FEED THE FUTURE
The U.S. Government's Global Hunger & Food Security Initiative

Feed the Future Soil Fertility Technology Adoption, Policy Reform, and Knowledge Management (RFS-SFT) Project

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October 2019 – March 2020

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Cover photos:
Farmers use a hand-washing station amid the COVID-19 pandemic during field trials in Mozambique (March 2020);
Conducting a survey of agro-dealers in Rwanda (December 2019);
Chemical analysis of fertilizers at IFDC laboratories, Muscle Shoals (January 2020)

DISCLAIMER
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List of Acronyms

AAPFCO	Association of American Plant Food Control Officials
AEZ	agroecological zone
AFAP	African Fertilizer and Agribusiness Partnership
AFO	AfricaFertilizer.org
AFRAD	Supported Crop Fertilization for Sustainable Agriculture in Niger
AFU	Agriculture and Forestry University
AgMIP	Agricultural Model Intercomparison and Improvement Project
AGRA	Alliance for a Green Revolution in Africa
AGRIFOP	Agribusiness-Focused Partnership Organization
APEX	Agricultural Policy/Environmental eXtender
ARS	Agricultural Research Service
ATT	Feed the Future Ghana Agriculture Technology Transfer Project
B	boron
BAME	*Bureau d'Analyses Macro-Économiques*
BARI	Bangladesh Agricultural Research Institute
BAU	Bangladesh Agricultural University
BRRI	Bangladesh Rice Research Institute
C	carbon
Ca	calcium
CA	conservation agriculture
CASC	Conservation Agriculture Service Center
CASCAPE	Capacity Building for Scaling up of Evidence-based Best Practices in Agricultural Production of Ethiopia
CE SAIN	Center of Excellence on Sustainable Agriculture Intensification and Nutrition
CIMMYT	International Maize and Wheat Improvement Center
CIRAD	*Centre de Coopération Internationale en Recherche Agronomique pour le Développement*
COMRAP	COMESA Regional Agricultural Inputs Programme
CT	conventional tillage
Cu	copper
DALRM	Department of Agricultural Land Resources Management
DAP	diammonium phosphate
DAT	days after transplanting
DSSAT	Decision Support System for Agrotechnology Transfer
DST	Decision Support Tool
EiA	Excellence in Agronomy
EIAR	Ethiopian Institute of Agricultural Research
EnGRAIS	Enhancing Growth through Regional Agricultural Input Systems (project)
ES	elemental sulfur
EthioSIS	Ethiopian Soil Information System
FAK	Fertilizer Association of Kenya
FAO	Food and Agriculture Organization of the United Nations
FAR	Food security through climate Adaptation and Resilience in Mozambique
FDP	fertilizer deep placement
Fe	iron

FFT	Fast Fourier Transformation
FSI+	Fertilizer Sector Improvement (project)
FTF	Feed the Future
FY	fiscal year
GDA	General Directorate of Agriculture
GHG	greenhouse gas
GSSAT	Geospatial Decision Support System for Agrotechnology Transfer
HQ	Headquarters
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IER	*Institut d'Economie Rurale*
IFA	International Fertilizer Association
IFDC	International Fertilizer Development Center
INERA	*Institut de l'Environnement et Recherches Agricoles*
INRAN	*Institut National de la Recherche Agronomique du Niger*
IRRI	International Rice Research Institute
ISFM	integrated soil fertility management
IZA	International Zinc Association
K	potassium
KALRO	Kenya Agricultural and Livestock Research Organization
KeFERT	Kenya Fertilizer Platform
KGF	Krishi Gobeshona Foundation
KMT	Kenya Markets Trust
KSU	Kansas State University
LandPKS	Land-Potential Knowledge System
LCC	Land Capability Classification
LSMS	Living Standards Measurement Study
MAP	Monoammonium Phosphate
MCA	Millennium Challenge Account
MCC	Millennium Challenge Corporation
Mg	magnesium
MoA	Ministry of Agriculture
MoALF	Ministry of Agriculture, Livestock and Fisheries
MOFA	Ministry of Food and Agriculture
MSU	Michigan State University
N	nitrogen
N_2O	nitrous oxide
NARC	Nepal Agricultural Research Council
NARCS	National Agricultural Research Council Secretariat
NARES	National Agricultural Research and Extension Systems
NIFA	National Institute of Food and Agriculture
NO	Nitrous Oxide
NSAF	Nepal Seed and Fertilizer
NTB	non-tariff barriers
NV	native vegetation
P	phosphorus
PARSEN	Fertilizer Sector Reform Support Project in Niger
PCU	polymer-coated urea

PEMEFA	Partnership for Enabling Market Environments for Fertilizer in Africa
PFP	partial factor productivity
POXC	potassium permanganate oxidizable C
PR	phosphate rock
QA	quality assurance
QC	quality control
R&D	research and development
RAE	relative agronomic effectiveness
RARI	regional agricultural research institute
RE	recovery efficiency
ReNAPRI	Regional Network of Agricultural Policy Research Institute
RFS	Bureau for Resilience and Food Security
RUA	Royal University of Agriculture
S	sulfur
SARI	Savanna Agricultural Research Institute
SFT	Soil Fertility Technology
SIL	Soybean Innovation Lab
SIIL	Innovation Lab for Collaborative Research on Sustainable Intensification
SMaRT	Soil testing, Mapping, Recommendations development, and Technology transfer
SO_4-S	sulfate
SOC	soil organic carbon
SOILS	Sustainable Opportunities for Improving Livelihoods with Soils
SRI	System of Rice Intensification
SRDI	Soil Resources Development Institute
SSA	Sub-Saharan Africa
SWAT	Soil and Water Assessment Tool
TAFAI	The African Fertilizer Access Index
TERI	The Energy and Resources Institute
TSP	triple superphosphate
UCF	University of Central Florida
UDP	urea deep placement
UDS	University for Development Studies
UF	University of Florida
UNADA	Uganda National Agro-Input Dealer Association
USAID	U.S. Agency for International Development
USDA	U.S. Department of Agriculture
WAAPP	West Africa Agricultural Productivity Program
WRB	World Reference Base
WSP	water-soluble phosphate
XRF	X-ray fluorescence
Zn	zinc
ZnO	zinc oxide
ZnO-NP	zinc oxide nanoparticle
ZOI	zone of influence

Feed the Future Soil Fertility Technology Adoption, Policy Reform, and Knowledge Management (RFS-SFT) Project

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Introduction

The International Fertilizer Development Center (IFDC) enables smallholder farmers in developing countries to increase agricultural productivity, generate economic growth, and practice environmental stewardship by enhancing their ability to manage mineral and organic fertilizers responsibly and participate profitably in input and output markets. On March 1, 2015, the U.S. Agency for International Development (USAID) and IFDC entered into a new cooperative agreement designed to more directly support the Bureau for Resilience and Food Security (RFS) objectives, particularly as related to Feed the Future (FTF).

Since 2016, IFDC's scientists and economists have contributed to USAID's cooperative agreement for Soil Fertility Technology Adoption, Policy Reform, and Knowledge Management under two workstreams specifically related to nutrient management technologies and policy reforms, with learning agendas and knowledge management as cross-cutting issues.

Since 2018, greater emphasis has been placed on coordination between field-based work in FTF countries and the support of scientists and economists from IFDC headquarters (HQ). Structural changes within IFDC are leading to more efficient communication, information, and technology flow between field research in FTF countries and HQ research. In addition to strengthening internal research efforts, IFDC, in collaboration with the Kansas State University (KSU) Feed the Future Innovation Lab for Collaborative Research on Sustainable Intensification (SIIL) and supported by USAID-RFS, initiated the Sustainable Opportunities for Improving Livelihoods with Soils (SOILS) Consortium in March 2019. The consortium focuses on conducting research in sustainable opportunities for improving livelihoods with soil fertility-related solutions with a range of likeminded academic and research partners globally.

The activities under the current work plan (FY2020) reflect three workstreams (Table 1), including SOILS Consortium-related research as Workstream 3, contributing to the FTF Soil Fertility Technology Adoption, Policy Reform, and Knowledge Management (RFS-SFT) project.

As part of the work planning process under the RFS-SFT project, since FY2019 IFDC has initiated engagement with country-level missions to obtain concurrence for research activity implementation, funded by the RFS central mechanism. So far, RFS-SFT has received concurrence from three missions – Kenya, Uganda, and Rwanda – and IFDC has regularly reported the progress of RFS-SFT activities to these missions since early 2019. For FY2020, we further plan to expand this to all other countries where we are engaged through RFS-SFT project activities: Bangladesh, Nepal, Mozambique, Zambia, Nigeria, Niger, Ghana, and Burkina Faso.

Table 1. FTF Soil Fertility Technologies (RFS-SFT) Project Workstreams

<table>
<tr><th colspan="4">Workstream 1</th><th colspan="3">Workstream 2</th><th>Workstream 3*</th></tr>
<tr><td colspan="4">Developing and Validating Sustainable Agricultural Intensification Technologies and Practices</td><td colspan="3">Supporting Policy Reform Processes, Advocacy, and Market Development</td><td>SOILS Consortium (Sustainable Opportunities for Improving Livelihoods with Soils)</td></tr>
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<tr><td>Improving Nitrogen Use Efficiency</td><td>Activated Phosphate Rock</td><td>Balanced Crop Nutrition</td><td>Sustainable Soil Intensification Practices</td><td>Documenting Policy Reforms & Market Development</td><td>Impact Studies, Assessments</td><td>Agro-Economic Studies</td><td>Identify holistic solutions, developing a roadmap toward enhancing soil fertility</td></tr>
<tr><th colspan="8">Cross-Cutting</th></tr>
<tr><td colspan="8">MELS, Knowledge & Data Management
Improving the Decision-Making Tools for Cropping System Model for Soil Sustainability Processes
University Partnerships, Capacity Building, Workshops</td></tr>
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**From March 2019 onward*

Under Workstream 1, IFDC continues "**Developing and Validating Sustainable Agricultural Intensification Technologies and Practices**," addressing nutrient management issues and advancing sustainable agricultural intensification in FTF countries. Workstream 1 activities concluding in FY2019 and those beginning in FY2020 are summarized in Section 1 and Table 9.

Under Workstream 2, IFDC supports "**Policy Reform Processes, Advocacy, and Market Development**." Relevant research will be conducted to support IFDC's global activities related to agricultural policy reforms, advocacy for change, and related efforts to achieve impact in FTF countries' agriculture. Workstream 2 activities are summarized in Section 2 and Table 10.

Under Workstream 3, IFDC supports activities under the **SOILS Consortium**, initiated by IFDC in collaboration with SIIL at KSU, with support from USAID-RFS. The SOILS Consortium also partners with a host of U.S. academic research entities from Michigan State University, University of Colorado, Auburn University, and USDA-ARS. SOILS Consortium partners will further engage in identifying research activities that offer holistic solutions to developing a roadmap toward enhancing soil fertility in selected countries. The objectives and research activities to be carried out through Workstream 3 are presented in Section 3 and Table 11.

