial SOC status (**Fig. 2**). SOC contents were generally between 1.5–2.5%, except for one field without past manure application that had SOC contents < 1%, and another field

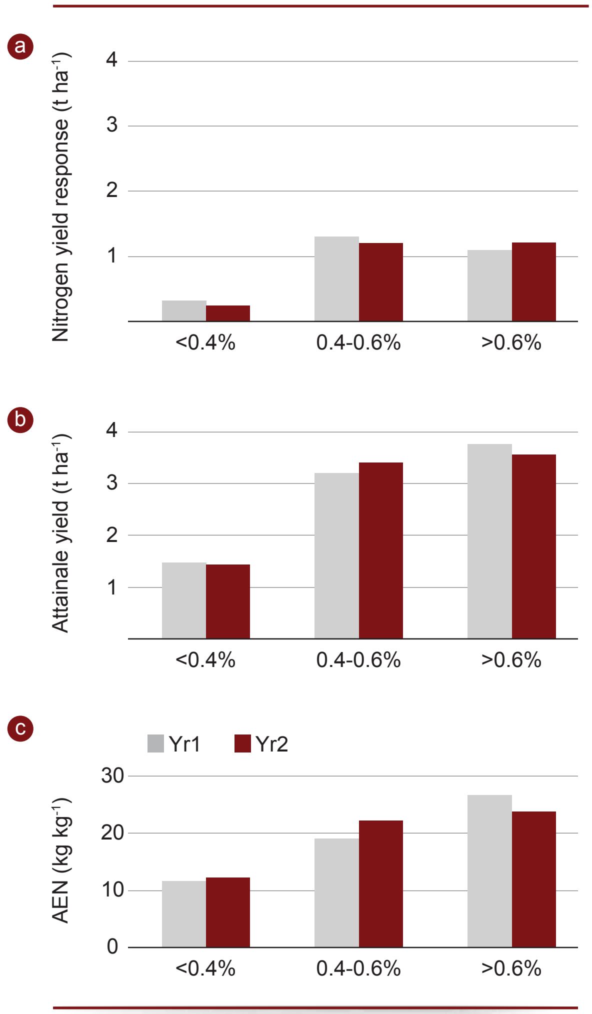

Figure 1. Baseline yield, attainable yields, and agronomic nitrogen use efficiencies for soil organic carbon ranges on a granitic sandy soil in Zimbabwe.

with manure applied in the past with SOC contents > 2.5% (**Fig. 2**). In the first three cropping seasons, yield responses to N were small in fields with SOC contents > 2%, while responses in fields with SOC contents between 1.5–2% were larger but highly variable (**Fig. 2a, b and c**). However in the subsequent three cropping seasons, yield response to N in fields with initial SOC contents > 2% increased while responses in fields with initial SOC contents between 1.5–2% remained highly variable, though the variability declined in the last cropping season (**Fig. 2d, 2e and 2f**). In each season, the field with SOC contents < 1% showed a moderate yield response to N that was consistently less than half of the largest yield response recorded in a particular season (**Fig. 2a, 2b, 2c, 2d, 2e and 2f**).

The initial lower yield response to N fertilization in fields with starting SOC contents > 2% can be attributed to larger soil N supply in these fields. However, continuous cropping without fertilizer N application led to a decline in soil N supply, which resulted in the larger response to N in later seasons. This indicates the fragility of SOC and soil N supply in such fields. It further demonstrates that such fertile 'non-responsive' fields can rapidly lose this status if applications of organic resources and fertilizer N are stopped. Therefore, while such fields may initially only require moderate quantities of fertilizer N to enhance AEN, larger fertilizer N applications or the co-application of available organic resources with moderate amounts of fertilizer N may be needed to maintain soil fertility and improve AEN over time. The consistently lower yield response to N in the field with initial SOC contents < 1% reaffirms the constrained response to fertilizer N under very low SOC contents, which has been attributed to the presence of additional biophysical constraints. Such fields may therefore require targeted measures, such as the application of large quantities of high-quality organic resources to improve SOC contents and address biophysical constraints for enhancing yield responses to fertilizer N applications. Zingore et al. (2008) showed that regular applications of large amounts of animal manure were required to significantly increase SOC, pH, available P, base saturation and restore crop productivity in degraded fields. The large variability in yield response to N observed for fields with initial SOC contents ranging from 1.5–2% demonstrates the huge uncertainty in the expected yield response to N at moderate SOC contents as previously observed for case study 1.

Summary

Critically low SOC levels characterize large areas of agricultural soils in SSA due to the predominance of coarse-textured soils and continuous cultivation with little additions of inorganic and organic nutrient resources. The close association of SOC with maize yields and agronomic N use efficiencies were evident in East and Southern Africa. Sandy soils in Zimbabwe with very low SOC levels (< 1%) were highly susceptible to degradation with a critical SOC level between 0.4–0.5%, below which the yields in control plots declined to less than 1 t ha^{-1} and fertilizer use efficiencies were very poor. In Kenya, SOC contents ranged from 1–3%, with clear patterns

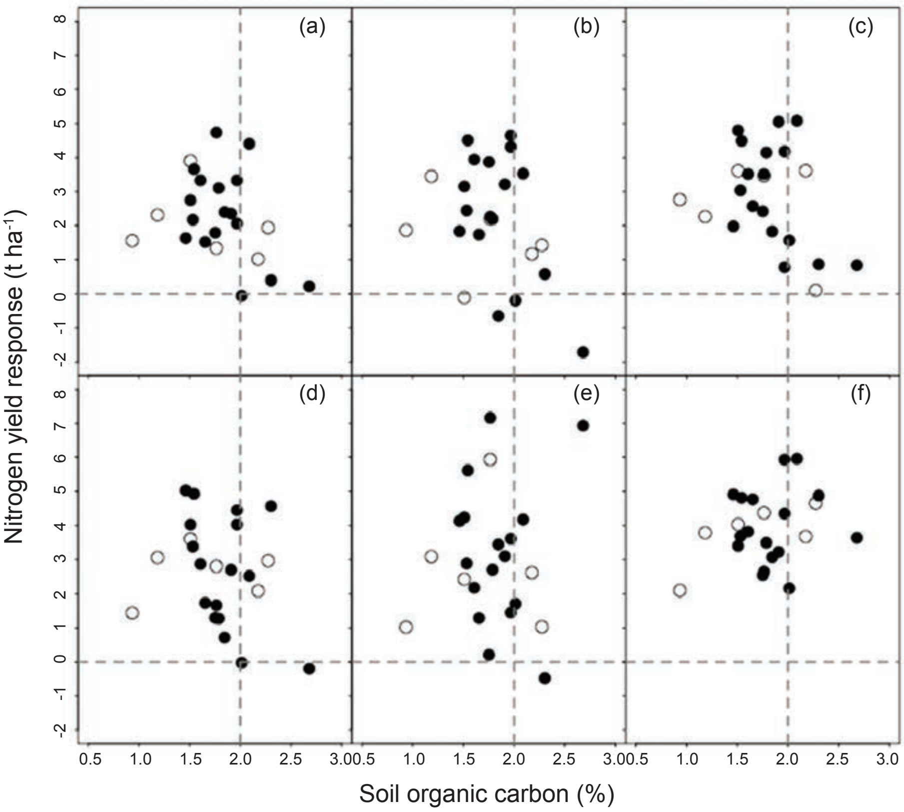

Figure 2. Temporal and spatial patterns in maize grain yield response to fertilizer N ($t\ ha^{-1}$) in on-farm trials (n=24) conducted across six consecutive seasons (long rainy season 2013 to short rainy season 2015), in fields differing in past manure applications in western Kenya. White circles represent fields without any farmer applying manure in the three seasons preceding the experiment. Black circles represent fields with some farmers applying manure within the three seasons preceding the experiment.

of degraded non-responsive soils with < 1.2% SOC, variable responses in mid-range SOC categories, and non-responsive fertile soils with high SOC soils (> 2%). ■

Dr. Zingore is the Director for Research and Development at the African Plant Nutrition Institute, Benguérir, Morocco. e-mail: s.zingore@apni.net. Dr. Njoroge is a Scientist at the African Plant Nutrition Institute, Nairobi, Kenya. e-mail: s.njoroge@apni.net.

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Why the Buzz on Regenerative Agriculture?

By Ken E. Giller

Regenerative Agriculture is taking the world by storm! Civil society, agribusiness, farmers, NGOs, multinationals—and increasingly researchers—are aligning around this new paradigm. But what is Regenerative Agriculture? What does it mean for the way we produce our food and for agricultural research in Africa?

I first heard the term Regenerative Agriculture in 2019 at an advisory meeting of a major food company. As an agricultural researcher I was embarrassed that I was not better informed, so together with an assistant we ran a quick scan of the topic. We found surprisingly little information in the scientific literature. But Regenerative Agriculture was everywhere on the Internet, in particular on YouTube and Twitter, and a large body of farmers were communicating on this topic. Over the course of 2020 a large number of companies started to make commitments to move towards Regenerative Agriculture in their supply chains, and many international environmental NGOs such as Greenpeace and The Nature Conservancy aligned with the concept. The basic narrative was that "*the food system is broken*" and Regenerative Agriculture could play a key role in fixing it. Although the idea of 'broken' food systems is often repeated, what this means is unclear. Many commentaries point to an agricultural crisis: a collapse in soil health, the sixth mass extinction of biodiversity, and the plateauing of crop yields. This begged the question as to why Regenerative Agriculture was gaining so much attention and demanded a deeper analysis. Here I provide a synopsis of the paper we wrote to try and understand the buzz around Regenerative Agriculture (Giller et al., 2021), and I specifically ask the question regarding what this means for Africa. In doing so I draw on papers from a special issue on '*Biomimicry and Nature-based Solutions*', which I edited together with Jim Sumberg (see Sumberg, 2022).

As we dug into both the academic and grey literature, we found that the term Regenerative

In the foreground a heavily depleted soil that is ripe for 'regeneration' on a smallholder farm in rural Zimbabwe. Note the good maize growth close to the homesteads which shows that these soil fertility gradients are created by a scarcity of manure and other inputs.

Agriculture had actually been around for a long time. It originated in the early 1980s from the Rodale Foundation, which is seen as the home of organic agriculture in the USA. A particularly useful article that I found in my personal archive was published in a conference proceedings from Tanzania by Richard Harwood (1983). I knew Richard Harwood through his advisory role as chair of the board of the Tropical Soil Biology and Fertility programme, of which I was also a member in the 1990s. The vision of Regenerative Agriculture portrayed by Harwood (1983) was one of closing nutrient cycles with less dependence on external inputs and a high degree of local and regional self-reliance. What Regenerative Agriculture actually entails today remains a hard question to answer. Because of the lack of any agreed definition the term is interpreted in many different ways (Newton et al., 2020). Nonetheless there is convergence that Regenerative Agriculture addresses two main issues: soil health and biodiversity loss. A synthesis of available reports indicated general agreement around a set of principles which include: 1) activities that encourage infiltration and percolation of water and prevent soil erosion such as minimizing tillage and maintaining soil cover, 2) practices that build soil carbon (C) and greater reliance on biological nutrient cycling, 3) practices that foster plant diversity, such as diverse rotations, 4) integration of livestock, and 5) reduced reliance on external inputs. Although many of these **principles** can be argued to lie at the heart of good agricultural practice, many suggested Regenerative Agriculture **practices** such as compost tea, permaculture and holistic grazing could be regarded as rather fringe approaches that are not generally applicable on most farms. Further, some of the principles appear to be difficult to implement together, for example, if land is prepared using zero or minimum tillage the need for herbicides to control weeds is increased.

