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SUB-SAHARAN AFRICA SOIL FERTILITY PRIORITIZATION REPORT

III. COMBINED SUMMARY

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Feed the Future Innovation Lab Collaborative Research on Sustainable Intensification

Kansas State University

REPORT

of the

Sub-Saharan Africa Soil Fertility Prioritization: III. Combined Summary©

Prepared by

Feed the Future Innovation Lab for Collaborative Research on Sustainable Intensification (SIIL)

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Executive Summary

The Feed the Future Innovation Lab for Collaborative Research on Sustainable Intensification (SIIL) at Kansas State University led a multi-stage effort to understand barriers to enhancing soil fertility in sub-Saharan African (SSA) and to provide evidence-based recommendations to overcome these barriers. The focus countries of interest were in West Africa, East Africa, the Great Lakes region, and Ethiopia. Recommendations were developed through the combined analysis of the *SSA Soil Fertility Prioritization Survey Results* and the *SSA Soil Fertility Prioritization Summit Results*. The following recommendations have been organized by emerging themes across all regions. Distinct priorities were identified for each region in the survey and summit reports; however, due to strong SSA-wide commonalities between priorities, this combined summary report will focus on unified themes and recommendations and interject identified regionally unique themes where appropriate. The survey and summit provided a rich and diverse view of solutions, barriers, and strategies for overcoming the identified primary soil limitations. Most of the recommendations presented are known and are based on established strategies; however, the evidenced-based process and methodology for prioritizing these recommendations makes this report useful for setting forth action plans for future investments and strategies to improve soil fertility in SSA. This combined summary report provides emerging recommendations from this diverse input, although the reader is referred to the *SSA Soil Fertility Prioritization Survey Report* and the *SSA Soil Fertility Prioritization Summit Report* for a complete presentation of the results. This is strongly encouraged when considering projects or initiatives in a specific region or focused on overcoming a specific soil limitation.

The most frequent reported limiting factors regarding soil characteristics that contribute to poor crop yields across all four regions are nitrogen deficiencies, phosphorous deficiencies, acidity, and low soil organic carbon content. For Ethiopia and the Great Lakes region, micronutrient deficiencies were also reported as part of the top five limiting factors, while low available water holding capacity was noted for West and East Africa. Given these prioritized limiting factors, our recommendations to improve soil fertility have focused on overcoming these limitations.

The survey results are complementary to the summit results and indicate that there are key biophysical and socioeconomic barriers and strategies that can either create an enabling environment or hinder progress towards improving soil fertility across SSA. Inorganic fertilizer access, use, and related implementation issues were prominent but many related biophysical (e.g. increased access and use of quality organic materials) and socioeconomic barriers (e.g. access to resources both financial and agronomic, and access to appropriate fertility recommendations and extension support) as well as solutions were identified as equally important to building soil fertility.

The combined biophysical and socioeconomic results provide a clear picture of the interdisciplinary and interconnected nature of priorities to improve soil fertility across each region. Thus, plans for improving soil fertility across SSA must take an integrated approach, inclusive of the identified biophysical and socioeconomic factors. Action plans that only focus on a singular or narrow factor, such as inorganic fertility availability or mineral fertilizer recommendations, alone will likely fall short of improving soil fertility. Each of these prioritized factors must be improved in such a way that no one of the identified priorities are limiting. For example, though it may be evident that the use of inorganic fertility can improve crop yields, incorporating this approach exclusively without the inclusion of appropriate recommendations, suitable extension services, access to financial resources, incorporation of organic amendments, and enabling policies will likely not be successful in improving soil fertility. A perspective of the current status of the soil fertility landscape and evaluation of the most limiting biophysical or socioeconomic factors in a given region is critical for recommending an appropriate action plan to improve soil fertility. Focusing on inorganic fertilizer use alone will fall short of improving soil fertility in most regions.