Cross-cutting activities are described in Section 4 and Table 12. These primarily include activities associated across all three workstreams, such as monitoring, evaluation, learning, and knowledge management-related activities. Here we include data management systems and tools, outreach activities with partner organizations, training, and capacity building initiatives.

1. Workstream 1 – Developing and Validating Sustainable Agricultural Intensification Technologies and Practices

Summary

With the primary emphasis on translational research, one of the main objectives of Workstream 1 is to bridge the gap between scientific research and effective technology dissemination to smallholder farmers in Feed the Future (FTF) countries. The technology dissemination process depends on conducting research on well-characterized sites with a collection of site-specific data on soils, daily weather, socioeconomics, and management. A summary of research activities and accomplishments for the five focus areas under Workstream 1 for this reporting period is presented here, followed by more detailed reporting.

1.1 Improving Nitrogen Use Efficiency

Improving nitrogen (N) use efficiency concentrates on minimizing N losses (accounting for more than 50% of applied N fertilizer) while increasing productivity. This is accomplished by developing and disseminating alternatives to urea, the world's primary N source, including modified and coated urea products, biofertilizers and bio-stimulants, and additives of organic materials and nutrients that improve N use efficiency. Increased efficiency can also be achieved by innovative N fertilizer application practices, such as mechanized fertilizer deep placement (FDP). Coatings and granulation of urea with sulfur (S), micronutrients, and organic additives also promote balanced fertilization. With N application in Africa already low, increased efficiency of applied N is key to achieving greater productivity and profitability while minimizing environmental impacts. Activities are conducted at laboratory, greenhouse, and field scales, targeting (i) the development and evaluation of more efficient N fertilizers; (ii) resolving technology scaling constraints to FDP; and (iii) climate resilience and mitigating greenhouse gas (GHG) emissions from N fertilizers.

Accomplishments:

- Urea coated with zinc oxide (ZnO) nanoparticles and dual-capped Zn-based nanoparticles were prepared for greenhouse trials. Enhanced crop productivity with lower nano-ZnO highlights a key benefit of nanofertilizers: the reduction of nutrient inputs into agriculture without yield penalties. In addition to overcoming the potential for drift with application of nanofertilizers at field-scale, coating of urea also improved N use efficiency through reduced N loss and improved plant N uptake.
- Maize field trials conducted on sulfur-deficient soils in Bangladesh and Myanmar showed significant yield advantage of urea-elemental sulfur fertilizer over conventional S sources, such as gypsum.
- Our research team had six journal articles published on improved nitrogen use efficiency and GHG emissions.

1.2 Activated Phosphate Rock

All commercially available phosphatic (P) fertilizers contain 100% water-soluble P (WSP). However, 100% WSP achieves only 10-20% efficiency. WSP is rapidly converted to labile P, active P, or stable P pools in the soil. It can be rendered unavailable in acidic soils through fixation and in alkaline soils through calcium phosphate precipitation. In sandy soils and under high-intensity rainfall, WSP can be lost to leaching. By contrast, phosphate rock (PR) is less soluble, and its utility is limited to highly acidic soils.

Activated phosphate rock is produced by compressing or granulating phosphate rock with small amounts of WSP. In contrast to WSP and PR, activated phosphate rock is not constrained by soil conditions. The activation processes are inexpensive compared to WSP production, which requires investments of more than $1 billion, is limited to regions with very large deposits, and produces large amounts of phosphogypsum, a byproduct and disposal challenge. Activated phosphate rock can utilize smaller national deposits, greatly reducing the need to import soluble P fertilizers, and is equally effective in a wide range of soils. Activated phosphate rock activities include: (i) greenhouse and field trials; (ii) validation and promotion of activated phosphate rock using local PR resources; and (iii) development of alternative PR activation processes.

Accomplishments:

- Greenhouse trials with two low-reactivity PRs (Angola and Togo) showed that activated PR performed as well as WSP fertilizers.
- Field trials on P-responsive soils in Ghana and Western Kenya validated the greenhouse results showing no significant difference between commercially available WSP and activated PR.
- Seven on-farm demonstrations in Northern Ghana and one in Angola are in progress.
- Alternative activation processes involving calcination and grinding for improving PR reactivity has been pursued. Preliminary results indicate doubling of P content with calcination.

1.3 Balanced Crop Nutrition

Balanced crop nutrition addresses most soil-deficient nutrients and soil problems, such as acidity, alkalinity, salinity, and moderate drought. Most SSA farmers only have access to NP and NPK fertilizers, but landscape-level soil analyses by IFDC and others have indicated widespread deficiencies of other nutrients – S, zinc (Zn) and boron (B) – as well as acidity constraints and associated deficiencies of calcium (Ca) and magnesium (Mg). These nutrients are inexpensive in general to supply because they are required in smaller quantities relative to N, P, and K and can have major impacts on crop yields. Research to date indicates that multiple deficiencies of secondary and micronutrients are the norm rather than the exception and must be addressed simultaneously to optimize fertilizer response. Secondary and micronutrients may be added as granules in blends, incorporated as coatings on NPK granules, or incorporated into the NPK granules; however, the relative efficiencies of these different methods are not completely understood. In addition, the different characteristics of micronutrients (chemical composition, hardness, and fineness) affect their efficacy.

Activities focus on: (i) demonstrating improved returns to balanced crop nutrition; (ii) developing cost-effective ways of adding nutrients to NPK fertilizers; and (iii) evaluating and developing accurate and cost-effective soil testing methods to identify multiple soil nutrition constraints.

Accomplishments:

- Micronutrient-coated urea, diammonium phosphate (DAP), and monoammonium phosphate (MAP) were produced under lab and "field/garage" conditions. Abrasion tests and other physical property tests are being conducted.
- Greenhouse evaluation of urea coated with ZnO and zinc sulfate ($ZnSO_4$) gave similar sorghum grain yield and Zn uptake as urea and blends of Zn uniformly applied. These results confirmed urea-Zn interactions within the coated urea granule did not reduce plant availability of Zn.
- In a moderate drought study, fertilization with organic manure and ZnO ameliorated drought effect on greenhouse wheat yield, phenological development, and nutrient uptake.
- Nutrient omission and balanced fertilization trails from Bangladesh, Ghana, Kenya, and Nepal highlighted significant yield advantage of balanced fertilization, either as blends or compounds, over NPK. Compared to the "balanced" fertilizer treatments, the omission of S (minus S treatment) reduced the maize grain yields by >30%, omission of Zn resulted in an average of ~24% yield reduction, and B omission resulted in an average of ~11% yield reduction.
- Utilizing IFDC's large fertilizer collection, X-ray fluorescence (XRF) results when compared with wet-chemistry results gave R^2 values of 0.99 to 0.85 for K, Mg, S, Cl, Ca, Cr, Fe, Co, Cu, Zn, Mn, Ni, Mo, As, Se, and Pb.

1.4 Sustainable Intensification Practices

Poor crop residue and fallow management, excessive tillage, over-grazing, and monocropping result in soil degradation, particularly on soils inherently low in organic matter and are having severe environmental impacts in South and South-East Asia and SSA. Integrated soil fertility management (ISFM) and conservation agriculture (CA) practices can be employed to reduce and reverse this degradation and build healthy soils for improved production and environmental services. Sustainable intensification practices combine ISFM, CA, and alternative organic amendments, biofertilizers, and bio-stimulants to develop climate-smart cropping systems.

Accomplishments:

- Synergistic benefits of CA and ISFM practices were observed on maize grain yield. In general, grain yields from the treatments with CA practices were 30-45% greater than grain yields from the treatments without CA practices. Under both CA and conventional tillage (CT), activated PR performed equally as good as DAP.
- Maize grain yield and grain protein content were significantly higher with urea-elemental S application than with gypsum (conventional S source).

- Soil carbon buildup was higher under CA than CT as evident from higher values of potassium permanganate oxidizable C and soil respiration.
- On average under CA management, rice yield was 3,230 kg/ha compared with CT (2,846 kg/ha), an increase of 380 kg/ha (monetary equivalent of $114/ha).

Detailed reporting of Workstream 1 follows.

1.1 Improving Nitrogen Use Efficiency

The major focus of this activity is improving nitrogen (N) use efficiency by minimizing N losses while increasing productivity.

1.1.1 Development and Evaluation of Enhanced Efficiency N Fertilizers

Development of smart fertilizers that are climate-responsive, enhance climate-resilience, require one-time application, have high N use efficiency, and reduce reactive N and phosphorus (P) additions to the environment is one of the major focuses of the following sub-activities. Promising enhanced efficiency products already available or soon to be released in the market, including urea-ammonium sulfate, urea-S, urea-Zn, urea-B, Agrotain-coated urea, and controlled-release urea products, are being evaluated under field conditions in sub-Saharan Africa (SSA) and South Asia. These enhanced efficiency fertilizers are ideally suited for farmers in the focus countries since they face greater climatic vulnerability than their counterparts in developed countries.

A. Developing enhanced efficiency N fertilizers

The objective of this activity is to develop enhanced efficiency N fertilizers using agricultural wastes, alternative renewable and biodegradable materials, and alternative slower release fertilizers and amendments, such as PR, ES, Zn, B, polyhalites, and urea polymers as coating material. One such product will be urea coated with capped ZnO nanoparticles.

The laboratory and greenhouse formulation and characterization of products are conducted in partnership with the University of Central Florida (UCF). The activity for FY2020 includes private sector partners and The Energy and Resources Institute (TERI)-Deakin Nanobiotechnology Center, India. Specific activities include product formulation, nutrient release in water, nutrient release during soil incubation, and quantifying volatilization and leaching losses.

Progress:

Enhanced efficiency urea: an innovative approach to systemic delivery of Zn micronutrient

To prepare nanoparticles' suspensions for coating urea in a fluidized bed, we were able to increase the concentration of zinc in the stock suspension to 20,000 ppm metallic Zn. This increase in concentration did not affect the stability of the suspensions since the capping agent/metal ratio was kept the same. Suspensions were supplied as prepared to support the coating process at IFDC.

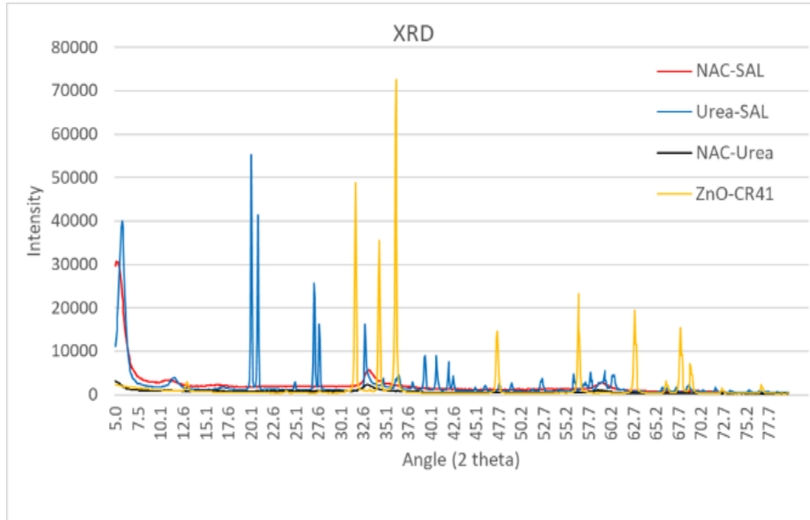

Figure 1. Diffractogram of dual capped Zn-based nanoparticles.