> Regenerative Agriculture moves the goalposts from a 'do no harm' to 'do better' approach ... A common set of **principles** can be identified, but the huge diversity of farms, farming systems and take-off points across the world means that a tailored approach is needed for implementation of **practices**.

The promise of Regenerative Agriculture to address climate change

Interest in Regenerative Agriculture is clearly driven, at least in part, by the promise that sequestration of C in soil can help to mitigate climate change. For example, one organization promoting Regenerative Agriculture, 'The Carbon Underground', is supported by a bewildering array of organizations including multinational companies, different food brands, research institutes local and regional policy organizations, and civil society NGOs. For many companies, their interest in Regenerative Agriculture is linked to their commitments to drastically reduce, or achieve net zero, C emissions in their supply chains. Perhaps fortunately, an exaggerated claim that locking up C in soil could compensate for *all* current emissions of greenhouse gases has led to some ardent supporters of Regenerative Agriculture to call attention to the misleading nature of this statement.

In essence, overblown estimates of soil C storage are due to rapid rates of C accumulation being extrapolated linearly into the future. Yet we know that if more organic matter is added to soil, the initial rate of soil C increase will be rapid, but that the rate will attenuate as a new equilibrium value is reached (**Fig. 1**, Baveye et al., 2018). While the attention to building soil C stocks is welcome, the primary benefits are in providing a good environment for crop growth rather than a means to solve a climate crisis (Powlson et al., 2022). The contribution to climate change mitigation from building soil organic matter should be seen as a secondary benefit of ensuring soil fertility and soil health, rather than the primary objective. It should be acknowledged that there is clearly disagreement within the scientific community on the importance of

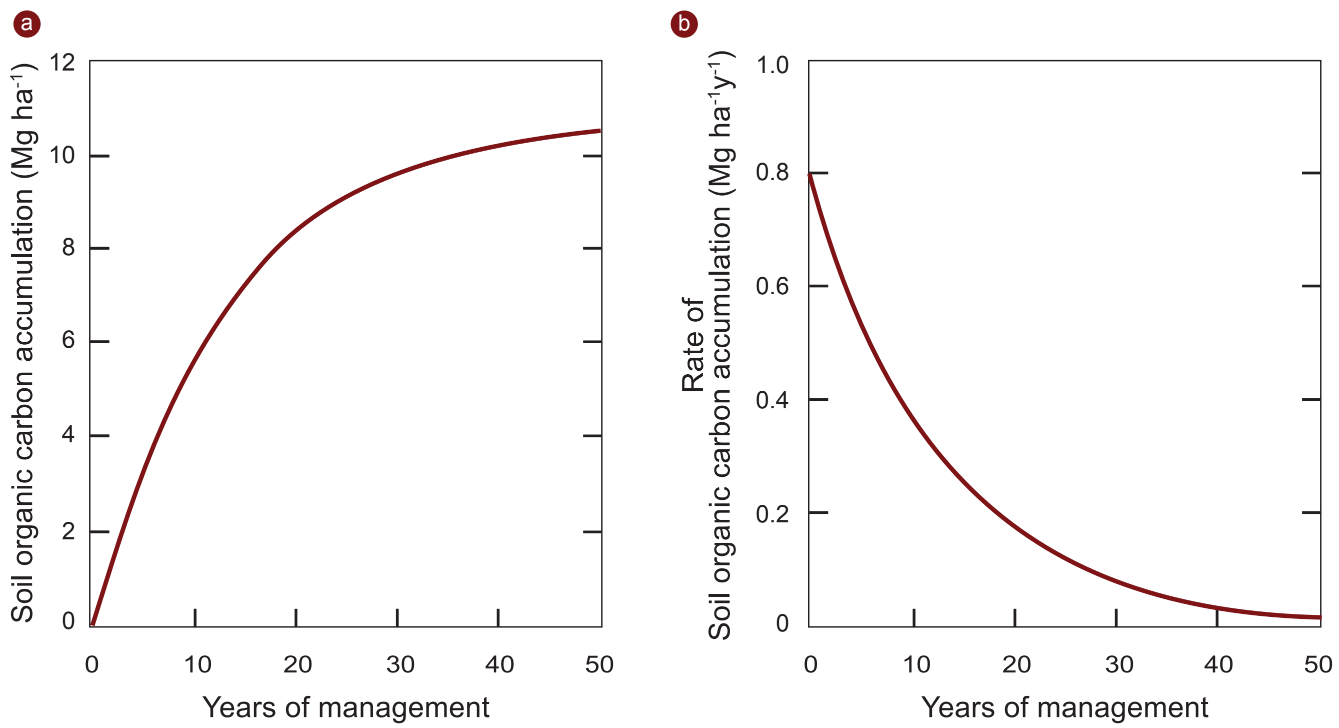

Figure 1. a) If the amount of organic resources returned to soil each year is increased, soil organic matter may accumulate rapidly towards a new equilibrium value. **b)** the initial rapid rate of accumulation attenuates as the new equilibrium is approached (after Baveye et al., 2018).

soil C sequestration in mitigation of climate change. Yet there is increasing concern (e.g., Janzen et al., 2022) that earlier claims of the amounts of C that can be stored in soil were overly optimistic and attract attention away from the urgent need to reduce greenhouse gas emissions.

The magical role of soil biodiversity

FAO recently published a collection of 10 children stories rather aptly entitled '*The Magical World of Soil Biodiversity*' (FAO, 2021), which reflects the naïve belief that stimulating soil biodiversity can solve problems of agricultural production. Pulleman et al. (2022) unpack the mystery of soil biodiversity and debunk claims that inoculation with beneficial microbes and switching to a more fungal-dominated soil microflora can lead to greater soil C sequestration and more sustainable production. No doubt soil life is key to the functioning of healthy soils, but it is very difficult to manipulate directly. Soil biodiversity is more likely a result than a means of good soil management for sustainable production.

What does this mean for agriculture in sub-Saharan Africa?

Whilst there is no doubt that agriculture faces serious challenges, the increasing promotion of Regenerative Agriculture in Africa (e.g., ARASG, 2021) raises a number of concerns:

1. Scant attention is given to starting points and local contexts

The huge diversity of agricultural systems around the world dictate that sustainability challenges vary over time and space. However, scant attention is given to the starting points and local contexts. The principle of reducing reliance on external inputs is relevant in situations where intensive agriculture leads to eutrophication, for example in the Netherlands and China, but this does not transfer well to most of Africa where crop yields remain far below their potential due to poor soil fertility (see Zingore et al., 2022, this issue). The amounts of nutrients available in organic manures or contributed through nitrogen fixation are insufficient, so rather than reducing external inputs, increased use of mineral fertilizer is key to boosting agricultural productivity. On this specific issue, the debate around Regenerative Agriculture is similar to the promotion of agroecology, which also calls for a blanket reduction of external inputs (HLPE, 2019). It is essential that local stakeholders should be in the lead in determining the research agenda (Giller, 2020), as calls to promote Regenerative Agriculture or agroecology, such as the EU research priorities for Africa, ignore the critical need to increase nutrient inputs in Africa.

2. The potential for farmers to directly benefit from C sequestration is limited

It can be argued that soils on smallholder farms that have been intensively cropped with few inputs are ripe for regeneration because their soil C stocks have been depleted (e.g., see the photo from Zimbabwe). But building soil C under such conditions is difficult. As indicated above, the amounts of animal manures available are insufficient and crop productivity needs to be increased by adding nutrients to provide the crop residues to be able to sequester C. In addition, a huge proportion of the cropland in SSA is found on sandy soils that have a limited capacity to store C. Add to that the timescale needed to build soil C and the complexity of organizing markets for C credits among smallholders, and the idea that smallholders can directly benefit from C sequestration belongs to a distant future.

3. All agrochemicals bundled into one

Although concerns for human and environmental health from fertilizers and pesticides differ enormously, in the calls for Regenerative Agriculture to reduce external inputs they are simply treated in the same way. Whereas pesticides are designed to kill one or more target organisms, nutrients can be considered to be environmentally benign if used in a correct way. In this regard the 4R principles (i.e., ensuring the right nutrient source is applied at the right rate and time, and in the right place) are useful guidelines to ensure efficient and appropriate use of fertilizer.

4. Little attention is given to alternative methods of pest and disease control

Management of pests and diseases is probably one of the greatest challenges for food production in future as environmental concerns lead to the banning of an increasing number of agro-chemicals. A major challenge will be to find new methods of integrated pest management (IPM). In this regard, diversification of cropping systems (a central tenet of Regenerative Agriculture) shows great promise in promoting natural control of insect pests and diseases, but it is no silver bullet (van der Werf and Bianchi, 2022). Simply aiming to reduce external inputs without providing alternative control measures is counterproductive.

5. The promise of 'holistic grazing' is overplayed

The concept of 'holistic grazing' actually originated in Africa, as a means of restoring productivity of degraded rangeland through mimicking the action of wildlife (Savory, 1983). By herding livestock at high intensity on small areas of land, the manure deposited should restore nutrient stocks and poaching by the hooves of the cattle would break up capped soil, and lead to substantial sequestration of C in soil (Savory, 2013). Whilst there is no doubt that high intensity grazing is a useful management tool under certain conditions it seems unlikely that it provides greater benefits than simpler forms of rotational grazing have over unmanaged continuous grazing, which are much more likely to be widely adopted (Franke and Kotzé, 2022).

6. The 'on farm' focus gives little consideration of ecological footprints and 'land sparing'

Discussion and promotion of Regenerative Agriculture is focused mostly on field or farm level management practices. Particularly within the African context there is a strong need to increase agricultural productivity to prevent further expansion of agriculture and loss of natural habitats. Sparing of land for biodiversity in Africa will inevitably require more intensive use of fertilizer as discussed above. Promotion of strategies aimed at reducing agricultural outputs in other parts of the world, such as the European Green Deal and Farm to Fork strategy, will increase the pressure for conversion of land use for agriculture in Africa (Dekeyser and Woolfrey, 2020).

BOX 1. Five questions to guide agronomic engagement with Regenerative Agriculture (from Giller et al., 2021).

1. What is the problem to which Regenerative Agriculture is meant to be the solution?
2. What is to be regenerated?
3. What agronomic mechanism will enable or facilitate this regeneration?
4. Can this mechanism be integrated into an agronomic practice that is likely to be economically and socially viable in the specific context?
5. What political, social and/or economic forces will drive use of the new agronomic practice?

Conclusion

The article we wrote on Regenerative Agriculture (Giller et al., 2021) attracted a huge amount of attention from many quarters – some with questions on how to define the practice. How does Regenerative Agriculture differ from other approaches such as Sustainable Intensification? – and how can we build on the huge positive momentum around Regenerative Agriculture? Given the fact that we lack clear definitions these are hard questions to answer, but in essence Regenerative Agriculture moves the goalposts from a 'do no harm' to 'do better' approach. As I have indicated above, a common set of **principles** for Regenerative Agriculture can be identified, but the huge diversity of farms, farming systems and take-off points across the world means that a tailored approach is needed for implementation of **practices**. In this context, the absence of a strict definition of Regenerative Agriculture may in fact be more help than hindrance as it may encourage a flexible and adaptive approach. A guide to how agronomists can effectively engage with Regenerative Agriculture is proposed in **Box 1**. Whatever the approach, measuring and monitoring progress will remain a challenge. Focus on continuous improvement of agricultural practice, whilst avoiding unfounded and exaggerated claims, would seem to be the best way forward. ■

Dr. Giller is Professor of Plant Production Systems at Wageningen University and a member of the Scientific Advisory Committee of the African Plant Nutrition Institute. e-mail: ken.giller@wur.nl

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Award and Grant Deadlines – 2022

YOUNG AFRICAN PHOSPHORUS AWARD

The **Young African Phosphorus Fellowship Award** was implemented to encourage the development of scientific programs relevant to understanding and improving phosphorus management in African agro-ecosystems.