Overall recommendations were developed from a combined analysis of the *SSA Soil Fertility Prioritization Survey and Summit* and are presented in this combined summary report. The four emerging themes were:

- Strengthening Inorganic Fertilizer Systems
- Increased Access and Use of Quality Organic Materials
- Capacity Building along the Entire Knowledge Transfer Value Chain
- Strengthening Farming Systems across Biophysical and Socioeconomic Factors

To address the soil fertility in SSA, items in all four themes should be addressed simultaneously and in combination rather than isolation. All active partners in the entire value chain from private industry, government and non-government agencies, research, education and extension services should be engaged. There is a critical need for improved linkages among partners and organizations. Public sector agencies can play a significant role in creating a platform for bringing together and linking key partners in research, education, extension, service providers, input providers, and farmers. However, there is also a need to enhanced institutional capacity across the value chains. There need to be more focus on engaging with policy makers to create enabling environment so that available resources and inputs are available to farmers and input providers.

Introduction

The health of our soils is the basis of the productivity of our farming systems, the food and nutrition security of our societies, and the improvement of livelihoods and poverty alleviation in our world. Soils of sub-Saharan Africa (SSA) are unhealthy largely due to years of nutrient mining and limited organic or inorganic resupply. As such, crop yields have stagnated and high levels of food insecurity and poverty persist. The World Bank (2013) estimates that over 80 percent of Africa's agricultural lands are degraded, having either biophysical or chemical constraints that limit food production. These degraded soils are estimated to affect 485 million Africans and cost the continent nearly US$9.3 billion annually (Thiombiano and Tourino-Soto, 2007). Without addressing soil health issues, smallholder farmers cannot benefit from yield gains offered by improved plant genetics and other associated agronomic practices. Limited by soil degradation, yield increases from improved crop varieties are estimated at only 28 percent in Africa as compared to 88 percent in Asia (IFDC, 2013).

Following the Green Revolution, SSA remains one of the only regions of the world where per capita food production has remained stagnant (Sanchez, 2002). However, there has been a renewed focus on soil fertility following the call of H. E. Kofi Annan for a "uniquely African Green Revolution." Soil fertility has been consistently identified as a primary limiting factor in SSA preventing the dramatic yield increases seen by the rest of the world. However, obstacles in overcoming barriers to achieving healthy and fertile soils have persisted. Over thirteen years after H. E. Kofi Annan's call, and numerous activities and investments in SSA soil fertility, cereal yields still hover around 1.5 MT ha^{-1} as compared with 3 MT ha^{-1} in Latin America, and South Asia, 5 MT ha^{-1} in China, and greater than 10 MT ha^{-1} in North America, Europe, and Japan (AGRA, 2016). There is now a renewed need to refocus and prioritize sustainable soil fertility efforts in an inclusive and evidence-driven way that looks holistically at the barriers to improve soil health and productivity in SSA.

Soil and plant analysis, paired with agroecologically specific fertilizer response functions, is often the first step to producing evidence-based fertilizer recommendations for efficient crop response. Though this model has been attempted across SSA to varying effect, its self-sustaining business model and adoption by smallholder farmers has been limited. Further, past soil fertility improvement efforts have often focused on inorganic fertilizer use as the primary mechanism for improving soil fertility and improving crop yields; however, in SSA conditions where soils are already degraded (i.e. limited organic matter (OM) and organic nutrient pools), a focus on inorganic fertilizer use alone has had limited success in improving SSA soil fertility. Long-term solutions, such as approaches building OM and organic nutrient pools, and supporting inputs and management practices will likely be an essential component to achieving sustainable soil fertility in SSA. These past lessons have led to the need for a more inclusive evaluation of the soil fertility landscape aiming to evaluate the entire soil fertility supply chain; one that is inclusive of interdisciplinary approaches (production, social, regulatory/policy, environmental) to understand soil fertility barriers and the establishment of evidence-based priorities to overcome these barriers.

McGahuey et al. (2016) provided an extensive external strategic review of the International Fertilizer Development Center's (IFDC) programs, organizational structure, infrastructure, management, and accountability systems. Portions of that review are relevant to this effort, particularly those that address the promotion and use of fertilizers in Africa. The review identified potential for the IFDC to be an integral part of the next "ever-green revolution" by adopting appropriate sustainable intensification practices through use of fertilizers, and soil fertility management technologies contained within the concept of integrated soil fertility management (ISFM). The review was clear in that smallholder farmers in Africa had yet to realize such benefits. The review proposed several scenarios for the future of the IFDC with the preferred scenario being that the organization regain and preserve its uniqueness as both a research institution and a project implementing organization.