X-ray diffraction (XRD) analysis of dual coated nanoparticle powder was performed in order to evaluate the crystallinity of the nanomaterials. Powder samples were obtained by lyophilization. The washing procedure was repeated five times. Figure 1 shows the diffractograms of all samples. Urea-SAL capped nanoparticles showed more defined and intense peaks compared to NAC-SAL and NAC-urea samples. However, for all samples, the XRD peaks did not match bulk ZnO CR-41 diffraction peaks.

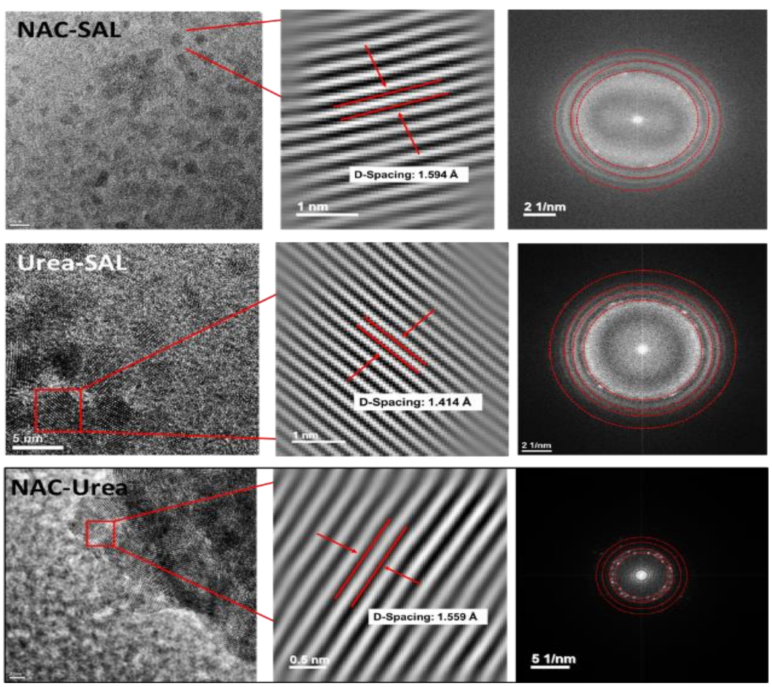

Figure 2. HR-TEM images for dual capped Zn-based nanoparticles.

As the XRD analysis was inconclusive, in order to determine the crystallinity pattern of the dual capped Zn-based nanoparticles, HR-TEM Fast Fourier Transform (FFT) analysis was performed (Figure 2). According to the crystal lattice distances (d-spacing), it was possible to match the crystalline structure of the samples with Wulfingite zinc hydroxide (Table 2).

Table 2. FFT convolution results of dual capped Zn-based nanoparticles.

Sample	(h k l)	Angle	Wulfingite Zn $(OH)_2$
NAC-SAL	(2 1 1)	2.86 Å	2.72 Å
	(3 1 1)	2.20 Å	2.21 Å
	(2 2 1)	2.02 Å	2.01 Å
	(1 3 1)	1.59 Å	1.59 Å
Urea-SAL	(2 1 1)	2.73 Å	2.72 Å
	(0 2 1)	2.29 Å	2.28 Å
	(2 2 1)	2.02 Å	2.01 Å
	(4 0 2)	1.6 Å	1.6 Å
	(5 2 0)	1.41 Å	1.41 Å
NAC-Urea	(2 1 1)	2.92 Å	2.72 Å
	(0 2 0)	2.58 Å	2.58 Å
	(4 1 1)	1.83 Å	1.82 Å
	(1 3 0)	1.68 Å	1.68 Å
	(4 1 1)	1.56 Å	1.55 Å

Facile coating of urea with low-dose ZnO nanoparticles promotes wheat performance and enhances Zn uptake under drought stress

Zinc oxide nanoparticles (ZnO-NPs) are promising novel fertilizer nutrients. However, their ultra-small size hinders large-scale field application due to potential for drift. Thus, as a delivery mechanism, urea was coated with ZnO-NPs (1%; low) or bulk ZnO (2%; high) and evaluated in wheat in a greenhouse, under drought and non-drought conditions, in comparison with plain urea and urea with separate ZnO-NP or bulk ZnO amendment. This study is published and can be accessed at https://www.frontiersin.org/articles/10.3389/fpls.2020.00168/full. Briefly, ZnO-NPs and bulk-ZnO showed similar urea coating efficiencies at 74-75%. Drought delayed panicle emergence and reduced grain yield and Zn uptake. Contrarily, ZnO-NPs accelerated panicle emergence, irrespective of coating, whereas bulk ZnO did not affect panicle emergence. Grain yield increase was 51% or 39% with ZnO-NP-coated or uncoated urea, respectively, compared to control, while that from the bulk products was minimal, compared to the control. Zn uptake increased 24% or 8% with coated or uncoated ZnO-NPs, respectively, and 78% or 10% with coated or uncoated bulk-ZnO, respectively. Coating urea with ZnO-NPs demonstrably enhances plant performance and Zn accumulation, potentiating field-scale deployment of nano-scale Zn. Notably, lower Zn input from ZnO-NPs enhanced crop productivity, comparable to higher input from bulk-ZnO, highlighting a key benefit of nanofertilizers: the reduction of nutrient inputs into agriculture without yield penalties.

Nano-Zinc-Coated Urea Fertilizer for Efficient Delivery of Zinc Micronutrients

IFDC and UCF have partnered to develop nano-zinc-coated urea fertilizer, both for the efficient delivery of Zn and for improving N use efficiency in crops. Using capped ZnO-NPs synthesized at UCF, capped ZnO-NP-coated urea at 1% and 3% Zn-to-urea ratios has been produced. Greenhouse evaluation on sorghum with the objective of quantifying the effect of the urea-zinc products, compared to conventional zinc sources (bulk zinc oxide and zinc sulfate) on biomass production, grain yield, and shoot and grain Zn, N, and P accumulation is planned for late April. Upon completion of activities, the results will be disseminated in conferences and peer-reviewed publications. Any new intellectual property resulting from this innovative project will be evaluated by UCF and IFDC for joint ownership.

B. Field evaluation of existing enhanced efficiency N fertilizers and technologies for improved yield and reduced N pollution (Ongoing)

Field trials are ongoing in Bangladesh, Ghana, Nepal, and Myanmar (FY2017-18 funds) comparing modified urea products with conventional urea and UDP in upland crops and lowland rice systems. The proposed trials will be completed by September 2020. Field activities will be conducted in partnership with input and service providers, farmers, local universities, and Africa Research In Sustainable Intensification for Next Generation (Africa RISING), and with cost-sharing from the Feed the Future Nepal Seed and Fertilizer (NSAF) project and the private sector. Except for Myanmar, officials of the ministries of agriculture in the other countries will be engaged in dissemination.

Progress:

Bangladesh: As a follow up to last season's maize trial, two additional maize trials were established for rabi maize in December 2019 with sulfur-enriched urea fertilizers in sulfur-deficient areas of Bangladesh (Figure 3). The treatments (1-5) include all limiting nutrients at recommended rates with the following S sources applied at 50 kg S/ha – Thiogro ES 13%, Thiogro ES 75%, gypsum, Thiogro ESS 13%, and ammonium sulfate; (6) all limiting nutrients at recommended rates minus S; (7) NPK recommended rate; (8) farmer practice; (9) all limiting nutrients at recommended rates with NPKSB as S source; and (10-11) Thiogro ES13% at 25 and 75 kg S/ha, respectively. The trials were laid out in a randomized complete block design with four replications. In both the trials, maize crop is at flowering stage. The tentative harvest date is end of May 2020. Lab analysis of harvested plant and soil samples will take 1-2 months; however, analysis may be delayed if the COVID-19 situation continues beyond May 2020.

Figure 3. Evaluation of urea-sulfur fertilizers in the North-West part of Bangladesh (sulfur-deficient site).

Results of the past season's field trials showed that application of S fertilizers had additive effect on the grain yield, protein content, and S concentration, with an increase of up to 12%, 34%, and 26%, respectively, over farmer practice (Figure 4). Among the different sulfur sources, significantly higher output (biomass S or N uptake), RE (apparent recovery efficiency of applied S), and PFP (partial factor productivity of applied N or S) were observed in ES 13% and ES 75% compared to gypsum and ESS 13%.

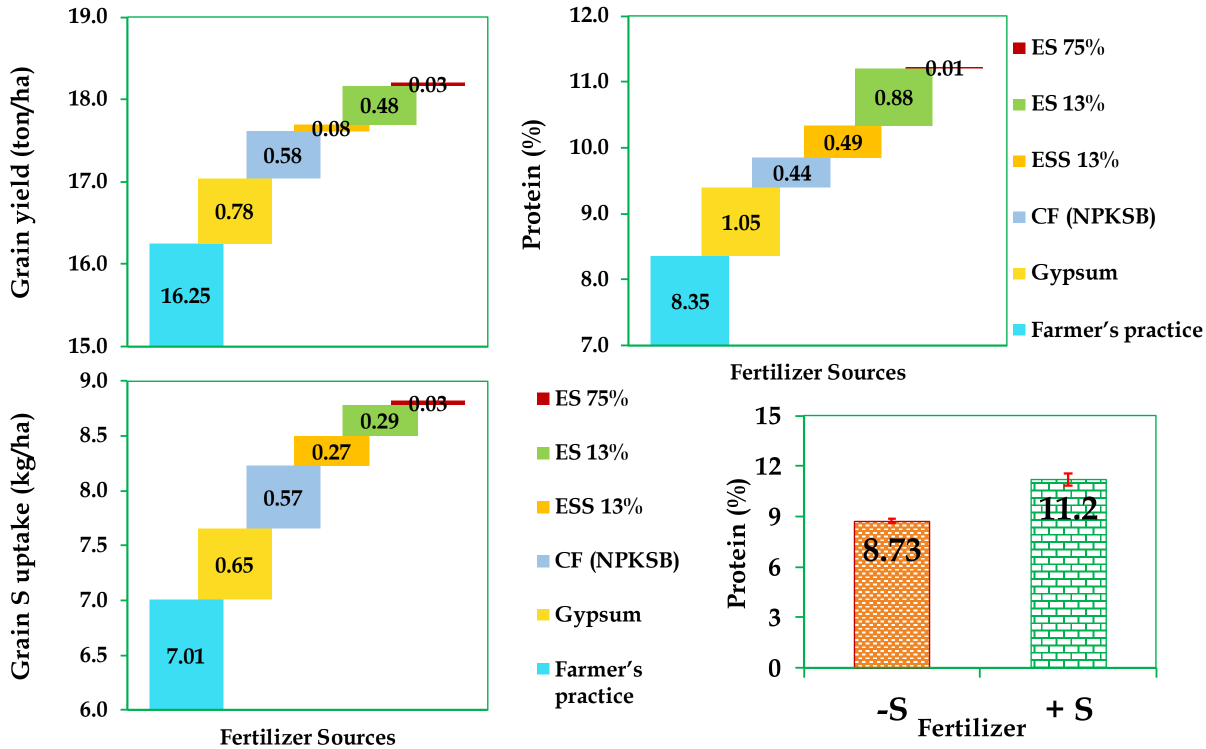

Figure 4. Effects of sulfur-enriched urea fertilizers on maize grain yields, protein (%), and S contents across two locations in Northern Bangladesh.