Funding: Awards of USD $5,000 are available to five early-career scientists.

Eligibility: Full time scientists working at an African NARES institution or university, who are 40 years-old or younger at the closing date for applications, and who have completed their Ph.D. programs.

Application deadline: June 30, 2022 • Learn more at: **www.apni.net/p-fellowship-apply**

AFRICAN PLANT NUTRITION OUTREACH FELLOWSHIP

The **African Plant Nutrition Outreach Fellowship Award** was established to support researchers exploring innovative ideas for education, training and communication programs relevant to improving the use and efficiency of plant nutrients in African agro-ecosystems.

Funding: Awards of USD $5,000 are available to two recipients.

Eligibility: Scientists, extension specialists or educators working at an African NARES institution, African university, nonprofit organization, or in the private sector.

Application deadline: August 31, 2022 • Learn more at: **www.apni.net/outreach-fellowship-apply**

Other Ongoing Award Programs to Watch

AFRICAN PLANT NUTRITION RESEARCH FUND

Created through partnership between APNI and Mohammed VI Polytechnic University (UM6P), the **African Plant Nutrition Research Fund** is aimed at enabling the scaling of improved nutrient and soil fertility management in Africa. The fund also seeks to extend research initiatives that have synergy with the priority research areas of APNI.

Funding: Grant funding of no more than $20,000 USD per year, for up to two years, is available.

Eligibility: The lead applicant (Principal Investigator) must be from an African National Agricultural Research and Extension System (NARES) institution or African university. Students are not eligible for this award.

Status: Call completed April 30, 2022 • Learn more at: **www.apni.net/research-fund**

AFRICAN PLANT NUTRITION SCHOLAR AWARD

The **African Plant Nutrition Scholar Award** was established to encourage development and success within graduate student programs specializing in the sciences of plant nutrition and management of crop nutrients in Africa. Students in the disciplines of soil science, agronomy, and horticultural science or tree crop science with a focus on plant nutrition are encouraged to apply.

Funding: Awards of USD $2,000 are available to ten graduate students.

Eligibility: Candidates must be currently enrolled in a M.Sc., M.Phil., or Ph.D. program as of the application deadline.

Status: Call completed April 30, 2022 • Learn more at: **www.apni.net/scholar-apply**

Enhancing Agronomic Efficiency of Fertilizers in Sub-Saharan Africa: Evidence from the Field

By Tilahun Amede and Asseta Diallo

Smallholder farmers have faced a myriad of constraints that collectively act to limit the effectiveness of scarce fertilizer inputs. Case study examples provided from the Ethiopian Highlands provide a means to discuss key interventions that can help raise nutrient use efficiency across fields with varying responsiveness to fertilizer application.

While global fertilizer use has significantly increased since the 1960, and played an important role in the Green Revolution in South America and Asia, fertilizer use in Africa has remained very low, near 18 kg nutrients ha^{-1}. Increased use of fertilizers, improved seed, and irrigation in Asia and Latin America have combined to increase cereal yields from 1.3 t ha^{-1} in the 1960s to above 4.0 t ha^{-1} in 2009 (Van der Velde et al., 2013). During the same time, average cereal yields in sub-Saharan Africa (SSA) have stagnated near 1.5 t ha^{-1} while the yield gap, attributed mainly to low and inefficient use of agricultural inputs, remains very high.

While smallholder farmers in SSA appreciate the benefits of fertilizers, and African governments have increasingly invested in fertilizer purchases since the 2006 Abuja declaration, access to fertilizer remains severely restricted. Bationo et al. (2004) found that farmers in SSA removed about 4.4, 0.5, and 3.0 million (M) t ha^{-1} yr^{-1} of nitrogen (N), phosphorus (P), and potassium (K); while only returning 0.8, 0.3, and 0.2 M t, respectively, and little has changed since then. Hence, soil nutrient mining amounts to five times nutrient application every year. Many factors constrain the use of fertilizer by smallholder farmers and this situation is especially aggravated by the following issues:

1. Access to inputs: Smallholder farmers have limited financial resources and market access to appropriate chemical fertilizers. Fertilizer prices are impacted by long value chains and unregulated markets, particularly in landlocked countries, where prices could double over short distances. Past samples of average prices for urea found them lowest in Ghana (0.80 USD kg^{-1}), Kenya (0.97 USD kg^{-1}), and Nigeria (0.99 USD kg^{-1}), while fertilizers are most expensive in landlocked countries (Burundi: 1.51, Uganda: 1.49, and Burkina Faso: 1.49 USD kg^{-1}; Bonilla Cedrez et al., 2020). Unless strategic and targeted use of fertilizers is employed, the economic returns to investment in fertilizer by smallholder farmers is very poor under the prevailing production and market conditions. The most recent increases in fertilizer prices are already impacting the costs of both inputs and food imports in SSA.

2. Low agronomic fertilizer use efficiency: Crop responses to fertilizer are on average low, but tend to be highly variable at various spatial scales in SSA (Kihara et al., 2016; Vanlauwe et al., 2011). This is caused by soil chemical constraints (e.g., soil acidity), soil physical constraints (e.g., soil crusting), drought, pests and diseases, and a lack of high yielding varieties (Vanlauwe et al., 2011; Zingore et al., 2015). The options for circumventing these yield-limiting factors through cropland expansion, to feed Africa's growing population, are increasingly limited. Moreover, crop response to fertilizer can be highly variable across short distances (**Fig. 1**). The types and amounts of nutrient required are commonly dictated by soil type, landscape position, seasonal climate, and on-farm management (Amede et al., 2020). Improving agronomic practices and targeting of fertilizer inputs within farms and landscapes can improve nutrient use efficiency (NUE) without reducing productivity (Fixen et al., 2014).

In the context of SSA, there are three typical categories of crop response to fertilizer application, which are depicted in **Fig. 1** and **Box 1**.

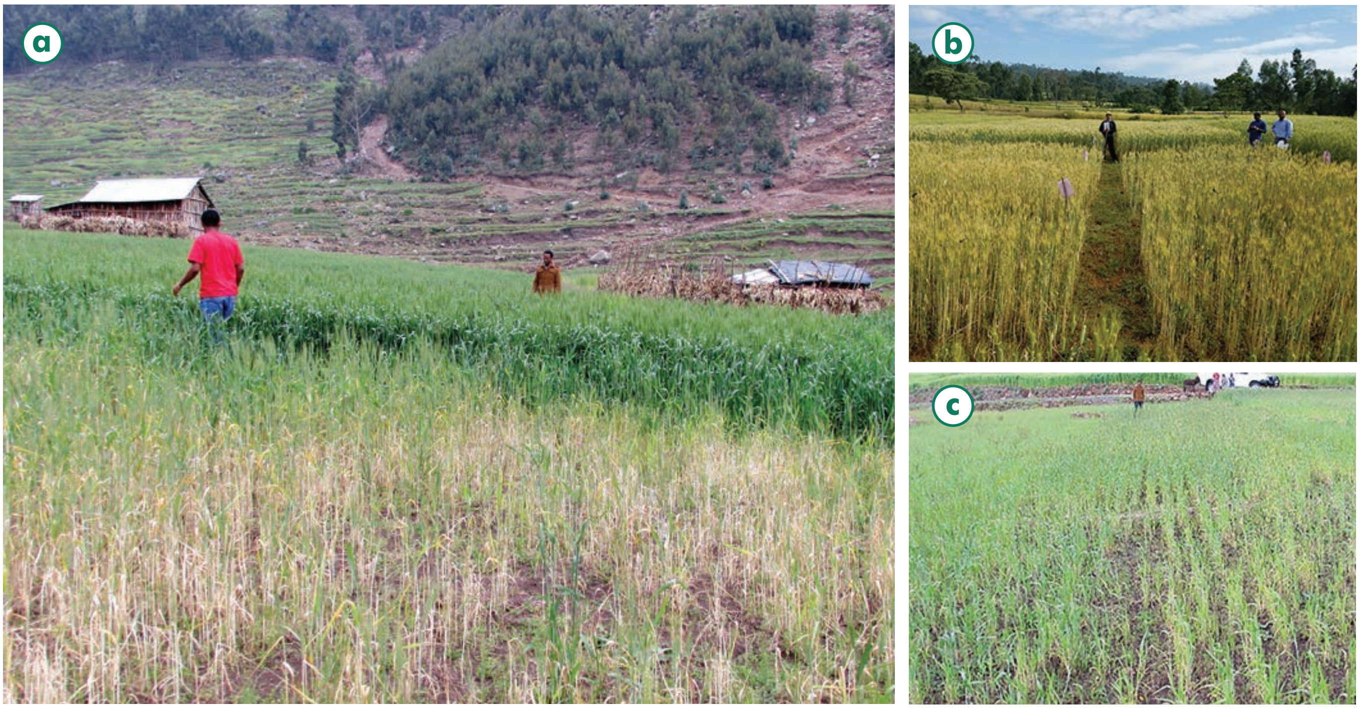

Figure 1. Differential wheat responses to NPKS (138-69-40-20 kg ha^{-1}) application in three distinct farming areas of the Ethiopian highlands (Amede, 2015).

Box 1.

Type I: Where crop response to fertilizer application is high

Farm 1 is located in Endamohoni, Northern Ethiopia, an area receiving > 700 mm of rainfall (**Figure 1a**). Fields are in footslope positions and soils are slightly acidic. The wheat crop was most responsive to N application (85% of the yield increase), followed by P. Wheat yields can be remarkably high (up to 8 t ha^{-1}) on the deep, N-limited soils that are commonly situated close to homesteads. These flat-land soils also have loamy textures, neutral pH, and high soil water holding capacity (Amede et al., 2020; Desta et al., 2022). The proportion of farmland with these responsive traits vary from 25–60%, depending on the geomorphology, climate, and slope forms. These farms usually receive preferential treatment by farmers, including compost and manure application, addition of crop residue and timely weeding. These are also areas where the growing season is long enough to support high yielding varieties, which allows for extended uptake of nutrients by crops.

Type II: Where crop response to fertilizer application is moderate

Farm 2 is located in high annual rainfall (1,080 mm) area of Lemo, Ethiopia (**Figure 1b**). These soils are relatively flat and deep Nitisols, which are acidic and prone to P-fixation and excessive leaching. Wheat is most responsive to N and P, although about 33% of the yield gains can be attributed to potassium (K) fertilizer. These are relatively well managed farms usually situated in midslopes, where farmers regularly apply fertilizers (mainly DAP and urea). Grain legumes are commonly included within crop rotations.

Type III: Where crop response to fertilizer is very low or non-responsive

Farm 3 (**Figure 1c**) is located less than a kilometre away from Farm 1. This farm is situated in the hillslopes, where erosion is severe, soils are shallow, and soil organic matter (SOM) is low. Farmers rarely apply manure as they receive very limited return for their investment. These fields are commonly characterised as "outfields" with low pH, shallow soils with sandy surface textures and subsurface hardpans. The site rarely responds to fertilizer NPKS application, regardless of the rate or time of application.