The review concluded by providing responses to 12 review questions, part of which directly addressed soil fertility issues in Africa. In particular, the review noted the difficulty for the IFDC to cover the entire dual value chain (soil nutrient inputs through agricultural outputs) approach for increasing fertilizer use. It was suggested that the IFDC could perhaps better address soil fertility constraints by returning to an applied-research, program-theme-based organization that coordinates and manages adaptive research-based technology development and dissemination efforts. The goal would be to develop cost effective fertilizer products and soil fertility management practices and work with extension systems to extend those practices to farmers. Capacity development would also need to be an integral part of these efforts. Not surprisingly, these recommendations align quite closely with the conclusions from the *SSA Soil Fertility Prioritization Survey and Summit* results.

Methodology

The Feed the Future Innovation Lab for Collaborative Research on Sustainable Intensification (SIIL) led an inclusive process to identify critical soil fertility priorities in SSA focused around identifying key barriers (e.g. increasing soil organic matter, nutrient limitations – both macro and micro) and key sustainable strategies and priorities to overcome the identified barriers. This objective was realized through an evidence-driven survey and summit involving key leaders and actors from across international agricultural research centers (IARCS), national agricultural research and extension systems (NARES), national universities, extension agencies, developmental agencies, agronomic/soils researchers, private sector, social scientists, regulatory agencies, and farmer organizations to systematically identify evidence-driven soil fertility barriers and priorities to overcome these barriers. The focus of the evaluation was to identify opportunities for high impact across large geographical regions. SIIL prioritized findings in four key SSA regions during the survey and summit.

Focus Regions:

- West Africa region: Senegal, Burkina Faso, Ghana, Niger, Mali
- East Africa region: Tanzania, Kenya
- Great Lakes Area: Rwanda, Uganda, Burundi, Malawi
- Ethiopia (kept separate due to unique agroecology)

Survey Methodology

In May of 2017, the SIIL team compiled an initial list of survey participants drawing from SIIL's institutional Listserv, the investigator's relevant contacts, IFDC's relevant contacts, American Society of Agronomy public Listservs including the Sustainable Intensification Community and communities within the Global Agronomy Section (i.e. Agronomic Solutions for Smallholders, Agronomy in Africa, Gaining Access to Agronomic Inputs), authors of key publications (AGRA, 2016; Wortmann, 2017)), and SIIL regional coordinator's relevant contacts. Additionally, relevant contacts were requested from leading regional scholars working in SSA soil fertility. At the same time, the team drafted survey items to systematically identify evidence-driven soil fertility barriers, suggestions to overcome these barriers, and prioritize current and future innovations for research, development and scaling. To review and refine these items, the SIIL team sent the draft survey to leading biophysical and social scientists for additional input. Based on feedback collected through the pilot stage, items were finalized at the end of May. The survey sections included questions to rank a list of limiting factors regarding soil characteristics contributing to poor crop yields, rank lists of biophysical and socioeconomic limitations to enhancing soil fertility, provide recommendations to improve soil fertility five to ten years from now and report demographics.

The SIIL team sent an initial invitation to participate in the Soil Fertility Prioritization survey during the first week of June 2017. In an effort to expand the study, SIIL implemented a snowball technique whereby recipients were asked to identify other experts in the field who might be willing to participate in the survey. As a result of this request, an additional 81 names were added to the survey distribution list, for a total of 1,115 contacts.

The SIIL team launched the on-line survey in Qualtrics™ on June 9, 2017 with a closing date of July 5, 2017. The team also scheduled reminder messages to be sent out twice a week to all survey recipients who had not yet responded. The reminder messages were delivered on June 13, 16, 20, 23, 27, 30 and July 3. Throughout the survey administration process, respondents continued to provide contact information for others to be included in the survey. By the closing date, the SIIL team had distributed the survey to 1,157 contacts. From this distribution, a total of 491 individuals responded to the survey representing a 42% response rate.