Myanmar: S source trials on maize were conducted at two locations – Aungban and Inn Pet Let. The following six treatments were evaluated under randomized complete block design with four replications:

1. Farmer practice (75:19:19 kg N, P_2O5 and K_2O/ha)
2. All limiting nutrients at recommended rates minus S (200:110:120 kg N, P_2O_5, and K_2O/ha plus 20 kg Mg, 25 kg Ca, 3 kg Zn, and 4 kg B per hectare)
3. Same as (2) with 50 kg S/ha as Thiogro ES 13%
4. Same as (2) with 50 kg S/ha as Thiogro ESS 13%.
5. Same as (2) with 50 kg S/ha as Thiogro ES 75%.
6. Same as (2) with 50 kg S/ha as locally available Gypsum.

At Aungban, S application resulted in a significant increase in maize grain yield compared to farmer practice and S check (Figure 5). At Inn Pet Let, S was not limiting; however, a significant increase in yield over farmer practice was observed due to balanced fertilization. The high soil S content at Inn Pet Let was reflected in significantly higher grain and plant tissue S content than at Aungban.

Preliminary results from S rate trials (0, 25, 50, and 75 kg S/ha) applied as Thiogro ES13% conducted at Kyauk Htat, Kalaw township, and Taung Pu Lwin, Pindaya township, in Shan State also showed no response to S. However, at both locations, farmer practice gave significantly lower maize yield with imbalanced fertilization (NPK only).

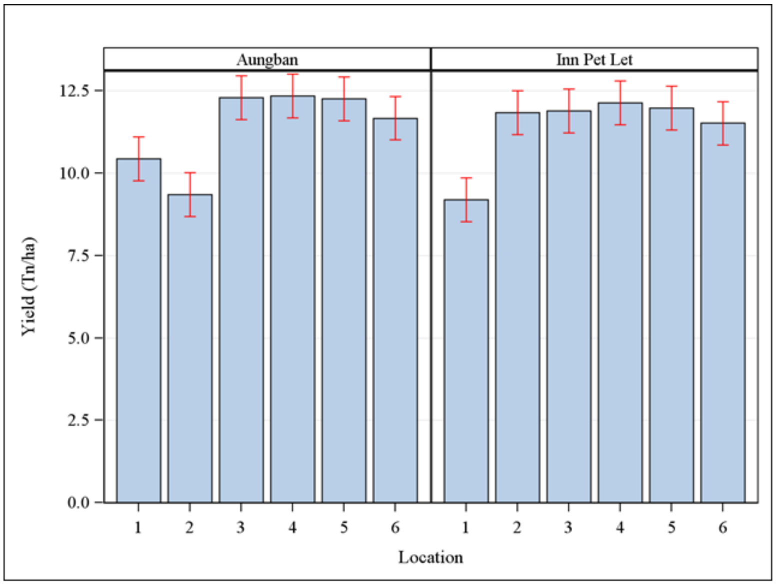

Figure 5. Effect of S source and farmer practice treatments (x-axis) on maize grain yield at Aungban and Inn Pet Let, Myanmar.

1.1.2 Scaling Fertilizer Deep Placement (FDP) Technology for Granular and Briquette Fertilizers (Ongoing)

While the benefits of FDP are well-documented, scaling has been slow. To date, the primary model for FDP has been compacting urea and urea-containing fertilizers into briquettes at the agro-dealer level, and applying the briquettes either by hand or mechanically. This model has several constraints; the most limiting factor for scaling of FDP is the applicator. Briquette deep placement is a slow, tedious process, which limits its adoption by large-scale farms or where labor availability is low or labor costs are high.

Progress:

1. A manual injector-type applicator with adjustable volume has been developed. We intend to test it in Kenya in July, provided travel is not restricted.
2. Combined seed and subsurface fertilizer applicator for dryland crops developed by National Agro Machinery Industries, Ludhiana, is being evaluated in Myanmar with request for changes relayed to the manufacturer.
3. Transplanter/FDP applicator development by Mississippi State University is expected to be completed by September 2020.
4. Bangladesh: Trials using a mechanized FDP applicator, in partnership with the Bangladesh Rice Research Institute (BRRI) and the private sector, have been postponed until next boro season and FY2021 workplan period, viz., November-December 2020 with delays in Mission concurrence as well as COVID-19-related shutdown.

1.1.3 Climate Resilience and Mitigating GHG Emissions

Fertilizers play a unique role in both emitting and sequestering greenhouse gases and improving crop resilience to abiotic and biotic stresses. The proposed activities will highlight the resilience and GHG mitigation features of deep placement technology in improving crop yields under adverse environments.

A. Mitigating GHG emissions from rice-based cropping systems through efficient fertilizer and water management (Ongoing)

Results generated from 2013-2019 GHG trials in Bangladesh and IFDC HQ are being used to evaluate soil carbon (C), soil N, and GHG modules of the Decision Support System for Agrotechnology Transfer (DSSAT) model (see Section 1.5). In addition, through partnership with Krishi Gobeshona Foundation (KGF), the GHG emission methodology will be extended to on-farm trials.

Progress:

A research proposal has been submitted to KGF in partnership with Bangladesh Agricultural University (BAU) for extending the GHG mitigation research activities into different agroecological zones (AEZs) of Bangladesh. The activities may be postponed or canceled as KGF has not yet approved the BAU-IFDC proposal.

B. Increasing fertilizer use efficiency and resilience in saline soils (New)

About 1 million hectares of arable land in Bangladesh are affected by salinity (53% of the coastal zone) in different forms. Cropping intensity in the coastal zone is low at 133% compared to the national average of 192% (about two crops per season). Salinity causes unfavorable environmental and hydrological conditions that restrict normal crop production throughout the year. Fertilizer use efficiency has to be improved in order to increase productivity of salt-tolerant crops. The proposed research evaluates different customized compound fertilizers (including secondary and micronutrients) along with organic amendments for enhancing soil fertility, crop productivity, and farm profitability.

Progress:

Two field experiments were established in January 2020 on salinity-affected areas of Bangladesh in partnership with BRRI (Figure 6). In these field experiments, two varieties of *Boro* rice (BRRI dhan67 [salinity resistant] and BRRI dhan88 [farmer choice]) were tested with six treatment combinations: UDP, customized fertilizers, gypsum, and organic amendments (ash and cow dung). The experiment was laid out in a split-plot design, distributing the variety to the main plots and treatments to the sub-plots, with three replications. Soil amendments (cow dung and ash) were applied three days prior to transplanting. Urea briquettes were placed at a depth of 10 cm at the center of four rice hills 10 days after transplanting (DAT). Prilled urea was applied in three equal splits at 7, 35, and 55 DAT, respectively.

The rice crop is at ripening growth stage. The tentative harvest date is mid-May 2020. Lab analysis of harvested plant and soil samples will be taken within two months; however, analysis may be delayed if the COVID-19 situation continues beyond May 2020.

Figure 6. Saline soil management trials in the South-West part of Bangladesh.

C. Adapting balanced subsurface fertilizer management (NP, NPK briquette) to intensive rice cropping systems (SRI) in Burkina Faso (Ongoing)

This is an ongoing activity that started in March 2019 in partnership with *Institut de l'Environnement et de Recherches Agricoles* (INERA) in Burkina Faso and *Institut d'Economie Rurale* (IER) in Mali to adapt the use of multi-nutrient FDP briquettes to SRI under flooded and alternate wetting and drying (AWD) conditions.

Progress:

The AWD SRI trials in Burkina Faso were completed and presented in the last report. A split-plot design was used, with continuous flooding and AWD as the main plot factors and five subplot treatments as given in Table 3. The AWD SRI trials in Mali have been completed and the results showed no statistical difference between the AWD and the continuous flooding through irrigation, although the AWD resulted in slightly higher paddy yield (Table 3). Technical issues preventing proper control of water supply during the growing season were reported, which had a major impact on the overall performance of the trials.

Table 3. Irrigated rice grain yield and biomass as affected by fertilizer treatments under continuous flooding and alternate wetting and drying in Mali

Treatment Factors	Grain Yield (kg/ha)	Biomass (kg/ha)
SRI with no mineral fertilizer	3,307c*	14,556c
SRI with half of basal NPK fertilizer recommendation + 72 kg of urea (broadcast) 6 weeks after transplanting	4,278b	16,466bc
SRI with half of basal NPK fertilizer recommendation + UDP (one 1.8-g urea supergranule per 4 plants 7-10 days after transplanting = 72 kg urea per ha)	4,302b	17,792b
SRI with half of basal NPK fertilizer recommendation + 113 kg of urea (broadcast) 6 weeks after transplanting	4,529ab	16,381bc
Conventional transplanting (3-4-week seedlings, 1-2 plants/hill, 20 cm x 20 cm) with half of basal NPK fertilizer recommendation, with one 1.8-g urea supergranule per 4 hills	5,082a	21,463a
Continuous flooding	4,187	17,694
Alternate wetting and drying	4,412	16,969

* For each factor, means followed by the same letter within each column are not statistically different at $P<0.05$

Multi-nutrient FDP: In Burkina Faso, the multi-nutrient FDP briquette activities have been scheduled for the normal winter season of June 2020. The COVID-19 pandemic is likely to affect smooth implementation of this activity. Therefore, before engaging in an agreement, INERA was asked to propose an adaptive plan that will ensure that the trials, if initiated, would be completed as anticipated in December 2020.

In Mali, under irrigated conditions, the multi-nutrient FDP trials showed higher paddy yield with one-time placement of two NPK + Zn briquettes (T5), whereas placement of two NPK briquettes (T4) performed equally well as the conventional UDP (basal NPK fertilizer + urea briquette one week after transplanting) (Table 4). These results suggest that fertilizer application in paddy rice could be simplified as a one-time deep placement of briquettes of appropriate multi-nutrient fertilizers.