Interventions to increase agronomic fertilizer use efficiency and crop yield

Our observations from the fields of the Ethiopian Highland region lead us to suggest the following major intervention areas to improve crop response to application of external inputs in non-responsive soils.

1. Appreciate the influence of soil and landscape diversity

Crop response to fertilizer application typically varies within very short distances (**Fig. 1**), and this is mainly associated with changes in geomorphology, soil types and landscape positions, and farm management. Fertile soil, with adequate and balanced nutrients, could be considered as productive soil if the climatic and management conditions are favorable for crop growth.

Not all soils in SSA with low nutrient content respond to fertilizer applications. In a cross-continental study on maize response to NPK fertilizers, Kihara et al. (2016) reported that maize was highly responsive in only 11% of the fields, 'intermediately responsive' in 36% of fields, and 'non-responsive' in 53% of fields. Similarly, the application of mineral fertilizers failed to increase maize yields by more than 0.5 t ha^{-1} in up to 68% of farmer fields (Roobroeck et al., 2021). Moreover, Roobroeck et al. (2021) showed that 15% of maize fields in Kenya, 34% in DR Congo, 14% in Tanzania, and 55% in Nigeria were non-responsive to fertilizer applications. Low maize response was recorded mainly in nutrient poor, acidic and degraded soils, similar to the observations from wheat systems (Amede et al., 2020). Roobroeck et al. (2021) found neutral pH and low aluminum (Al) concentrations to be associated with a cluster of highly responsive sites across countries. This calls for land suitability indicator tools for major cereal crops.

Landscape position is another major factor dictating crop response in the East African highlands, where geomorphological variability is high (Amede et al., 2020). Farming systems and landscape positions are highly variable and hence nutrient mobility in the soil and their effect on plant uptake are also likely to vary. Desta et al. (2022) found crop yields to be strongly and significantly affected by landscape positions across agro-ecologies and farming systems (**Fig. 2**). Sorghum response to fertilizer application was 50–300% higher in footslopes compared to hillslopes, depending on locations and inputs levels. The high NUE in valley bottoms compared to hillslopes was explained by higher soil water holding capacity, higher adsorption and desorption capacity of cations, higher SOM content, and deeper topsoils. Due to its close relationships with other covariants such as SOM and soil depth, landscape position could serve as an important proxy soil fertility for smallholder farmers and extension agents.

2. Rejuvenate soils with cover crops and liming

High NUE requires good agronomic management of soil water and crop nutrients (Fixen et al., 2014). Soil water status is strongly linked to SOM content, which at 0.5–1.5% is very low in SSA. The differential treatment of fields within the farms highlighted in **Fig. 1** created a clear soil fertility gradient over years, with SOM in the outfields being up to 40% lower than homestead fields in the study area. Low SOM affects crop responses to nutrient application through reduced soil water holding capacity, soil biology, and retention of nutrients (Zingore et al. 2015; Vanlauwe, et al., 2011). As an example, fertilizer application following fast growing cover crops like vetch contributed to the SOM pool, soil water content, and improved wheat grain yields by 40% compared to use of fertilizers alone (Amede et al., 2021).

Soil acidity has been a major problem that affects nutrient availability in Acrisols, Nitisols and Leptosols that dominate the high rainfall Ethiopian highlands. Crop yields are consistently low in these low pH soils regardless of amount of nutrients added, primarily due to P-fixation and Al-toxicity. Adequate liming substantially increased maize and wheat yields by about 70%, compared to recommended NPK fertilizer rates alone (Agegnehu et al., 2021), while cover crops increased soil pH by a unit of 0.5 (Amede et al., 2021). In fact, the yield impact was higher in non-responsive soils in hillsides and low pH soils. Application of lime in acidic soils along with improving SOM contributes to enhanced NUE of cereal crops in global crop production systems (Fixen et al., 2014).

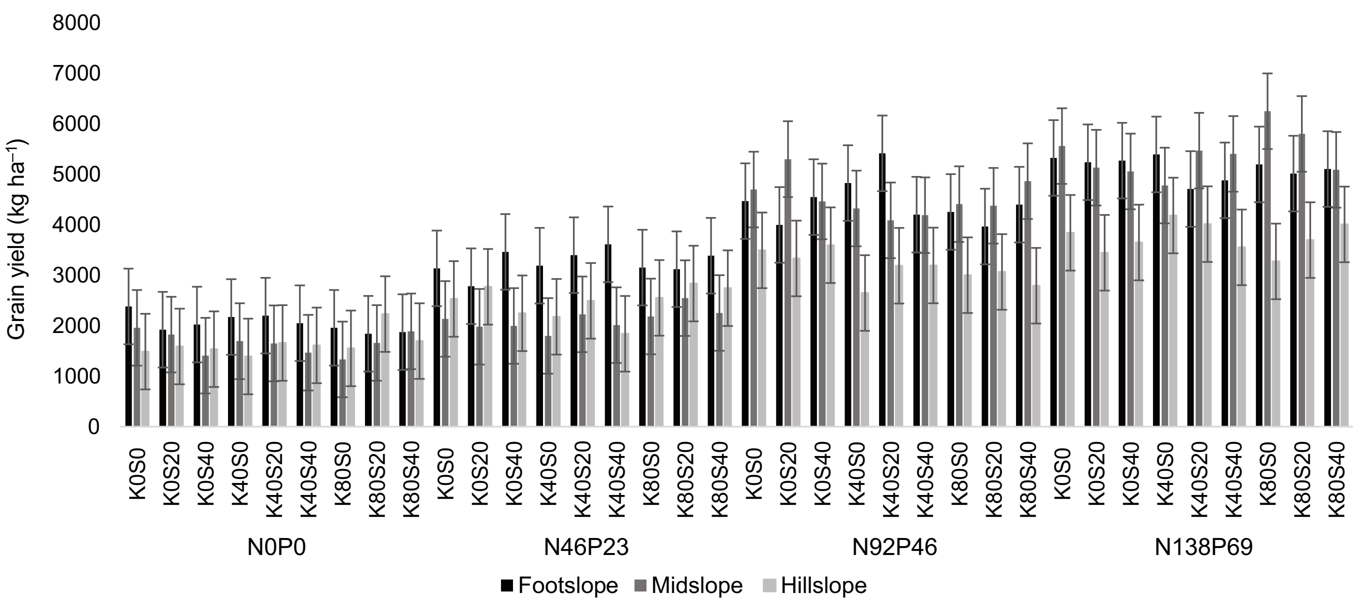

Figure 2. Interaction of landscape position and NPKS fertilizer application rates for sorghum grown in the East African Highlands (Desta et al., 2022).

3. Increase plant population for enhanced resource use efficiency

The benefit of good agronomy in enhancing agronomic efficiency has been highlighted earlier (Vanlawe et al., 2011; Fixen et al., 2014), contributing to lower costs and improved efficiency by concentrating applied nutrients in the root zone.

One major driver of yield loss in SSA is low plant density in farmers' fields. While low plant density has been practiced in low or no input systems of SSA, this same population cannot support optimal yields with increased use of fertilizers and improved varieties. Modern hybrids are able to withstand greater stress attributable to high population densities than older hybrids, which in turn enables producers to establish higher plant populations, leading to higher yields per unit area (Duvick, 1997). In small scale farming of SSA, low plant population of cereals (commonly < 18,000 maize plants ha^{-1}) is found to be a major constraint affecting crop yield and NUE. For instance, Amede (1995) found that the maize population in smallholder farmers' fields is about 46% lower than the commonly recommended plant density. Maize grown in dry environments yielded better with higher plant population near 65,000 plants ha^{-1} (Amede, 1993); while in humid areas with optimum fertilization, maize yield increased with populations up to 100,000 plant ha^{-1} (Haarhoff and Swanepoel, 2018).

Increased use of N fertilizer should be accompanied by increased plant density to maximize NUE and reduce N losses (Haarhoff and Swanepoel, 2018). Similarly, Zhao et al (2019) argued that farmers' limited knowledge of appropriate plant population density and density loss is an urgent problem that needs to be solved in maize production as about 60% of farmers were failing to account for these factors over the growing season. Amaral et al. (2020) showed that maize yield in Mozambique in 2017 was less than half (0.8 t ha^{-1}) of that observed in Malawi (2.0 t ha^{-1}) and almost a third of the yield in Zambia (2.5 t ha^{-1}), and this was mainly attributed to very low planting density of < 20,000 plants ha^{-1}. There has been also a recommendation for smallholder maize farmers in Kenya to initially target 60,000 maize plants (CropNuts, 2022) even though the recommended plant population in the extension system, developed by KALRO, is only between 37,300 and 52,700 plants ha^{-1} (Esilaba et al., 2021).

Summary

Crop yields in SSA are mainly constrained by nutrient deficiency. Recent hikes in fertilizer costs will exacerbate this problem. In the absence of soil testing and crop response-based fertilizer recommendations, smallholder farmers achieve low agronomic and economic returns by applying low rates of fertilizers across all their fields. Existing fertilizer recommendations fail to account for both farming system diversity and the impact of a field's location within the landscape. Landscape position dictates crop yield responses due to the effects of slope, water holding capacity, and inherent soil fertility. In addition, higher plant population, use of N-fixing cover crops and good agronomy (including weed control) would help farmers use fertilizer more efficiently. In more than 1,000 field trials with wheat and sorghum, at least 80% of yields stemmed from applying N and P fertilizer, with the highest benefit obtained in the valley bottoms and flat lands. ■

Dr. Amede (e-mail: tamede@agra.org) and Dr. Dialo are with the Alliance for Green Revolution in Africa (AGRA), Nairobi, Kenya.

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Towards a Farmer-Centric Framework for Scaling Productive and Sustainable Cereal Cropping Systems

By Ivan S. Adolwa, Thomas Oberthür and Simon Cook

A case is made for an innovation system framework that integrates farmer-centric and systemic approaches to scaling plant nutrition innovations for positive transformation of cereal cropping systems in Sub-Saharan Africa. A case study from Ethiopia helps to build the case.

Cereal-based cropping systems are vital food production systems across Africa. In these systems, livelihoods are mainly derived from cereals such as maize, millet, sorghum, and wheat; and also legumes, pulses, roots and tubers. In East and Southern Africa, maize-mixed farming systems are the most important food production systems representing 32 million ha (19%) of the cultivated area (Dixon et al. 2001). These systems are encumbered by food insecurity, hunger and poverty, but these problems can be alleviated by successful yield intensification and crop diversification (Garrity et al. 2012).

Ultimately, a vision of success for cereal cropping systems in Africa includes the improvement of smallholder farmer livelihoods through better value creation and return on investment (ROI) (**Fig. 1**). Precision nutrient management (PNM) combined with the 4R Nutrient Stewardship (i.e., right nutrient source at the right rate, time, and place) and best crop management practices provides a plausible pathway for sustainably increasing the productivity of African cereal crop yields from the current 2.5 t ha^{-1} to attainable yields of 5-7 t ha^{-1} (Phillips, 2014; van Ittersum et al., 2016). Continued stagnation in productivity results from a major failure in current research and scaling processes, which embark on agricultural technology transfer with little regard for the unique socio-organizational conditions of target areas (Adolwa et al. 2017; Schut et al. 2020). Agricultural systems are increasingly being viewed in terms of complex systems thinking, where rapid transformation is seen to arise from multiple coinciding influences, events, trends or even shocks (Schut el al. 2020). In complex adaptive research and development systems, continuous monitoring and learning through feedback loops, system/sub-system interrelationships and context, reflexive thinking, trade-offs and uncertainty, and adaptive management are key (Cook et al. 2018; Klerkx et al. 2012).