On July 10, the SIIL team downloaded the survey data from the on-line system, aggregated all responses and began preliminary analysis. The team used basic descriptive statistics to summarize the quantitative data in the survey. For the open-ended questions, the team conducted a content analysis to identify any common themes or trends in the responses within each region.

Summit Methodology

On August 14th and 15th of 2017, the SIIL team convened 35 participants for the Sub-Saharan Africa Soil Fertility Prioritization Summit in Dakar, Senegal. The participants were identified as key thought leaders on soil fertility issues in their respective regions. Participants represented international agricultural research centers (IARCS), national agricultural research and extension systems (NARES), national universities, extension agencies, developmental agencies, agronomic/soils researchers, social scientists, regulatory agencies, private sector, and farmer organizations. The summit built from the survey results and was designed to further explore the soil fertility limitations, solutions, barriers, and strategies to overcome these barriers through a facilitated process to capitalize on the expertise of the participants.

Participants were separated into regions based on their expertise and asked to identify solutions to nitrogen deficiency, low soil organic carbon content, phosphorous deficiency, and acidity, since these were the top soil limiting characteristics identified in the *Sub-Saharan Africa Soil Fertility Prioritization Survey* (See Survey Report) across all regions. Each region had between seven to nine participants. For each limiting soil factor, each region separately identified their top solutions to overcome this limitation. Solutions were recorded on flip charts. Each participant was given four large Post-its and asked to write two biophysical and two socioeconomic barriers to these solutions. All Post-its were read aloud and posted for all to see. Participants organized the barriers into clusters and titled the clustered barriers by theme. Participants developed strategies to overcome the clustered barriers and the strategies were recorded on flip charts. This process occurred from start to finish for each limiting soil characteristic and separately for each region.

The following day, all solutions were displayed for everyone to review. All participants convened as a group and through consensus, categorized and named common solutions identified by all regions. These common solutions were titled as a group and posted for ranking. Each participant was given two dot stickers and was asked to place their sticker by the solutions that they felt would provide the largest breadth and depth in addressing soil fertility issues within the Sub-Saharan Africa Region.

Way Forward

Some of the items to consider moving forward were developed through the combined analysis of the *SSA Soil Fertility Prioritization Survey Report* and the *SSA Soil Fertility Prioritization Summit Report*. The following recommendations have been organized by emerging themes across all regions. Distinct priorities were identified for each region in the survey and summit reports; however, due to strong SSA wide commonalities between priorities, the combined summary report focused on unified themes and recommendations. Where appropriate, the report includes the unique themes identified per region. The survey and summit provided a rich and diverse view of solutions, barriers and strategies for overcoming the identified primary soil limitations. Most of the recommendations presented are well known and are based on established strategies; however, the evidenced-based process and methodology for prioritizing these recommendations makes this report useful for setting forth action plans for future investments and strategies to improve soil fertility in SSA. This section provides emerging recommendations from this diverse input although the reader is referred the *SSA Soil Fertility Prioritization Survey Report* and the *SSA Soil Fertility Prioritization Summit Report* for a complete presentation of the results. This is strongly encouraged when considering projects or initiatives in a specific region or focused on overcoming a specific soil limitation.

The most frequently reported limiting factors regarding soil characteristics that contribute to poor crop yields across all four regions are nitrogen deficiencies, phosphorous deficiencies, acidity, and low soil organic carbon content. For Ethiopia and the Great Lakes region, micronutrient deficiencies were also reported as part of the top five limiting factors, while low available water holding capacity was noted for West and East Africa. Given these prioritized soil limiting factors, our recommendations to improve soil fertility have focused on overcoming these soil limitations.

The survey results are complementary to the summit results and indicate that there are key biophysical and socioeconomic barriers and strategies that can either create an enabling environment or hinder progress towards improving soil fertility across SSA. Inorganic fertilizer access, use, and related implementation issues were prominent solutions to building soil fertility; however, many related biophysical (e.g. increased access and use of quality organic materials) and socioeconomic barriers (e.g. access to resources both financial and agronomic, and access to appropriate fertility recommendations and extension support) were also identified as important solutions to building soil fertility.