Table 4. Rice plant height, grain yield, and biomass as affected by fertilizer treatments in irrigated system in Mali.

	Plant Height (cm)	Grain Yield (kg/ha)	Biomass (kg/ha)
T1: Control	86c*	2,531b	3,653b
T2: Conventional recommendation, basal NPK at land preparation, and urea broadcast (6-8 weeks after transplanting) = 126 kg/ha N; 34 kg/ha P_2O_5; 34 kg/ha K_2O	91b	3,223a	4,714ab
T3: Basal application of recommended NPK at land preparation + UDP (1.8-g urea briquette for 4 plants = 112.5 kg/ha 7-10 days after transplanting) = 86 kg /ha N, 34 kg/ha P_2O_5, and 34 kg/ha K_2O	92ab	3,064a	5,080a
T4: UDP, two 2.4-g NPK 33-12-8 briquettes for 4 plants (placed 7-10 cm deep, 7-10 days after transplanting) = 99 kg/ha N, 36 kg/ha P_2O_5 and 24 kg/ha K_2O	94ab	3,277a	4,610ab
T5: FDP, two 2.4 g NPK 33-12-8 + 1.9 Zn equivalent to 99 kg/ha N, 36 kg/ha P_2O_5, 24 kg/ha K_2O and 4.7 kg/ha Zn	94a	3,338a	5,380a

* Means followed by the same letter within each column are not statistically different at $P<0.05$

1.2 Activated Phosphate Rock

Activated PR is produced by compressing or granulating phosphate rock with low amounts of water-soluble P sources, such as diammonium phosphate (DAP) or monoammonium phosphate (MAP). Activated PR activities included: (i) greenhouse and field trials; (ii) validation and promotion of activated PR using local PR resources; and (iii) development of alternative PR activation processes.

1.2.1 Activated Phosphate Rock Trials under Greenhouse and Field Conditions (Ongoing)

Ongoing greenhouse and field trials are evaluating the performance of activated PRs from Togo and Angola against conventional P fertilizers, such as DAP, MAP, and triple superphosphate (TSP). To evaluate the long-term potential of activated PR, residual PR trials are planned (ongoing) under both field and greenhouse conditions. The results from the field trials in Kenya and Ghana using activated PR from Togo and the greenhouse trials with Togolese and Angolan PR are reported here.

Partnership: Private sector, University for Development Studies (UDS), Savanna Agricultural Research Institute (SARI), and local agricultural extension agents.

Progress:

Greenhouse studies conducted over the years using soils of different physico-chemical characteristic and multiple crops suggest that activated PR (a combination of a modest amount of DAP or MAP with PR) could be a cost-effective means of enhancing P availability in PRs without the usual soil pH constraint on the agronomic effectiveness of PRs. While the residual benefits of PR application over WSP sources has been known, the activated PR significantly improves PR response during the first season of application. Overall, the greenhouse findings for

Togo and Angola PR, representing low reactivity PRs from SSA, show activation was both agronomically and economically effective.

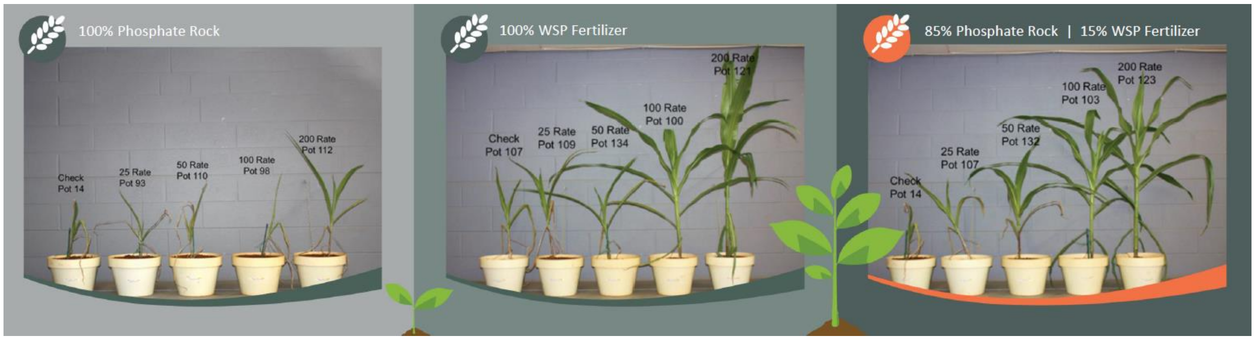

Figure 7. Maize response to Angolan PR, water soluble P (MAP), activated PR (Angolan PR+MAP).

Field trials were conducted during FY2018-19 to validate the greenhouse results on the effectiveness of the "activated" PR under field conditions in Northern Ghana and Western Kenya. The field trials were conducted with the engagement of the University for Development Studies (UDS), Savanna Agricultural Research Institute (SARI), private agro-input dealers, and local agricultural extension agents. During the last quarter of FY2019, we established follow-up activated PR trials across the entire savanna (Sudan and Guinea savanna) agroecological zones of Ghana to validate the results obtained during the Year 1 field study. As with the Year 1 study, we used maize and soybean as test crops. For maize, the trials were conducted in soils with strongly acidic, moderately acidic, and near-neutral pH levels, whereas the soybean trials were established in soils with near-neutral pH levels. The follow-up trials were harvested during the months of November and December 2019.

Apart from three cases in which DAP was significantly more effective than the activated PR, generally, the results of the Year 2 trials were not significantly different from the results obtained in Year 1. Results across the 15 locations show that "activating" PR with a modest amount (20%) of WSP increased its effectiveness by increasing grain yield about twofold in acidic soils and greater than threefold in near-neutral soil, making PR as effective as the water-soluble P (Figure 8). In the strongly acidic soils, the relative agronomic effectiveness (RAE) of the activated PR was on average >3% more than DAP, with the raw PR product being ~36% as effective as DAP. However, in the near-neutral soil pH, the activated PR was ~76% as effective as DAP, whereas the raw PR was <3% as effective as DAP.

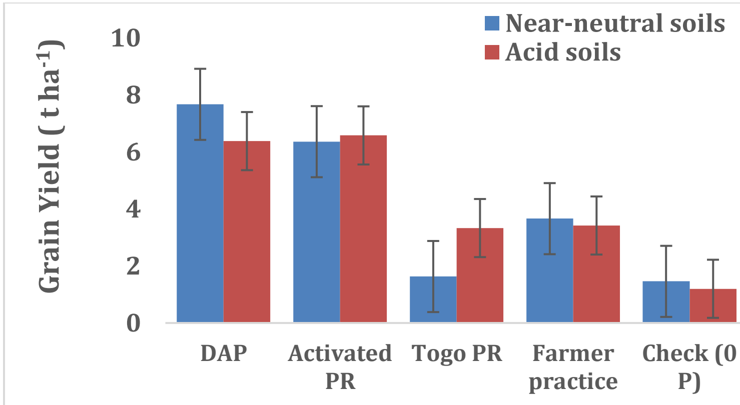

Figure 8. Average maize grain yield of P sources tested in acidic and near-neutral soils.

Similarly, for the soybean crops based on RAE, on average the activated PR products were >80% as effective as TSP, whereas the raw PR was ~32% as effective as TSP. In addition, the results showed that, for both crops, the effects of soil pH on P availability observed for the raw PR was eliminated when the activated PR products were used, because yields were comparable regardless of soil pH, similar to the observation in Year 1 trials. From the combined results, we conclude that incorporating a modest amount (20%) of WSP into raw PR will significantly increase the agronomic effectiveness of an otherwise unreactive PR for direct application to increase productivity of smallholder farmers in SSA.

Due to the COVID-19 pandemic, plant tissue analyses to determine nutrient uptake from selected plots have been put on hold. After determining plant nutrient uptake, we will use economic and statistical models to determine economically optimum activated PR rates. Also, we planned to conduct a stakeholder workshop (involving key public and private sector players) to discuss the two-year trial results and fathom a way forward for activated PR production vis-à-vis importation of WSP for farmers in the region, but this activity has also been put on hold due to the COVID-19 pandemic.

Table 5 shows response to DAP, PR, and various activated PR treatments from Western Kenya. Despite all soil testing from low to very low in Mehlich-3 P, yields were quite high, possibly in response consistent rains throughout the season. Yields were inconsistent, with the first two sites (Table 5) yielding comparably to DAP, while the third and the fifth sites yielded similarly to the no-P control. Averaged across all five sites, the activated PR treatments (with and without urea) were not statistically different from the PR and control treatments, though yield averages were greater. Likewise, the yields of activated PR treatments were not significantly different from DAP. The results were influenced by good P availability in spite of seemingly low soil P levels. Ear leaf analysis did not indicate P deficiency, and the total P uptake in the total biomass (grains, cobs, and stover) was comparable to P uptake in the same components from 10 mt/ha yields from literature values from North America.

Table 5. Maize yield (at 13% moisture content) in response to PR and activated PR treatments at farmer field sites in Western Kenya.

County	Uasin Gishu		Trans Nzoia		Uasin Gishu		Uasin Gishu		Bungoma		Across Sites	
Farmer Name	Kisiero		Lunani		Koech		Kiplagat		Motia			
Treatment	(mt/ha)											
DAP	10.60	a	9.27	a	7.48	a	9.00	a	6.68	a	8.61	a
DAP:PR 20/80	10.25	ab	9.30	a	6.37	b	8.09	ab	3.80	b	7.56	ab
DAP:PR w 9.1% urea	9.80	ab	9.15	a	6.40	b	8.01	ab	5.26	ab	7.72	ab
Togo PR + DAP (uncompacted)	9.33	ab	8.49	a	6.70	ab	7.46	b	5.32	ab	7.46	ab
Togo PR (uncompacted)	9.09	b	8.18	a	6.69	ab	7.85	ab	4.81	ab	7.32	b
No-P control	9.15	b	8.10	a	7.02	ab	7.27	b	4.48	ab	7.20	b
LSD (0.05)	1.43		1.27		0.86		1.39		2.24		1.16	

1.2.2 Validating and Promoting Activated PR using Local PR Sources and Producers (Linked with Workstream 3) (New)

PR and activated PR demonstrations will be conducted on soils of varying pH to further validate the role of activated PR as an alternative to WSP fertilizers. These trials will also serve to capture the interest of local PR producers and national governments.

Partnership: Local PR producers/miners, NARES, SOILS Consortium, and IFDC's Pilot Plant

Progress:

During FY2019-20, we established seven on-farm demonstrations within the savanna agroecological zones of northern Ghana, which fall within the zone of influence (ZOI) of the USAID FTF interventions, to show the agronomic effectiveness of the activated PR. The demonstrations were conducted in collaboration with key agro-input dealers in northern Ghana, government and private agricultural extension officers, and key stakeholders in the fertilizer value chain. The specific locations of demonstrations and the crops utilized for testing are presented in Table 6. In each demonstration plot, we compared the agronomic effectiveness of activated PR with raw "untreated" PR and WSP (either DAP or TSP, depending on the local availability). Three field days were planned for each location: (i) Planting Field Day, (ii) Green Field Day, and (iii) Brown Field Day. The first two field days were conducted in the previous reporting period, and the brown field day was held at crop harvesting time in November-December 2019.