Therefore, the target of increased cereal crop productivity calls for an innovative framework that translates scientific knowledge on PNM into innovations that can be adopted by famers at scale. African farmers will obtain higher ROI by adopting market-oriented models are anchored on structured markets and credit access. Knowledge transfer and agri-business could potentially propel the move towards cropping system commercialization and cereal yield gap closure (Green et al., 2016; Sanchez, 2015).

> "Agricultural systems are increasingly being viewed in terms of complex systems thinking, where rapid transformation or scaling is seen to arise from multiple coinciding influences, events, trends or even shocks.

Precision nutrient management is critical in tackling the spatial and temporal variability in African smallholder farming systems given its incorporation of spatial and temporal information improves farmer decision-making on nutrient use (Phillips, 2014). However, decision-making among farmers in SSA is constrained by a lack of organization and access to evidence-based information/data (Kassie et al. 2013). Also, there is a gap in understanding how to develop and sustain learning relationships between scientists and farmers in Africa.

A key platform on which PNM should be established is on-farm experimentation (OFE). The OFE approach is farmer-centric or farmer-driven, whereby scientists work with farmers to select treatment variables of interest (Cook et al. 2018; Lacoste et al. 2022). In this way farmers are not only passive recipients of technologies but are also experimenters, hence are central to the innovation process. Also, as is demonstrated in the photo of experimental fields in western Kenya, these experiments should be as large as possible to include effects of variation and mimic local conditions (Cook et al. 2018). In addition, OFE is characterized by evidence-driven (standardized data protocols), expert-enabled (added value through scientific engagement), co-design (of experiments), and scaling by co-learning (sharing of data, insights, or ideas) principles (Lacoste et al. 2022).

Experimental fields established in western Kenya for the OFE process. Farmer's field (left) and Scientifically-optimized field (right).

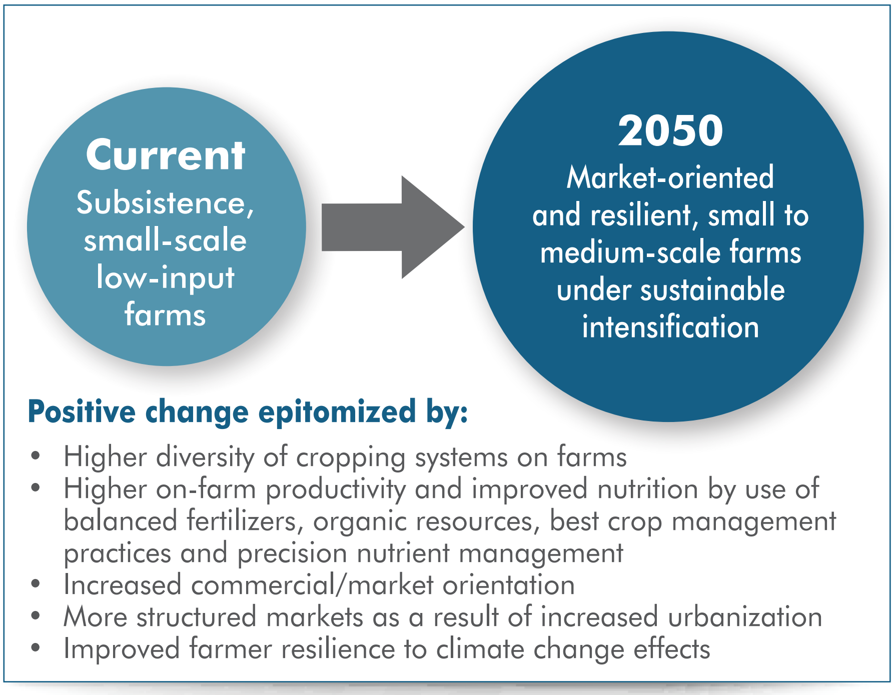

Figure 1. A vision of success for SSA agri-food systems.

Insights from an on-farm experimentation program in Tigray, Ethiopia

In a four-year experimentation program, farmer groups and scientists jointly designed experiments to improve crop yields (Kraaijvanger and Veldkamp, 2015; Kraaijvanger and Veldkamp, 2017). Experiments designed by farmers were based on their views, ideas, experiences, and year-on-year analyses. Farmer-designed experiments, which ran side by side with science-based ones were extremely diverse and involved, for example, combinations of organic and mineral fertilizers. Science-based experiments, which involved the recommended application (use of inorganic fertilizers +

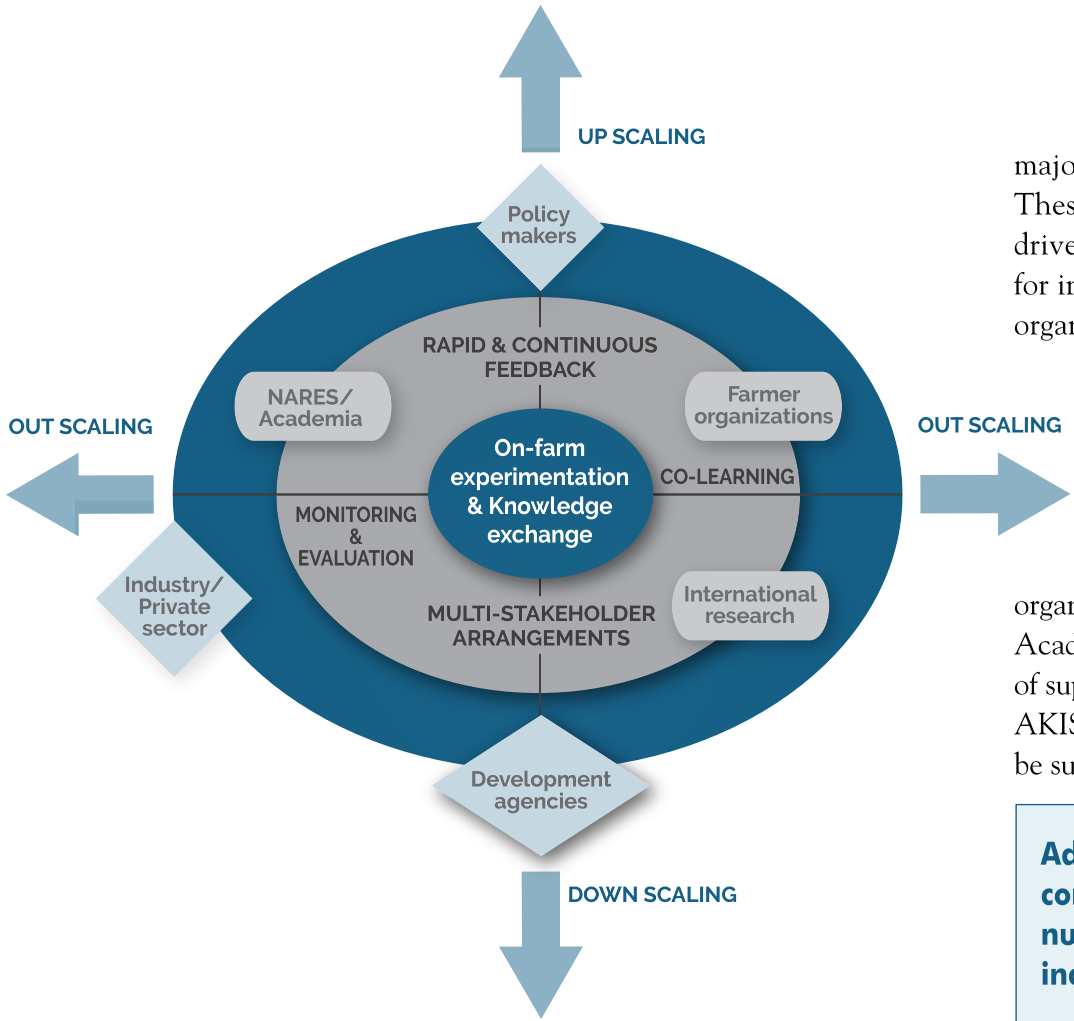

Figure 2. Scaling Framework for Cereal Cropping Systems.

sowing in rows) were aimed at being an inspiration for farmer groups to offer them alternatives for crop production. It was observed that farmers matched their experimental design with the requirements of their livelihood system. In this case, farmers focused on enhancing straw productivity (for fodder) at the expense of wheat grain yields. A key outcome with important implications on the trade-off between fertilizer cost and yield increase, was that farmer-led processes did not lead to significantly different average wheat grain yields (2,020 kg ha^{-1}) from the scientific-led process (2,200 kg ha^{-1}). Although this work contributes to our understanding of the choices farmers make in technology adoption and of the processes that underlie such decision-making, many more studies across several agro-ecological sites and regions need to be conducted to get a clearer picture.

A framework for scaling processes underpinned by the agricultural knowledge innovation systems (AKIS) approach, centered on OFE, is proposed for cereal cropping systems. A key question hinges on whether and how OFE can contribute to scaling processes in African farming systems.

An innovation system framework for cereal cropping systems

This model is centered around farmer-centric processes for experimentation (or OFE) and knowledge exchange on plant nutrition innovation in major cereal crops (**Fig. 2**). These processes are farmer-driven and provide a platform for international research organizations and national research and extension systems (NARES) to work effectively with farmers.

A tripartite of farmer organizations, international research organizations, and NARES/ Academia constitute a sub-system of support within the larger AKIS. For scaling processes to be successful, it is crucial that

Additional issues and considerations for plant nutrition innovation include:

1. A socioeconomic characterization of the farming systems to clarify factors that underpin farmer decision-making.
2. A review of innovations with high scaling potential for different locations.
3. Mapping stakeholder networks using tools such as Social Network Analysis to identify those partners best placed to fulfill scaling functions.
4. Identifying key bottlenecks to scaling and developing scaling strategies and approaches (e.g., Scaling Scan; Jacobs et al. 2018, Scaling Readiness; Sartas et al. 2020) to overcome such bottlenecks.
5. Monitoring and learning to track impact of scaling approaches (e.g., impact evaluation studies), and documentation frameworks for measuring and reporting of successes, failures, or processes.

this tripartite links with wider value-chain players (i.e., industry/private sector, policy makers, development agents) through mechanisms that propagate co-learning, multi-stakeholder arrangements, monitoring and feedback. Scaling entails three simultaneous and interdependent processes of up-scaling, out-scaling and down-scaling. Out-scaling refers to the horizontal spread of a technology within a homogenous stakeholder category in a certain locality (e.g., a farming community); up-scaling to the creation of conducive conditions and policies for scaling at higher levels (e.g., mainstreaming of new practices in national agricultural policies); and down-scaling the reduction or replacement of existing practices with new ones (Douthwaite et al. 2003; Schut et al. 2020). On-farm experimentation enhances farmer learning and contributes to the efficacy of the three scaling processes. According to Sewell et al. (2014), such co-learning is centered on dialogue and relationships of mutual trust to co-construct shared understanding. By building the individual and collective capacity of actors, particularly farmers, such understanding can be translated into management decisions that put learning into practice. Therefore, an integration of farmer-centric and systemic approaches to scaling is pursued. ■

Dr. Adolwa is APNI's Farming Systems Scientist based in Nairobi, Kenya. e-mail: i.adolwa@apni.net. Dr. Oberthür is APNI's Director of Business & Partnerships. Dr. Cook is Professor, Curtin and Murdoch Universities, Perth Australia.