The combined biophysical and socioeconomic results provide a clear picture of the interdisciplinary and interconnected nature of these priorities to improve soil fertility across each region. Thus, plans for improving soil fertility across SSA must take an integrated approach, inclusive of the identified biophysical and socioeconomic factors. Action plans that focus only on a singular or narrow factor, such as inorganic fertility availability or mineral fertilizer recommendations, will likely fall short of improving soil fertility in most regions. Each of these prioritized factors must be improved in such a way that no one of the identified priorities are limiting. For example, though it may be evident that the use of inorganic fertility can improve crop yields, incorporating this approach exclusively, without the inclusion of appropriate recommendations, suitable extension services, access to financial resources, incorporation of organic amendments, and enabling policies will likely not be successful in improving soil fertility. A perspective of the current status of the soil fertility landscape and evaluation of the most limiting biophysical or socioeconomic factors in a given region is critical for recommending the appropriate action plan to improve soil fertility.

Throughout the review of McGahuey et al. (2016), the need for enhanced applied research and extension systems to improve soil fertility conditions for smallholder farmers in Africa is mentioned. Further, survey and summit results suggest that the entire value chain needs to be addressed in order to facilitate change, but it is unclear if this should be entirely addressed by IFDC or in collaboration with other development partners. The survey and summit results cover the first half of the dual value chain (soil nutrient inputs) and support and extend the review findings. Improvements in the availability, affordability, and use of existing and newly developed plant nutrient sources as part of ISFM is a clear need identified in the review and in this effort. Capacity building is also a critical component. While many common issues are identified in both the review and this effort, the survey and summit results highlight the complexity of addressing the overall goals with regard to regional differences in crops, soils, climate, economics, culture, the availability of existing fertilizers, and the potential for developing new plant nutrient sources within and across regions. More detailed analyses would be required to develop strategies for maximizing the impact of deployed resources to enhance soil fertility conditions in SSA.

Emerging Themes and Priorities across Regions

Strengthening Inorganic Fertilizer Systems

Inorganic fertilizer availability, use, and related implementation factors were a prominent theme identified and prioritized across all regions to overcome nutrient deficiency (i.e. participants prioritized N and P deficiency; micronutrient deficiency was also prioritized for Ethiopia and the Great Lakes region) and improve soil fertility. However, identified existing barriers to inorganic fertilizer use were numerous and spanned both biophysical and socioeconomic barriers. The availability and affordability of quality inorganic fertilizers was consistently identified across all regions, as was the lack of access to financial resources or credit to purchase fertilizers, quality soil testing, regional and crop specific fertilizer application recommendations, opportunities to build and maintain soil organic matter to improve fertilizer response, and skilled public and private sector service providers to deliver and support appropriate nutrient management recommendations to farmers (i.e. right rate, right time, right source, right place). It is clear that action plans to overcome nutrient deficiency and improve soil fertility by increasing availability and use of inorganic fertilizer must also devote significant consideration to these prioritized barriers. If any one of the prioritized factors are limiting, increased availability and use of inorganic fertilizer alone will likely not achieve sustained soil fertility.

As such, it is our recommendation to encourage an interdisciplinary systems approach to increase inorganic fertilizer availability and use for the goal of improving soil fertility. This recommendation aims to strengthen the entire inorganic fertilizer system from the supply of quality inorganic fertilizers to the capacity building of extension service providers to extend recommendations to farmers. This systems approach will require the strengthening of access to quality and affordable inorganic fertilizers, financial resources and credit to purchase fertilizers, quality soil testing (i.e. lab or mobile based), regionally specific fertilizer application recommendations, opportunities to build and maintain soil organic matter to improve fertilizer response, and skilled public and private sector service providers to deliver and support appropriate nutrient management recommendations for farmers. An inclusive perspective of each of these factors in a given region is essential to identify which barriers are limiting and are in greatest need of resource investments. Critical to this recommendation is the need for systems and platforms that can integrate and connect these services.