Table 6. Attendance of the brown field days of the activated PR demonstrations.

Location	Latitude	Longitude	Date	Total	Distribution					
					Gender		Stakeholders			
					Female	Male	Farmers	Extension Agents	Agro-Input Dealers	Others
Mankpan	8.8994 N	0.1224 E	11/14/2019	43	14	29	30	2	3	8
Jeffisi	10.719 N	2.2281 W	11/16/2019	57	16	41	42	1	5	9
Kpachie	9.4791 N	1.4335 E	11/19/2019	54	21	33	37	2	4	11
Chuchuliga	9.3514 N	0.7276 E	11/22/2019	58	21	37	41	2	6	9
Kulmasa	9.8250 N	2.5161 W	11/28/2019	56	24	32	39	2	6	9
Yendi	9.4325 N	0.0042 W	12/10/2019	44	16	28	30	2	4	8
Pusu Mamongo	10.738 N	0.8521 E	12/13/2019	53	22	31	38	2	4	9

A field trial in Angola was established in December 2019 at Huambo with 13 treatments:

- Control.
- 100% Phosphate Rock (50, 100, and 150 kg P_2O_5/ha).
- Blend A 85% Phosphate Rock(50, 100, and 150 kg P_2O_5/ha).
- Blend B 75% Phosphate Rock (50, 100, and 150 kg P_2O_5/ha).
- 100% MAP (50, 100, and 150 kg P_2O_5/ha).

Preliminary results based on visual grading at seven weeks after planting showed dominance of MAP > Blends > PR > Control (Figure 9).

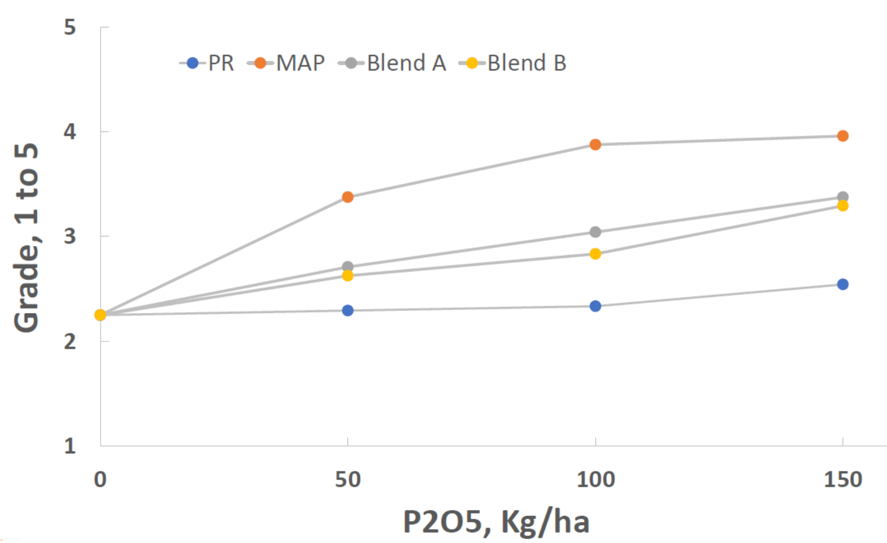

Figure 9. Maize response to P application by grade, Huambo, January 28, 2020.

1.2.3 Alternative Activation Process for Enhanced Efficiency P Fertilizers (New)

Current phosphatic fertilizers and fertilizer production processes are inefficient and result in poor use efficiency of PR, a finite essential resource. In addition to waste of P, large amounts of undesirable byproducts are generated during phosphatic fertilizer production, which poses a disposal problem. Expanding on our activated PR findings, laboratory and greenhouse research are being conducted to investigate alternative "activation" processes using bio-organic acids, biofertilizers, and bio-nanotechnology. This research will also provide opportunities to remediate heavy metals from phosphatic fertilizers.

Partnership: Private sector, TERI-Deakin Nanobiotechnology Center.

Progress:

PR from Angola was calcined at 400-1000°C as an alternative activation process. Calcination resulted in a decrease in surface area, which may have reduced the reactivity of the calcined PR. On the other hand, calcination may improve reactivity with lower loss on ignition (Figure 10). Calcination also led to a significant increase in total P_2O_5 content of the PR from 32.8% to 63.0%. Next, citrate solubility P will be determined to quantify the effect of calcination on available P. Full results will be available by next reporting.

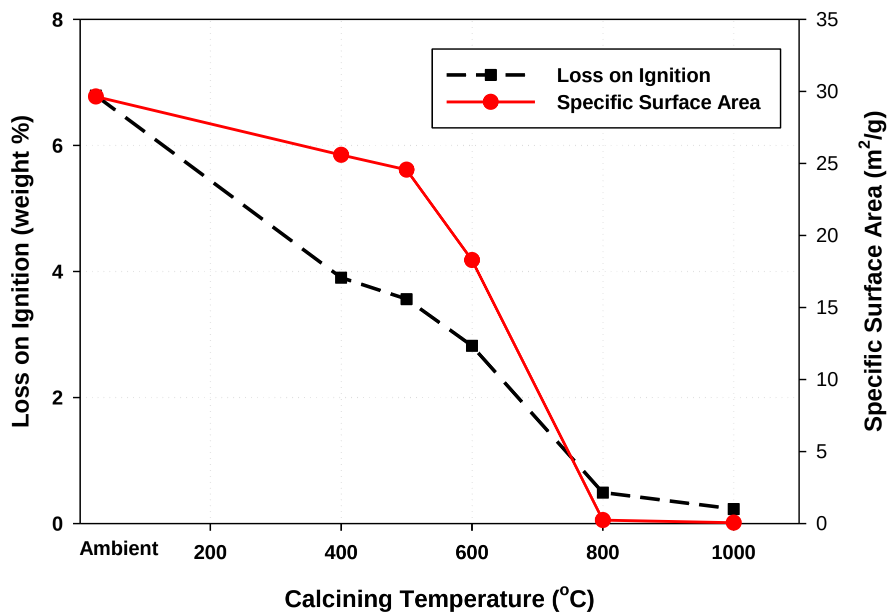

Figure 10. Effect of calcination on loss on ignition and specific surface area of PR.

1.3 Balanced Crop Nutrition for Site-Specific Fertilizer Recommendations

Balanced crop nutrition can address most soil-deficient nutrients and soil problems, such as acidity, alkalinity, salinity, and moderate drought. Most sub-Saharan African farmers have access to only NP and NPK fertilizers, but landscape-level soil analyses by IFDC and others have indicated widespread deficiencies of other nutrients, including S, Zn, and B, as well as acidity constraints and associated deficiencies of calcium (Ca) and magnesium (Mg). Secondary and micronutrients may be added separately in blends, incorporated as coatings on NPK granules, or incorporated into the NPK granules; however, the relative efficiencies of these different methods are not completely understood. In addition, the different forms of micronutrients (chemical composition, hardness, and fineness) affect their efficacy. The proposed activities highlight the importance of balanced-nutrient fertilizers and fertilization and the most cost-effective and efficient ways of delivering these nutrients to maximize nutrient use efficiency, productivity and, thus, profitability.

All field trials will include collection of soil, climatic, and socio-economic data to facilitate site-specific fertilizer recommendations and technology transfer to other sites.

1.3.1 Efficient Incorporation of Micronutrients into NPK Fertilizers and Evaluation of Multi-Nutrient Fertilizers

The activities focus on the improved delivery, distribution, and efficiency of nutrients (N, P, K, S, Zn, B, Mg, Ca) supplied from multi-nutrient fertilizer granules. The effect of improved nutrient efficiency will be quantified with respect to increased yield, improved mineral nutrient and protein content of grains, and quality of protein. This study will be conducted in the United States, Bangladesh (ongoing), Ghana (ongoing), Kenya (ongoing), Myanmar (ongoing), Mozambique (ongoing), and Nepal (new).

Partnership:

University of Central Florida, Tennessee State University, U.S. Department of Agriculture's (USDA) National Institute of Food and Agriculture (NIFA) (cost-share), Soybean Innovation Lab (SIL), Agriculture and Forestry University (AFU), Tribhuvan University, Bangladesh Agricultural Research Institute (BARI), Soil Resources Development Institute (SRDI), Kenya Agricultural and Livestock Research Organization (KALRO) (in-kind), Nepal Agricultural Research Council (NARC) (in-kind), Food security through climate Adaptation and Resilience (FAR) Project, Mozambique Farmers Association, HarvestPlus, International Zinc Association (IZA), and other industry partners (cost-share)

Progress:

A. Micronutrient rates, sources (S, Zn, B, Cu), and nutrient omission trials in cereals and vegetables – crop yields and nutrient acquisition (Ongoing)

Zn, S, copper (Cu), and iron (Fe) deficiencies are widespread, affecting both crop yield and human nutrition. Grain samples from selected trials will be analyzed for methionine and cysteine, Zn, Cu, P, and phytate content.

Sulfur, zinc, and boron on maize: At five sites in Western Kenya, we evaluated the effects of various sources of sulfur, zinc, and boron on maize yield. The sources were applied at rates of 9 kg S/ha in the S trial, 0.6 kg Zn/ha as granular coatings in the Zn trial, and 0.3 kg B/ha in the B sources and rates trial, except as noted in the B trial in which half the B rate was used. The granular Zn sulfate treatment was applied at 2 kg Zn/ha. All treatments received 92 kg N, 45 kg P_2O_5, and 20 kg K_2O/ha. Sites were preselected to have low to medium S, Zn, and B, as per a Mehlich-3 soil test.

Results are shown in Table 7. While some differences were evident at various sites, treatment response was not consistent across sites, and none of the treatments with S, Zn, or B source resulted in yields significantly greater than control plots. While we did not analyze plant samples from these particular trials, analyses from the PR trial and a polysulfate trial at these sites showed total S, Zn, and B uptake comparable to what has been reported in the literature for 10 mt/ha yields in North America. Thus, it appears that deficiencies did not emerge, despite the indications from soil analysis. As such, the experiment was inconclusive.

Table 7. Maize response to various sources of S, Zn, and B in Western Kenya.