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Resilient Fertilization Strategies to Enhance Rice Productivity in Submergence-Prone Areas

By Sampson Agyin-Birikorang, Upendra Singh, Ignatius Tindjina, Alhaji Abdul-Rahman Issahaku, Haruna Waku Dauda, and Cisse Boubakary

Previous efforts to mitigate the negative impacts of submergence on rice production have focused mainly on varietal improvement. Synergistic effects of submergence-tolerant rice varieties and appropriate fertilizer management strategies are critical to enhance resilience of rice to submergence.

Rice is an important staple crop in SSA, and ensuring adequate availability throughout the year is critical for regional food security. However, in the face of climate variability, it will be difficult for countries in this region to achieve self-sufficiency in rice production. Globally, more than 16% of rice-producing lowlands are adversely affected by excess water stress, caused by either flash floods with complete submergence for a relatively short duration (commonly ranging from a few days to few weeks), or longer-term stagnant flooding of 20-50 cm water depth through most of the season (Asubonteng et al., 2001). Although rice is well known for its ability to grow in flooded soils, most rice cultivars cannot survive under submergence for more than a week, often resulting in total crop loss (Ismail et al., 2013). Efforts to improve rice productivity under such conditions have mainly focused on varietal improvement, which have resulted in breeding of several high yielding submergence-tolerance rice cultivars (Africa Rice Center, 2004). However, to achieve optimum production levels of

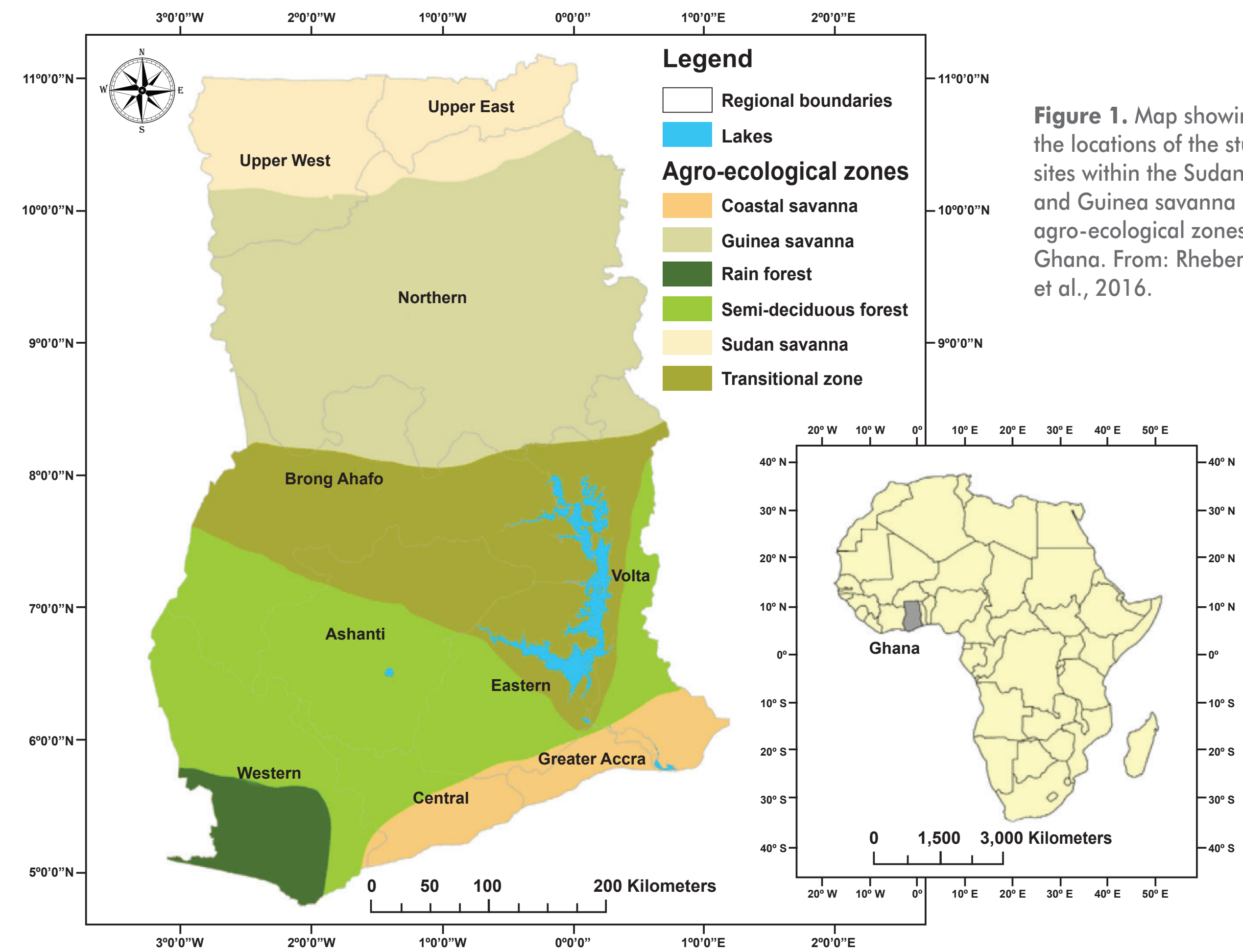

Figure 1. Map showing the locations of the study sites within the Sudan- and Guinea savanna agro-ecological zones of Ghana. From: Rhebergen et al., 2016.

these rice cultivars, there is the need to maximize the benefits for the genotypes with nutrient management strategies tailored for the specific environmental conditions. Optimal nutrition of rice seedlings before submergence and post-submergence is necessary for rice plants to fully develop cellular and metabolic requirements essential for surviving short-term submergence. Therefore, the objective of the study was to determine the most effective fertilization strategy that enhance rice production resilience in submergence-prone areas.

Field trial description

The trials were conducted during the 2016 and 2017 growing seasons in three flood-prone communities within the Guinea- and Sudan-savanna ecological zones of northern Ghana: (i) Daffiama (10° 51' 0" N, 2° 45' 0" W) and (ii) Bazua (11° 1' 0" N, 0° 24' 0" W) in the Sudan-savanna agroecological zone, (iii) Gbabshie (9° 5' 0" N, 1° 49' 0" W) in the Guinea savanna agro-ecological zone (**Fig. 1**).

The experiment was laid in a split plot design with rice variety as the main plot and fertilizer treatments as the second subplot factor. The main plot and subplot treatments were completely randomized. The treatments comprised of two submergence-tolerant rice varieties (NERICA L19 and NERICA L49), and five fertilization strategies, including: (i) Farmer Practice (FP), where recommended rates of granular fertilizer was surface broadcast, (ii) Modified Farmer Practice (MFP), where recommended rates of granular fertilizers were incorporated into the soil at 7-10 cm deep, (iii) Urea Deep Placement (UDP), a technology with placement of urea supergranules (USG) 7-10 cm deep, (iv) Microdosing (MD) where small quantities of fertilizer are strategically placed directly in the rhizosphere, and (v) a control where no fertilizer was applied.

To prevent spread of water and fertilizer between plots, 50 cm wide levees were constructed around each plot, which were separated by 3 m alleys. Twenty-one-day old rice seedlings were manually transplanted into the puddled soils in 20 cm x 20 cm geometry. Except for the control, a recommended rate of 60 kg P ha^{-1} and 25 kg K ha^{-1} were applied to all plots at transplanting as basal fertilizer in the form of triple superphosphate (TSP) and muriate of potash (MOP), respectively, together with 5

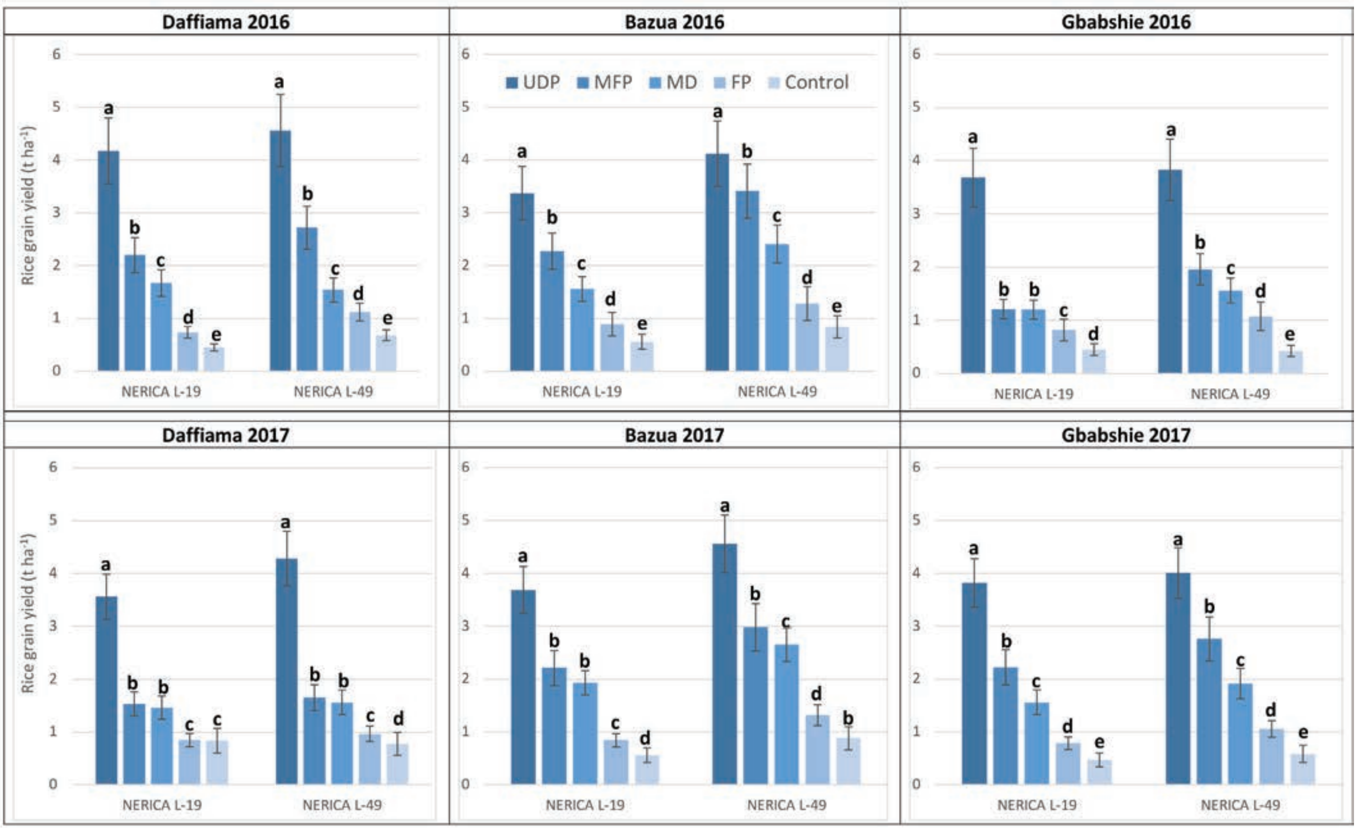

Figure 2. Grain yield of rice produced under short-term submergence conditions in three communities in northern Ghana during the 2016 and 2017 growing season. Each bar represents average of 4 replicates; error bars represent standard error of the mean. Bars of rice variety for a location at a particular year with same letter on top are not significantly different (P > 0.05).

kg Zn ha^{-1} (as zinc sulfate), 20 kg S ha^{-1} (as zinc sulfate and ammonium sulfate) and 40 kg N ha^{-1} (as ammonium sulfate and urea). For the MD treatment, basal fertilizers were placed directly in the transplanting hole following the procedure of Vandamme et al. (2018). The MFP and UDP treatments had basal fertilizers uniformly incorporated in the soil (5-7 cm deep). Fertilizer was surface broadcast in the FP treatment.