Recommended strategies prioritized in the survey and summit reports include the need for improved access to well-equipped soil analysis labs and/or mobile testing equipment (e.g. spectral, agroecologically interpolated fertilizer recommendations) that can provide affordable, research based, and crop and region specific recommendations to farmers. Soil analysis labs or mobile soil analysis platforms must be linked with regionally specific fertilizer response trials in order to provide appropriate fertilizer recommendations. In particular, soil testing practices should address soil chemical characteristics that limit crop response to fertilizer or plant nutrient supplements in addition to assessing plant available nutrients. Since most soils are nutrient deficient and will likely remain so, improving basic soil conditions to increase the likelihood of a crop response to nutrient additions is critical. In many cases, extensive correlation and calibration studies to determine the proper amount of fertilizer to add in order to achieve maximum yields or to allow buildup of plant nutrients would not be needed. Simple fertilizer response curves (nutrient added vs yield) would be sufficient and extremely valuable. These fertilizer recommendations should be obtained through applied research that addresses the “response curves” for crop yields to nutrient additions.

Further, participants recommended the use and development of regional and crop specific fertilizer blends, which may include micronutrients where fertilizer trials indicate response. Essential to this process is the need for well-trained public and private extension service providers and information communication technologies (ICTs). This would require investment in the quantity of people being trained and the quality of the trainings for those providing recommendations to farmers and conducting applied research to support their efforts. Many comments suggested public extension services specifically; however, it requires as pluralistic extension services, an approach that includes a variety of service providers, such as all research actors, IARCS, NARES, national universities, developmental agencies, NGO’s, FBO’s, the private sector, and farmer organizations should actively participate in these activities. There is a need for improved linkages between these multiple organizations. The use of smart phones and other technologies is also strongly encouraged in disseminating of knowledge and information.

On the socioeconomic side, the lack of financial resources was a prioritized barrier identified by all regions. In order to support the use and adoption of inorganic fertilizers, participants recommended linking farmers to financial resources such as microfinancing programs, voucher or subsidy programs with an exit strategy, farmer's cooperatives, crop insurance programs, improved policy/infrastructure and supply chains, and economically optimum fertilizer recommendations.

Increased Access and Use of Quality Organic Materials

Increasing access and use of quality organic materials was consistently identified and prioritized by all regions for the goal of improving soil fertility. However, identified barriers to increasing the access and use of quality organic materials were numerous and spanned both biophysical and socioeconomic barriers. Critical barriers included lack of access to sufficient quantities of animal manures, suitable information on the composition of manures and other carbon-rich amendments, skilled public and private sector service providers to deliver appropriate management recommendations, and the ability to retain crop residues on the soil. Intrinsic factors, such as adverse climatic conditions (i.e. limited precipitation and extreme temperatures) and soil texture (i.e. sandy soils), were also identified as critical barriers. Low input agriculture, limited appropriate scale mechanization for conservation agriculture, the multiple competing interests for crop residues, such as animal feed, home construction, fuel for cooking, and the impact of open grazing policies, were also noted as critical barriers. Both the quantity and quality of organic materials were of concern. The issue of land-tenure (i.e. long-term access to the same land) was identified for West Africa and access to mechanization, where appropriate, was identified for both Ethiopia and West Africa.

Depending on the unique agroecology of each system and region, various organic matter technologies were identified and recommended to increase organic C and plant essential nutrients to the soil through the addition of C-rich materials. In order to increase biomass production, these C-rich materials could include manures or composts, legumes (crops; shrubs/bushes; agroforestry and trees) or low C:N ratio crops, retention of crop residues, cover crops or green manures, or use of inorganic fertilizers. The option of adding biochar was specifically recommended for West Africa. Ethiopia and the Great Lakes and East Africa regions listed solutions that are consistent with ISFM, including crop rotations, cropping systems, optimizing C:N ratios through improved crop-livestock-soil management, and improved information and recommendations on soil fertility management. All regions listed components of conservation agriculture and improved agriculture practices related to reducing soil erosion and use of no-till practices. Agroforestry systems were particularly highlighted in West Africa and mentioned for parts of East Africa.