County	Uasin Gishu		Trans Nzoia		Uasin Gishu		Uasin Gishu		Bungoma		Across Sites	
Farmer	Kisiero		Lunani		Koech		Kiplagat		Motia			
Treatment	(mt/ha)											
Sulfur sources trial												
NPS 19-38-0 +7S	10.30	a	8.71	a	8.66	a	8.64	a	6.24	a	8.51	a
Ammonium sulfate	10.44	a	8.26	a	7.96	a	8.12	a	5.40	a	8.04	b
Polysulfate	9.68	a	8.84	a	8.79	a	8.36	a	5.58	a	8.25	ab
Amidas	10.69	a	9.25	a	7.67	a	8.29	a	5.52	a	8.28	ab
No-S control	9.56	a	9.10	a	8.26	a	8.18	a	5.89	a	8.20	ab
LSD (0.05)	1.22		0.95		1.04		0.51		0.85		0.43	
Zinc sources trial												
Zn oxysulfate	10.06	a	9.22	a	7.43	c	8.19	ab	5.87	ab	8.16	c
Zn oxide	9.64	a	8.78	a	8.55	ab	8.28	ab	6.60	a	8.37	abc
Granular Zn sulfate	9.81	a	8.80	a	8.56	ab	8.07	b	5.93	ab	8.23	abc
DDP Zn	10.01	a	9.22	a	7.81	bc	8.84	a	6.35	a	8.44	ab
Smart Zn	10.63	a	9.24	a	7.98	bc	8.89	a	6.04	ab	8.56	a
Zn sulfate coating	9.76	a	8.81	a	9.08	a	8.43	ab	5.90	ab	8.40	abc
No-Zn control	10.00	a	9.18	a	7.95	bc	8.65	ab	5.60	b	8.28	abc
LSD (0.05)	0.71		0.49	a	1.09		0.70		0.73		0.27	
Boron sources and rates trial												
Solubor in topdress	9.87	ab	8.36	ab	8.07	ab	8.50	ab	5.44	a	8.05	a
Solubor in basal	10.30	a	8.55	ab	7.11	bc	8.08	abc	6.17	a	8.04	a
Solubor in basal (1/2 rate, basal)	9.56	b	8.12	b	7.53	abc	7.87	abc	6.18	a	7.85	a
Borax pentahrate in basal	9.85	ab	9.27	a	8.40	a	8.19	abc	5.12	a	8.17	a
Borax pentahrate in basal, 1/2 rate	9.53	b	8.77	ab	7.89	abc	8.65	a	5.38	a	8.04	a
Ca borate in basal	9.48	b	8.71	ab	7.74	abc	8.45	ab	5.47	a	7.97	a
Ca borate in basal, 1/2 rate	9.43	b	8.76	ab	6.75	c	7.99	abc	5.23	a	7.63	a
No B control	9.58	b	8.95	ab	7.18	bc	7.73	b	5.76	a	7.84	a
LSD (0.05)	0.62		0.74		1.04		0.69		1.46		0.69	

Residual Sulfur Trials: Traditionally, sulfate (SO_4-S) is used as the main source of S for plant nutrition, since elemental sulfur (ES) has been reported as generally inert and not capable of supplying S for crop production. However, with advances in micro- and nano-sized elemental S, and other technological advances, ES is no longer the "inert or very slow-release S" that could not meet plants' S demand. During FY2018-19, in partnership with a private client (Shell), we established 12 field trials to evaluate the agronomic effectiveness of the new S fertilizer product under field conditions in northern Ghana. The combined results of biomass yield, grain nutrient (N and S) concentration, and the total aboveground nutrient uptake showed that the Thiogro ES product was as effective as the locally available sulfate (ammonium sulfate) fertilizer in northern Ghana. Even at a lower application rate (25 kg S ha^{-1}), the Thiogro ES produced yields that were statistically similar to those from ammonium sulfate fertilizer applied at 50 kg S ha^{-1}.

However, despite the increases in S uptake with an S application rate from the Thiogro ES fertilizer product, the proportion of the applied S taken up by the plants decreased with increasing S application rates. In general, across all treatments, the proportion of applied S taken up by the plants was <25%, suggesting that substantial quantities of the applied S were not taken up by the plants. Post-harvest soil analysis showed that large amounts of S remained in the soil from the plots receiving the Thiogro ES fertilizer product after crop harvest. The results of the soil analyses prompted a follow-up experiment FY2019-20 to determine the residual effects of the Thiogro ES fertilizer in supplying S to subsequent crops. We established 12 trials to evaluate the effects of the residual S from the applied Thiogro ES fertilizer product.

The trials were harvested in November 2019, and the biomass and grain yields were determined. The results are being collated for statistical and economic analyses. This has been delayed due to the COVID-19 pandemic, which has caused temporary closure of the labs undertaking the plant tissue and post-harvest soil samples.

<u>Greenhouse study with organic fertilizer and zinc oxide nanoscale and bulk particles</u> was conducted to mitigate the effects of moderate drought (40% field moisture capacity), organic manure (cow dung), and Zn (as nano [1.7 mg/kg] or bulk [3.5 mg/kg] particles) in wheat. Drought had contrasting effects on plant performance and quality indices. Notably, panicle emergence was delayed, and chlorophyll level, plant growth, biomass production, grain yield (Figure 11), and shoot uptake of nitrogen, phosphorus, potassium and Zn were reduced.

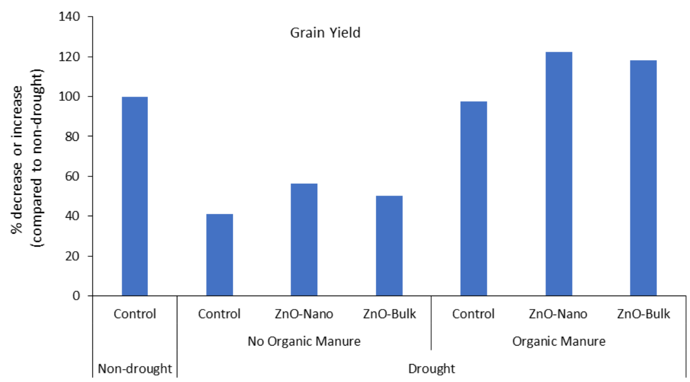

Figure 11. Effect of drought on wheat grain yield and the mitigation of drought-induced yield decline by organic manure and zinc oxide (ZnO) nano and bulk particles.

In contrast, grain Zn (Figure 12), S, and Mg contents increased under drought, while grain Fe and Ca contents were unaffected. Under drought, organic manure accelerated panicle emergence and increased shoot biomass, grain yield (Figure 11), and grain Zn (Figure 12) and S contents, while reducing plant growth and grain Fe content. Both Zn types increased chlorophyll levels, accelerated panicle emergence, marginally increased grain yield (Figure 11), and increased shoot and grain (Figure 12) Zn contents under drought.

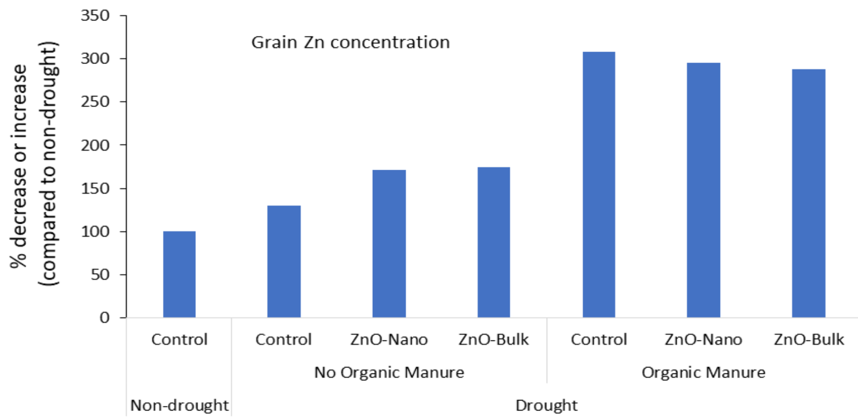

Figure 12. Effects of drought and supplementation of organic manure and zinc oxide (ZnO) nano and bulk particles on Zn content of wheat grains under drought.

This study demonstrates that moderate drought has profound effects on wheat metabolism, phenological development, productivity, and nutrient accumulation and that fertilization with organic manure and ZnO particles can interact with drought to modulate outcomes. The organic manure contained significant amounts of multiple nutrients, including Zn. Thus, it acted both as organic amendment and fertilizer. The study is completed with one journal publication as a deliverable, accessible at https://www.sciencedirect.com/science/article/pii/S0048969720313206.

B. Balanced fertilization through secondary and micronutrients (compound fertilizers) in maize on acid-prone soils (Ongoing)

This ongoing activity in acidic soils of Northern Bangladesh assesses the effect of balanced fertilization and amendments in maize. It was established in December 2019. Research findings will be finalized by the next reporting period. However, lab analysis of harvested plant and soil samples may be delayed if the COVID-19 situation continues beyond May 2020.

C. Promoting the commercial and experimental use of efficient micronutrient coatings (Ongoing)

The objective of this activity is to create awareness of the most efficient strategy (in terms of cost and volume) of applying micronutrients, such that researchers apply these strategies in trials and blenders use them in their fertilizer products.

Coating Study: The objective of this ongoing activity is more efficient formulations and coating process for uniform distribution of micronutrients that leads to improve availability of nutrients from coatings and the carrier granules to crops. The optimized coating process and formulations ensure the integrity of the granules. Improved crop availability of nutrients is expected because of better physical distribution, particularly of micronutrients, and reduced chemical interactions between carrier macronutrient(s) and coated micronutrients. Commercial adhesive products and micronutrient coating sources (zinc oxysulfate, disodium octaborate tetrahydrate [Solubor], and cuprous oxide), as well as mixing equipment has been procured to rapidly coat the micronutrients onto granular products. A quick laboratory screening has been completed to identify products with desirable attributes (uniform and stable coating, less dust). A full physical properties tests including abrasion tests will be carried out for the selected products. This research is still ongoing but delayed by the current COVID-19 situation.

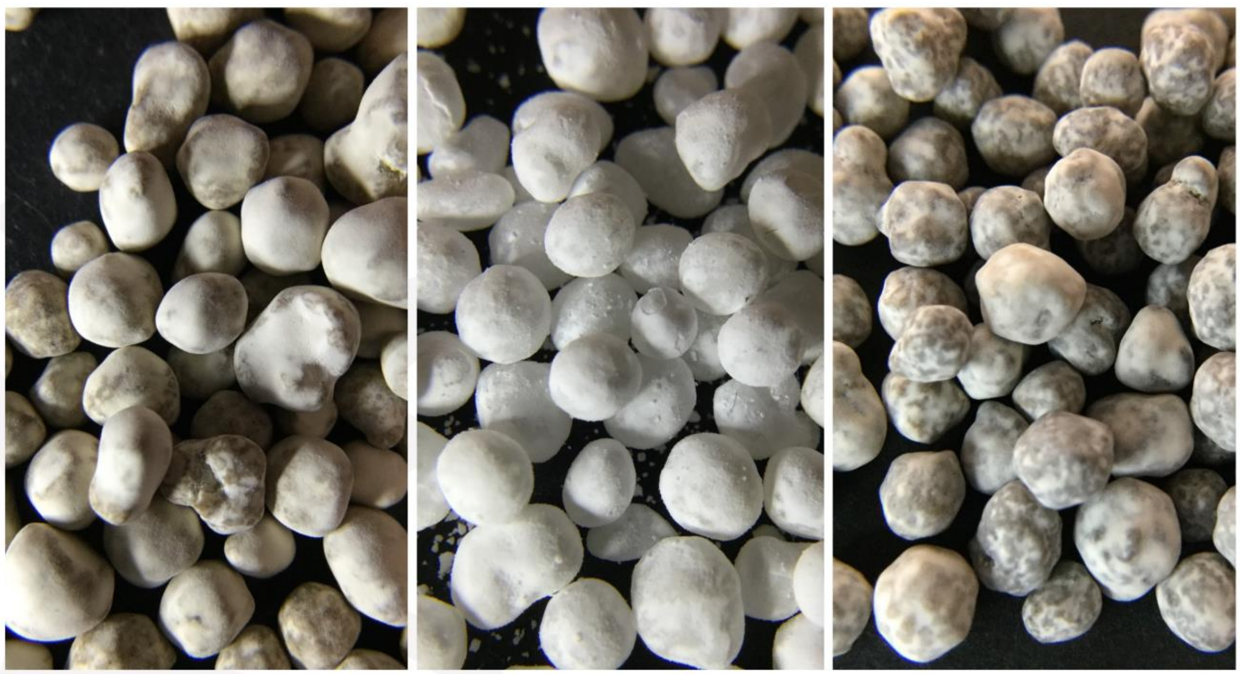

Figure 13. Urea, MAP, and DAP coated with micronutrients.