Following the procedure of Winings et al. (2017) and Agyin-Birikorang et al. (2018), a systems approach was used to compare the fertilizer management strategies, where no attempt was made to equalize the N application rate nor alter application timings recommended for each practice. For the Farmer Practice (FP) and its modification (MFP), supplemental N was applied at 58 kg N ha^{-1}, UDP received 52 kg N ha^{-1}, and MD received 38 kg N ha^{-1}. The supplemental N for the UDP was applied about 7 d after transplanting, whereas for all other fertilizer treatments supplemental N was applied about 6 weeks after transplanting, depending on the soil moisture conditions. The MD treatment involved strategic placement of a pre-determined quantity of fertilizer directly in the rhizosphere of each plant. For the UDP, one USG was applied in the center of four hills of rice, for every alternate row, at a depth of 7-10 cm.

At physiological maturity, effective tillers (panicle) and grain yield from experimental plots were recorded from 1 and 5 m^2 areas, respectively. Grain yields were adjusted to

Table 1. Apparent nitrogen recovery of NERICA L-19 and L-49 as influenced by different N fertilization strategies at submergence-prone areas of three communities in northern Ghana in the 2016 and 2017 growing seasons.

Location	Treatment	2016 Farming season N recovery efficiency		2017 Farming season (kg N uptake kg N^{-1})	
		NERICA L-19	NERICA L-49	NERICA L-19	NERICA L-49
Daffiama	Urea deep placement	0.59a	0.61a	0.45a	0.52a
	Modified farmer practice	0.24c	0.34b	0.21b	0.24b
	Microdosing	0.35b	0.36b	0.27b	0.29b
	Farmer practice	0.12d	0.18c	0.11c	0.13c
	Tukey test (0.05)	**0.06**	**0.06**	**0.08**	**0.11**
Bazua	Urea deep placement	0.48a	0.59a	0.45a	0.56a
	Modified farmer practice	0.35b	0.54ab	0.26b	0.38b
	Microdosing	0.37b	0.52b	0.36a	0.39b
	Farmer practice	0.24c	0.27c	0.11c	0.14c
	Tukey test (0.05)	**0.06**	**0.04**	**0.09**	**0.08**
Gbabshie	Urea deep placement	0.54a	0.56a	0.49a	0.51a
	Modified farmer practice	0.27b	0.31b	0.32b	0.26c
	Microdosing	0.29b	0.32b	0.34b	0.41b
	Farmer practice	0.19c	0.19c	0.12c	0.15d
	Tukey test (0.05)	**0.03**	**0.02**	**0.04**	**0.08**

a moisture content of 14% (Miah et al., 2016) to ensure uniform treatment comparison. Apparent N recovery efficiency (ARN) was calculated following a modification of the procedure described in Huda et al. (2016):

$$ARN = \frac{(UA\text{-}U0)}{FN}$$

where UA is N accumulation in the aboveground plant dry matter resulting from N application (kg ha^{-1}), U0 is N accumulation in aboveground plant dry matter resulting from the control, and FN is the quantity of N applied from the N fertilizer source (kg ha^{-1}).

Effect of fertilization strategies on rice grain yield

There were significant N fertilization effects on yields of the two rice varieties. Without fertilizer application, rice grain yields were very low: an average of 0.3 and 0.4 t ha^{-1} for the NERICA L-19 and L-49 (**Fig 2**). Across all three locations and in the two growing seasons, the UDP treatment produced the highest yields of 3.8 and 4.3 t ha^{-1} for NERICA L-19 and NERICA L-49, respectively, followed by MFP and MD. FP generated the lowest yields amongst treatments supplying fertilizer (0.8 and 1.1 t ha^{-1}), for NERICA L-19 and NERICA L-49, respectively.

Grain yield was strongly influenced by fertilization strategy. With UDP, yield of NERICA L-19 increased by an average of 620% over FP, and by 150% with MFP over FP, and 110% with MD over FP. Corresponding agronomic efficiencies were increased by 340%, 70% and 50% in the UDP, MFP and MD treatments, respectively, over the FP. Similar increases in grain yield and agronomic efficiency were observed for the NERICA L-49 variety. Although cultivation of submergent-tolerant rice cultivars is expected to enhance resilience to flooding (Ismail et al., 2013), effective nutrient management under submergent conditions is critical to optimize productivity (Gautam et al., 2019). Gaihre et al. (2015) showed that rice requires N in larger quantities than any other nutrient, and it is commonly the most critical yield limiting factor. Therefore, ensuring adequate N supply is essential for increased productivity of submergence-tolerant rice cultivars.

Effect of fertilization strategies on apparent nitrogen recovery

Average N uptake values for fertilizer treatments across sites, seasons and rice varieties were in the order UDP > MFP > MD > FP (**Table 1**). The high N recovery from the UDP treatments could be attributed to: (i) the smaller specific surface of USG that could prolong its dissolution (IFDC 2007, 2013, 2015) and (ii) the high film of ammonium (NH_4^+) concentration that remains in the immediate vicinity of the USG. This limits nitrification and results in the slow release of N (Prinčič et al. 1998). These factors possibly reduced N losses and matched N availability with the crop's N demand. In lowland and irrigated rice experiments, Kapoor et al (2008) and Miah et al (2016) also observed significantly greater N recovery with UDP compared to conventional granular/prilled urea application. ■

Summary

The results confirm that although the cultivation of submergence-tolerant rice cultivars is expected to reduce yield losses to submergence, effective nutrient management under submergent conditions is critical to increase productivity. Without fertilizer, average rice grain yields were very low at 0.8 t ha^{-1}. Rice yields were significantly increased by application of fertilizer. However, the yield of rice under submergence varied substantially with the fertilization strategy. The greatest yields and nutrient recovery efficiencies with fertilizer were achieved with the application of UDP, followed by the MFP, MD and FP treatments. Therefore, the synergistic effects of submergence-tolerant rice varieties and appropriate fertilizer management strategies are critical to mitigate the negative effects of submergence on rice production. UDP technology was the most effective fertilization strategy tested and provides an option for enhancing the agronomic and economic returns to investment in fertilizer for farmers growing submergence-tolerant rice cultivars.

Dr. Agyin-Birikorang is Senior Scientist at the International Fertilizer Development Center (IFDC), Muscle Shoals, AL, USA; e-mail: sagyn-birikorang@ifdc.org. Dr. Singh is with IFDC, Muscle Shoals, AL. Mr. Tindjina and Mr. Issahaku are formerly of the Agriculture Technology Transfer Project, IFDC, Tamale, Ghana, Mr. Dauda is formerly of the Agriculture Technology Transfer Project, IFDC, Wa, Ghana. Dr. Boubakary is Formerly of the Africa Rice Center, Tamale, Ghana.

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Enabling Adoption of Improved Agronomic Practices with ICT-based Farmer Advisory Services

By Regis Chikowo, Kennet Christensen, Brian King, and Sieg Snapp

The Malawi agricultural extension system is severely constrained and the existing extension network is grossly inadequate for effective information dissemination to farmers. The usefulness of Interactive Voice Response (IVR) technology to reach farmers with agronomic advisory was examined for two consecutive maize cropping seasons. This pilot work provides insight into the opportunities and pitfalls of employing IVR in agricultural technology dissemination.

An important precondition of agricultural development for livelihood improvement in Africa is securing the transition away from area expansion and towards productivity growth (Jayne and Sanchez, 2021). Higher agricultural productivity requires technical innovation that can encourage sustainable changes in farm practice. Greater and more efficient use of improved seed, mineral fertilizers, and organic inputs are widely recognized as preconditions for achieving productivity growth.

Over the past decade, the Malawi government has implemented a farm input subsidy program (FISP) to improve crop productivity by increasing farmers' access to agricultural inputs (Jayne et al., 2018). While progress has been made, the full benefits of the intervention have not been realized due to poor crop and nutrient management practices amongst farmers. This is partly due to a weak and constrained agricultural extension system characterized by a very high farmer-to-extension staff ratio of 2500:1 (IFPRI, 2015). There are limited prospects for improvement of the government extension services due to funding and capacity limitations. To reduce this extension gap, a network of lead farmers has been put in place to provide complementary services. Regrettably, even this combined effort falls far too short for effectively disseminating technologies to farmers. A diversified and pluralistic national strategy to promote agricultural extension and communication for rural development is perceived as a promising solution.

Maize is the staple crop grown by every smallholder farmer in central and southern Malawi. However, maize yields have remained poor due to multiple factors that include poor soil fertility, poor seed varieties, low and inappropriate fertilizer management. At the root of some of these challenges is farmers' lack of access to information and technologies due to an overstretched government extension system. While the Malawi government extension system has provided motorbikes to the extension workers to increase their mobility and reach more farmers, in practice, the motorbikes are rarely functioning, leaving the extension system grossly incapacitated. This is an untenable situation as most farmers rarely access agricultural extension services critical for adopting improved farming practices. Therefore, exploring alternative pathways for technology dissemination is essential for achieving Malawi's desired food security outcome.

> "I am now harvesting a lot of maize from a small plot. I have followed the advice for two seasons. I now use fertilizer appropriately. This is why I will have adequate maize this year from my farm.
>
> **STEVEN WILLIAMS FROM MTUBWI**

Mobile phone-based ICT (Information and Communications Technology) is well-rooted in the data-rich

Simple, cheap, but functional cellphones are a potential game-changer in each farmer's hand for excellence in maize agronomy.

domains, such as banking, with simple communication platforms and applications that can be readily adapted to the agricultural sector (Aker, 2011). The dissemination of technologies through remote media is increasingly used to complement traditional agricultural extension pathways (e.g., Tinzaara et al., 2021; Thimnu, 2020; Tadesse and Bahiigwa, 2015). There is increasing use of mobile phones among rural farmers, providing room for interactive voice response (IVR) technology to support extension for agricultural transformation. To be of value, IVR used in other sectors should be adapted to the context of smallholder farming systems, particularly recognizing that a large proportion of farmers are illiterate. We hypothesize that access to targeted agronomy messages through IVR leads to better and timely decision-making on farms, contributing to increased resource use efficiencies and maize productivity. Therefore, the main objective of this study was to deliver timely and targeted messages on good maize agronomy to a trial group of smallholder farmers in central Malawi through IVR messaging and to evaluate the resultant changes in the implementation of effective agronomic practices that have a strong bearing on resources use efficiencies in maize production.

Introducing IVR to farmers and setting the scene

In November 2018, four focus group discussion (FGD) workshops were held with 35 farmers, each in the Machinga district in southern Malawi. The initial objective of the workshops was to introduce farmers to the public information access "321" services provided by Airtel Malawi. Farmers were also introduced to the more targeted Via Mobile (VIAMO) platform with pointed IVR messages on maize agronomic practices. Other FGDs were held with a similar number of 'control' farmers for which discussions were limited to the broader Airtel 321 service.