There was a clear need to prioritize soil fertility strategies that increase the access and use of quality organic materials such as those identified. The optimum strategy will depend on the unique agroecology of the region with the prioritized goal of building or maintaining soil C to improve soil fertility. However, it should be stated that the survey and summit results do not necessarily support the concept of C sequestration that is often discussed in the scientific literature. Rather, the benefits of frequent C additions to the soil, both for the improvements in soil physical properties and as part of ISFM practices, without necessarily increasing soil C stocks, is where the greatest improvements will be realized. Improving access and utilization of quality soil and organic material testing labs or mobile analysis systems, skilled private and public extension service providers, improved mechanization, and enabling polices are critical to overcoming the identified and prioritized barriers. Most of the organic material strategies are knowledge intensive and thus a significant investment should be made in building this capacity for both regional knowledge creation and delivery of improved organic material technologies.

The need for basic and applied research was clearly identified and prioritized by all regions for the purpose of increasing access and use of quality organic materials. Applied research on crop residue management, tillage, soil erosion, cropping systems, cover crops, and soil compaction were specifically mentioned. For basic research, soil microbial processes as related to soil health and nitrogen fixation, biochar, use of soil applied polymers, and the optimization of C and nutrient flows were highlighted. Policy and development issues that would encourage the application of C-rich materials and retention of crop residues to/on the soil were strongly emphasized. Policy briefs related to open grazing, land ownership, issues related to burning of brush and crop residues, and the promotion of soil quality improvement were also highly recommended. Strategies for appropriate mechanization related to providing appropriate scale planters (hand-held or two-row drawn by animals or single-axle tractor) and other equipment needed for conservation agriculture and minimum tillage practices were also recommended.

Capacity Building along the Entire Knowledge Transfer Value Chain

Capacity building along the entire soil fertility, knowledge transfer, value chain was consistently identified and prioritized by all regions for the goal of improving soil fertility in terms of knowledge creation, knowledge transfer, and building institutional and facilities capacity. For overcoming N, P, and micronutrient deficiency as well as low soil organic C, acidity, and low available water holding capacity, the lack of capacity along the soil fertility, knowledge transfer, value chain was consistently identified as a critical barrier to improving soil fertility. Specifically, the lack of skilled public and private sector extension service providers and supporting information transfer platforms was heavily emphasized, though the lack of capacity of national agricultural research institutions, farmers and end users, soil analysis testing laboratories and technicians was also emphasized. Many survey and summit respondents prioritized capacity building for a wide range of extension services which was inclusive of IARCS, NARES, national universities, developmental agencies, NGO's, FBO's, the private sector, and farmer organizations.

Respondents clearly indicated that knowledge development and capacity building are essential strategies to improve soil fertility. Survey and summit participants identified and prioritized the need fora wide-range of well-trained public and private sector extension and service providers along with all research actors connected to regionally specific research. Emphasis was placed on expanding the capacity of this sector by improving their training and strengthening linkages between research, extension services, and farmers; expanding research, leading to improved/updated recommendations for cropping system-, site-, and region-specific conditions; increasing the capacity of local soil testing facilities or mobile platforms that can provide affordable and accurate services; increasing farmer training, with a focus on peer-training and on-farm demonstrations; and encouraging private sector investment. In order to have a significant impact on improving soil fertility, there is a strong need for more qualified professionals, supplied with location and cropping systems specific information, working directly with farmers. The public sector agencies should take the lead in creating platform that can bring the entire active partner together for effective engagement and operationalize policies and activities.

Capacity building across the entire soil fertility, knowledge transfer, value chain was strongly identified as a catalyst to both of the earlier identified themes of *strengthening inorganic fertilizer systems* and *increasing access and use of quality organic materials*. In an attempt to improve access to information on fertilizer use and the composition carbon-rich amendments, respondents recommended the need for capacity building of farmers, private and public extension service providers, and lab facilities with particular focus on connecting these groups to regional and crop specific research on inorganic and organic fertilizer amendments. The development of the private sector and enabling agricultural policies were also recommended to increase the availability of private sector service providers to deliver soil fertility management recommendations.