During the FGDs, we encouraged farmers to provide narratives on how they manage their farms in general. Farmers were aware of the climatic and soil fertility limitations in their region. For example, farmers highlighted poor rainfall distribution as a key constraint. However, there were inconsistencies on interventions to improve productivity, with a minimal understanding of the water-nutrient interactions that are key in marginal agro-ecological conditions. Assessment of the main knowledge gaps was instrumental in formulating appropriate and relevant maize agronomy content for the IVR system.

IVR content development and packaging

The maize agronomy content for IVR messages was developed and packaged based on empirical data from trials (e.g., Snapp et al., 2018) and other publicly available extension material on maize agronomy in Malawi. After the content was developed, VIAMO recorded the IVR content in different formats and pre-tested with a group of farmers to evaluate the effectiveness of voices, tone, style formats for communicating agronomy information to farmers. The pre-testing phase revealed that the content presented in a conversation mode was more effective in improving farmers' decisions on maize agronomy. We scheduled tailored agronomic advisory messages to be delivered

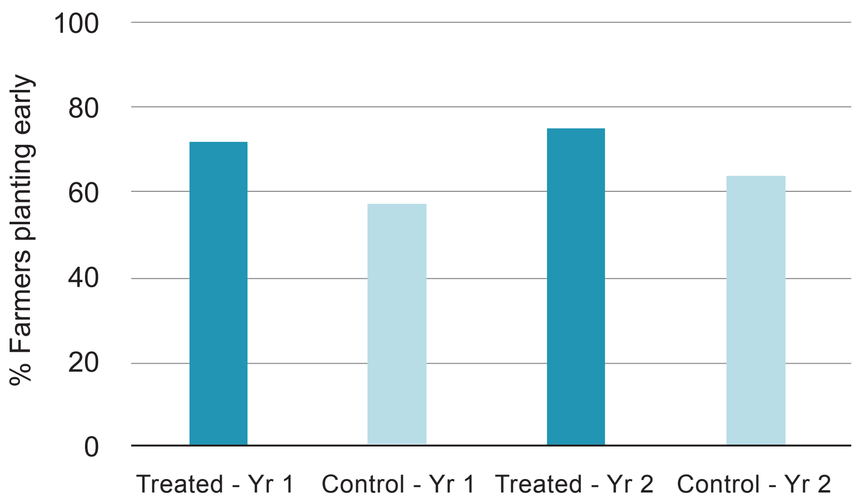

Figure 1. Effect of IVR messaging on maize early planting. Farmers who planted by 30 November were considered to have planted early for both years.

timely during the maize production calendar.

For example, at the time of planting, the message on planting was phrased as follows: "*Have you planted your maize seed yet?, press 1 for Yes and 2 for No.*" Once the farmer indicated that they had planted, we proceeded to enquire if they had applied NPK fertilizer at the time of planting maize as a reminder for the need to apply NPK fertilizer at the next earliest opportunity.

Delivery of IVR messages

Between October 2018 and May 2019, the 140 trial farmers received IVR messages on key maize agronomic practices, beginning about three weeks from the expected onset of the cropping season until about maize physiological maturity. In contrast, the 140 farmers in the control group did not receive any maize agronomy messages other than the general messages from the Airtel 321 platform.

The best agronomic practices provided by IVR included: land preparation, planting density, fertilizer types and their application, and weeding. The program sent one message per week, repeated at least three times to each trial farmer, based on the cropping season calendar. For unreachable participants on the first attempt, calls were repeated at least three times per day.

In October 2019, we initiated a second cycle and increased the number of trial farmers to 650, including those initially engaged in October 2018. Thus, we created an exposure time as a factor: 1) 510 farmers newly engaged during the 2019/20 cropping season – the 1-year IVR cycle farmers, and 2) 140 farmers initially engaged during the 2018/2019 cropping season – the 2-year IVR cycle farmers. This research design enabled investigating the effect of IVR exposure time on adopting good maize agronomic practices.

After each of the two IVR campaign cycles, we conducted electronic evaluation surveys for both trial and control farmers, with follow-up questions on main agronomic practices implemented by farmers on maize plots. There were slight differences in the evaluation approach for these two groups. We explicitly referred to their experience with IVR calls on improved maize agronomy for the trial group. For the control farmers, we reminded them that they had agreed to take part in the study based on our early interactions and FGDs.

Key results from piloting IVR for scaling maize agronomy

During the 2018/19 cropping season, 72% of IVR treated farmers planted maize early (by November 30th) compared with 57% of the control farmers who had planted maize by this date. The 2019/2020 cropping season data was comparable to the first season (**Fig. 1**). This response is significant as the benefits of early planting for improved maize productivity are widely established (e.g., Nyagumbo et al., 2017). Following a long dry season, early planting with first rainfall harnesses the early mineral nitrogen (N) flush from soil organic matter otherwise missed when farmers plant late (Sachs et al., 2010). Soil organic matter mineralization is often a significant source of plant-available N for low external nutrient input cropping systems. Farmers are also able to optimize seasonal rainwater use with early planting.

The messages on the benefits of early planting were effective at improving farmers' decision-making. The proportion of farmers who planted late, more than three

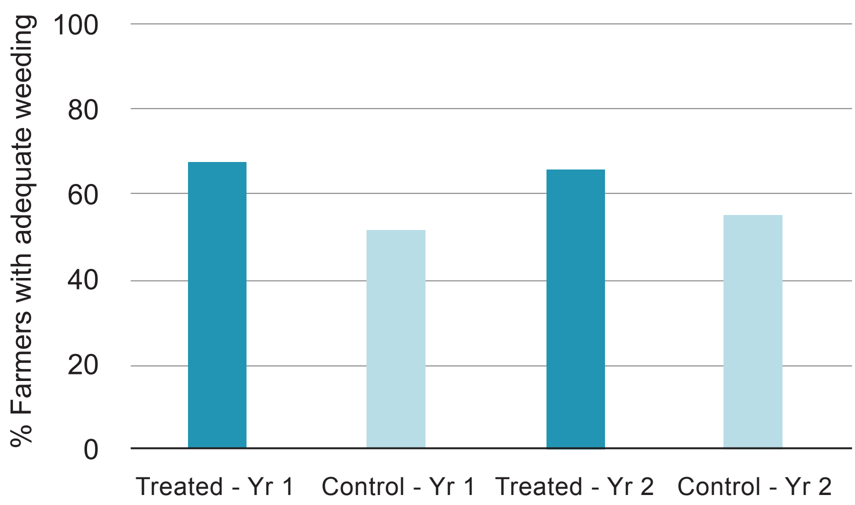

Figure 2. Effect of IVR messaging on weed control.

weeks after the onset of rainfall during the 2018/19 cropping season (after December 10th), was only 5% among IVR trial farmers compared to 20% for the control group. This positive response was repeated during the 2019/2020 cropping season.

About 90% of the young farmers (< 21 years) planted their maize within one week of the onset of rains for the treated group compared to 72% for the control group. The message on early planting was included in both the IVR and Airtel 321 platforms. The result suggests that extension communication through the remote media platforms was of more benefit to young farmers.

Access to NPK basal fertilizer was not influenced by IVR treatment. Purchase of fertilizer is often planned and done several months ahead of the cropping season. It is not surprising that there was no significant influence of IVR on access to NP fertilizer in the short-term. Also, access to fertilizer is expected to be mainly influenced by the capacity of farmers to purchase fertilizer. Farmers who had access to NPK fertilizer generally applied the fertilizer within two weeks after germination for both the treated and control farmers groups.

The timing of applying side-dressing urea fertilizer, on the other hand, was influenced by targeted information provided through IVR: 49% of farmers in the treated group applied urea fertilizer, about a month after planting as recommended, compared to 25% for the control group. Therefore, IVR treated farmers used urea fertilizer more efficiently as a side-dress than farmers receiving the general 321 service only. In the future, IVR urea side-dress fertilizer recommendations could be tailored to obtaining local weather as part of response farming where more fertilizer is applied during wetter seasons and some fertilizer withheld in poor rainfall seasons.

A more significant proportion of farmers (67%) in the IVR treated group weeded twice, compared to 51% belonging to the control group during Year 1. During Year 2, 65% treated farmers weeded twice compared with 55% in the control group (**Fig. 2**). This 10% gap could translate to significant maize production differences when scaled up in the community. Two weeding events or more are recommended for maize production, and content on this subject delivered to the IVR treated group seemed to have influenced farmer behavior. However, we noted that the number of farmers who responded to this topic was low; therefore, in-person interviews could be vital to augment remotely obtained farmer feedback.

Participation time significantly impacted the maize seed varieties selected by farmers. About 71% of Cycle 2 farmers used hybrid maize seed compared with 40% for the Cycle 1 farmers. The influence of IVR communication on the increased use of hybrid seed varieties is expected to lever increased fertilizer use in the long-term. Hybrid maize varieties are generally more responsive to fertilizer application and incentivize farmers to invest in increased fertilizer use. More Cycle 2 farmers also planted maize earlier, and 80% applied NPK between planting and germination compared with 69% for the Cycle 1 farmers. While poor practices in the use of urea fertilizer, such as applying too late, six weeks or later from crop emergence or surface placement as opposed to covering the fertilizer, were still prevalent for both farmer groups, a notable improvement in urea management was observed for Cycle 2 farmers. Urea fertilizer is prone to loss through volatilization when farmers fail to cover the fertilizer with soil. It is important to apply urea fertilizer in time for the organic molecule to mineralize and become available for crop uptake.

Farmers' feedback on the IVR delivery process

Further FGDs were held with both trial and control farmer groups during the post-IVR messaging phase, with 10-15 participants per session. Audio messages were disseminated to the control and treatment groups, followed by discussions on farmers' comprehension and perception. An analytical process was used to assess farmers' responses to the content and their behavior change. Participants indicated that the messages were relevant and informative.

"I am now harvesting a lot of maize from a small plot. I have followed the advice for two seasons. I now use fertilizer appropriately. This is why I will have adequate maize this year from my farm."—Steven Williams from Mtubwi.

Since farmers received maize agronomy advice ahead of the planting season they considered the messages to be timely and relevant for the maize cropping calender. Early planting was associated with healthier crops and less weed pressure as crops compared to late planted crops.

Farmers were satisfied with the dialogue messaging format and this is best expressed in the words of one of the farmers:

"When we first listened to the instructions, we thought they would be difficult to follow through, but they were not and this year it was even easier for us."—Daniel White, a 2-year Cycle farmer. ■

Summary

We demonstrated that IVR messaging could support tailored messages that enable the adoption of improved agronomic practices for maize on smallholder farms. The management practices that were improved by IVR messaging included early maize planting, correct timing of urea top-dress fertilizer application, and effective weeding, at least twice during the growing season. Further improvement in our research approach to improve the quality of evaluation data include triangulation of survey responses through in-person interviews and measurements of maize yield through plot cuts to determine the yield benefits. Overall, focus group discussions revealed that participants were satisfied with the dialogue messaging format.

Dr. Chikowo is Assistant Professor with Michigan State University, e-mail: chikowor@msu.edu. Mr. Christensen is Country Director with VIAMO. Dr. King is Coordinator of the CGIAR Platform for Big Data in Agriculture with CIAT. Dr. Snapp is Professor of Soils and Cropping Systems Ecology with Michigan State University.

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Sampling flowering (Top) and mature (Bottom) lentil plants within on-farm experiments evaluating responses to nitrogen, phosphorus and potassium application. Khemisset province, Morocco (Ain Sbit rural community).

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