As such, it is our recommendation to prioritize capacity building along the entire soil fertility, knowledge transfer, value chain as part of any action plan to increase soil fertility in SSA. Past efforts have placed particular focus on creating doctoral and masters level researchers to enable knowledge creation, which is still of high priority; however, survey and summit participants also emphasized the need for greater capacity building along the entire knowledge transfer, value chain to improve the bidirectional delivery of existing knowledge to farmers and end users. Participants noted that numerous proven strategies and innovations to overcome soil fertility barriers have existed for decades yet the bidirectional dissemination of these proven innovations to farmers is limited. The knowledge transfer, value chain to and from research and farmers adds value to the original innovation, adapts the original innovation to fit regional and farmer specific parameters, and thus should be strengthened to improve soil fertility. The use of mobile platforms and information communication technologies is strongly encouraged. Further priority should be given to building the capacity of public and private extension service providers, soil analysis technicians, farmers and end users, and to institutions and physical infrastructure. This would require investing in building the number and skills of a variety of public and private extension service providers, laboratory or mobile soil testing technicians, and farmers; strengthening linkages between researchers, soil analysis facilities/mobile testing platforms, and farmers - all with the goal of increasing the adoption of proven innovations and practices by farmers.

Strengthening Farming Systems across Biophysical and Socioeconomic Factors

Farming systems concepts were routinely identified and prioritized as critical to improving soil fertility in SSA. Farming systems recommendations expanded upon the traditional biophysical farming systems strategies to include socioeconomic factors in improving soil fertility. Depending on the region, recommendations such as legume integration, crop-livestock integration, crop rotations and diversification, and agroforestry were prominent strategies for improving soil fertility. Participants also identified the need for evaluation of farming systems for synergies and tradeoffs associated with the adoption of various innovations. This farming systems and innovation assessment should consider impacts across multiple domains (productivity; economics, environment, social and human conditions). There were also numerous integrated socioeconomic strategies identified and prioritized as critical factors for improving soil fertility in SSA. Prioritized socioeconomic strategies included: empowering women to enable improved soil fertility management and decision-making; integrating access to financial resources into the farming system to improve soil fertility outcomes; ratifying appropriate policies that provide market stability for both farm inputs and outputs and enables land ownership and grazing policies that support soil fertility improvements; establishing enabling conditions for private sector investment; strengthening the soil fertility knowledge transfer value chain; and increasing access to mechanization that enables minimum tillage thereby increasing soil fertility, reducing erosion and environmental contamination. The survey and summit participants clearly prioritized both biophysical and socioeconomic factors, integrated together across the farming system to improve soil fertility.

Barriers to smallholder farming systems in improving soil fertility spanned both biophysical and socioeconomic factors. Survey and summit participants identified and prioritized limited opportunities to maintain and build soil organic C, lack of availability of inorganic fertilizers, lack of access to financial resources, and lack of access to mechanization, as critical barriers to improving soil fertility.

As such, we recommend that action plans aimed at improving soil fertility in SSA on smallholder lands take an integrated farming systems approach that encompasses both biophysical and socioeconomic methodologies. Biophysically, improved farming systems integration with legumes, livestock, and/or agroforestry, where agroecologically appropriate, can provide access to *in situ* fertilizer, quality organic materials, income resilience, nutrition and food security and resilience and as such can increase the farmer's ability to improve her/his soil fertility. Socioeconomically, increasing women's empowerment, access to financial resources, access to bidirectional knowledge transfer, access to appropriate scale mechanization, and enabling political environments were highly recommended by participants in increasing the farmer's ability to improve her/his soil fertility.

To address the soil fertility in SSA, items in all four themes should be addressed simultaneously and in combination rather than isolation. All active partners in the entire value chain from private industry, government and non-government agencies, research, education and extension services should be engaged. There is a critical need for improved linkages among partners and organizations. Public sector agencies can play a significant role in creating a platform for bringing together and linking key partners in research, education, extension, service providers, input providers, and farmers. However, there is also a need to enhanced institutional capacity across the value chains. There need to be more focus on engaging with policy makers to create enabling environment so that available resources and inputs are available to farmers and input providers.

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