Greenhouse Study: Urea with integrated polymer and Zn coating was evaluated under greenhouse conditions with sorghum to improve micronutrient delivery in controlled-release fertilizer. It has been shown that polymer-coated urea (PCU) products lead to significant improvement in crop yield and N uptake and lower N losses. Under greenhouse conditions, the physical distribution of Zn products in a pot is not an issue compared to field conditions; hence, the objective of the study was to show that the coated Zn-urea products were as effective as separate applications of blends of Zn and coated urea. Overall, there were no significant differences between the zinc-coated products when compared to blended ZnO and $ZnSO_4$ products, indicating there was no negative interaction between urea and Zn products. As shown in Figure 14, application of $ZnSO_4$ and $ZnSO_4$-coated urea was superior to ZnO, particularly at lower Zn rates. Both coated ZnO and $ZnSO_4$ products were superior to commercially available MES-Zn.

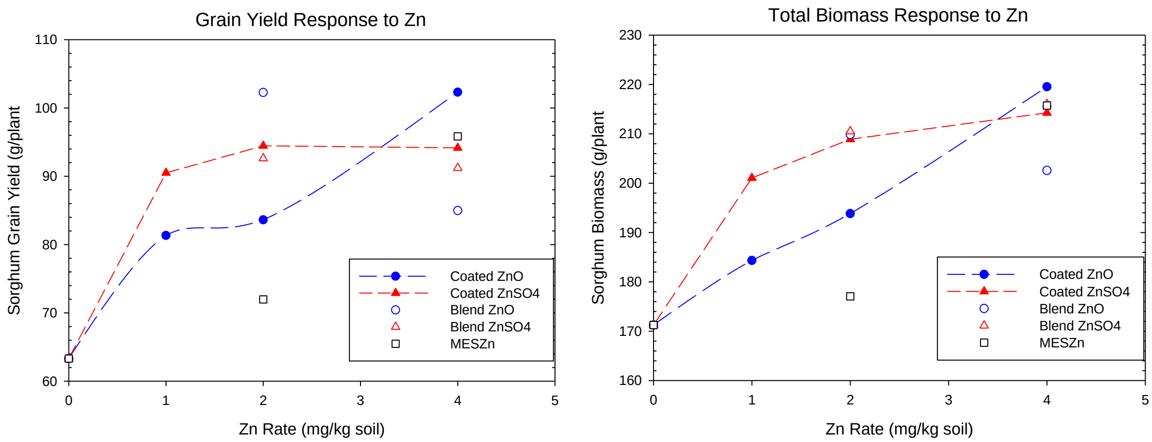

Figure 14. Comparison for grain yield and total biomass of with Zn blends and Zn-urea coated products.

D. On-farm nutrient omission trials on rice (Ongoing)

This activity is a repeat of an on-farm omission trial that was severely affected by Cyclone Idai in Buzi District, Mozambique, in 2019. The objective is to quantify the effect of secondary and micronutrients (S, Zn, Cu, and B) along with NPK in improving rice yields and to identify ways to close rice yield gaps. A total of 360 plots were established on 40 smallholder farmers' fields during the 2019 growing season, starting November-December. The trials are conducted in partnership with Yara Fertilizer Company, local agro-dealers, District Economic Activities Services, and IFDC's Food Security through climate Adaptation and Resilience (FAR) project.

Unfortunately, the heavy rains in Manica Province, Mozambique, and in Zimbabwe on February 14, 2020, led to overflow of Buzi River and prolonged submergence of rice plots. As a result, we only expect to collect data from 15 fields.

These field plots are also used for technology transfer to farmers through field days. With COVID-19 measures being practiced in Mozambique, we utilized the opportunity to incorporate COVID-19 awareness and practices during the field days while disseminating good crop fertilization practices among rice growers in Buzi District. During the field day, strict measures as prescribed by the Government of Mozambique were practiced to prevent the spread of COVID-19, which included convening a very small group of farmers (15) with social distancing of 1-1.5 meters and other hygienic measures, such as hand washing. Educating farming communities in rural areas on COVID-19 measures is critical, and the existing agriculture technology transfer initiatives can be easily used as a platform to promote such measures, i.e., combining health and agriculture messages effectively. This would further allow food-insecure countries, such as Mozambique, to continue business as usual, without interrupting their farming operations, and comply with measures to avoid the spread of COVID-19 among their communities. https://ifdc.org/2020/04/16/learning-together-but-apart-farmer-training-continues-with-a-hygienic-component/

1.3.2 *Facilitate Site- and Crop-Specific Fertilizer Recommendations for Increased Economic and Environmental Benefits from Fertilizer Use (Ongoing)*

Under this activity, data from the FTF Zone of Influence and IFDC programs are used to evaluate the Soil-SMaRT (Soil testing, Mapping, Recommendations development, and Technology transfer) framework for delivering balanced fertilizers to smallholder farmers. This also links with the cross-cutting Geospatial Decision Support System for Agrotechnology Transfer (GSSAT) activity in Section 4.1.

Partners:
SIL, Savanna Agricultural Research Institute (SARI), University for Development Studies (UDS), Ministry of Food and Agriculture (MOFA) in Ghana
Nepal Agricultural Research Council (NARC) and the NSAF project
L'Institut National de la Recherche Agronomique du Niger (INRAN)

Progress:

A. Generate site- and crop-specific balanced fertilizer recommendations – nutrient omission trials in Ghana (Ongoing)

These are ongoing nutrient omission studies that were conducted in 96 sites across the entire savanna (Sudan and Guinea savanna) agroecological zones of Ghana in FY2018. Year 2 nutrient omission trials were harvested in November-December 2019, and biomass and grain yields were determined. The complete results are being collated for statistical and economic analyses; however, preliminary results showed that across the sites with the near-neutral soils, applying only NPK fertilizer increased maize yield > fourfold relative to the control (no fertilizer application). By applying the complete suite of limiting nutrients ("balanced" fertilizer treatment), maize grain yield further increased by 40-60%. Compared to the "balanced" fertilizer treatments, the omission of S (minus S treatment) reduced the maize grain yields by >30%, omission of Zn resulted in an average of ~24% yield reduction, and B omission resulted in an average of ~11% yield reduction. Grain and total biomass yield from the moderately and strongly acid soil are being collated for analyses.

<u>Best-Bet Trials</u>: During FY2019-20, we established 15 trials in the savanna zones of northern Ghana to determine the economically optimum rates of secondary and micronutrients that could be added to the NPK-based recommendation that will result in increased productivity and profitability to the smallholder farmers. The trials were designed to have one treatment with identical fertilizer application rates used for the "balanced" treatment of the nutrient omission trials, one with lower rates, and one with higher rates of the secondary and micronutrient addition to the NPK-based fertilizer recommendation. Thus, at all locations, five treatments were compared: (i) control (no fertilizer application), (ii) locally recommended fertilizer application, (iii) best-bet fertilizer application (using the "balanced" application rates of the nutrient omission trials), (iv) "low" best-bet application (same NPK rates, but 50% of Zn, S, and B rates), and (v) "high" best-bet application (same NPK rates, but 125% of Zn, S, and B rates).

The trials were harvested in December 2019, and the biomass and grain yields were determined. The results are being collated for statistical and economic analyses, based on which validation trials will be established.

Due to the COVID-19 pandemic, plant tissue analyses to determine nutrient uptake from selected plots have been put on hold. Also, we had planned to conduct a stakeholder workshop (involving key public and private players) to discuss the two-year trial results and fathom a way forward for fertilizer formulations, blending, and importation for farmers in the region to increase productivity; however, this activity has also been put on hold.

B. Updating fertilizer recommendations in Nepal for cereal and vegetable crops (New)

Current fertilizer recommendations in Nepal are outdated (developed in the 1980s), and they are blanket country wide. The objective of the proposed activity is, therefore, to conduct knowledge-gap trials, facilitate the collection and assembling of all the available data on crop response to nutrient management in Nepal, and build a comprehensive database for use in updating fertilizer recommendations for Nepal's major crops. This is a partnership between the Nepal Agricultural Research Council (NARC) and the NSAF project on a cost-share basis. Results from ongoing trials on maize and cauliflower are presented.

Comparison of Compound and Straight Fertilizers in Maize: Field trials were conducted across five districts in 2019, in partnership with NSAF, comparing three blended formulations – NPK 12:32:16, NPK 10:26:26, and NPK 20:20:10 – with a combination of straight fertilizers, including PCU and urea deep placement (UDP) in maize. The eight treatments evaluated include: *control* (0:60:40 kg NPK/ha), *Government of Nepal recommendation* (120:60:40 kg NPK/ha), *topdressing at V6 and V10 stages – V6V10* (120:60:40 kg NPK/ha), *PCU* (60:60:40 kg NPK/ha), *UDP* (78:60:40 kg NPK/ha), *Complexal 1* (120:60:30 kg NPK/ha), *Complexal 2* (120:60:60 NPK/ha), and *Complexal 3* (120:60:30 NPK/ha). Each treatment received 20 kg $ZnSo_4$/ha.

Compound fertilizers produced significantly higher yields compared to the government recommendation (Figure 15). Results suggest that use of compound fertilizers/blends ensured balanced fertilization with increase yields. Compound fertilizers with recommended nutrient sources and rates are much easier for farmers to use because they apply only one fertilizer during planting time followed by topdressing with N as required. Yields with PCU and UDP at half the N rates and with one-time application only at planting were comparable to compound fertilizers.

The planned planting of maize for April this year will be affected by the COVID-19 pandemic; therefore, we will explore opportunities for rice season (June planting).

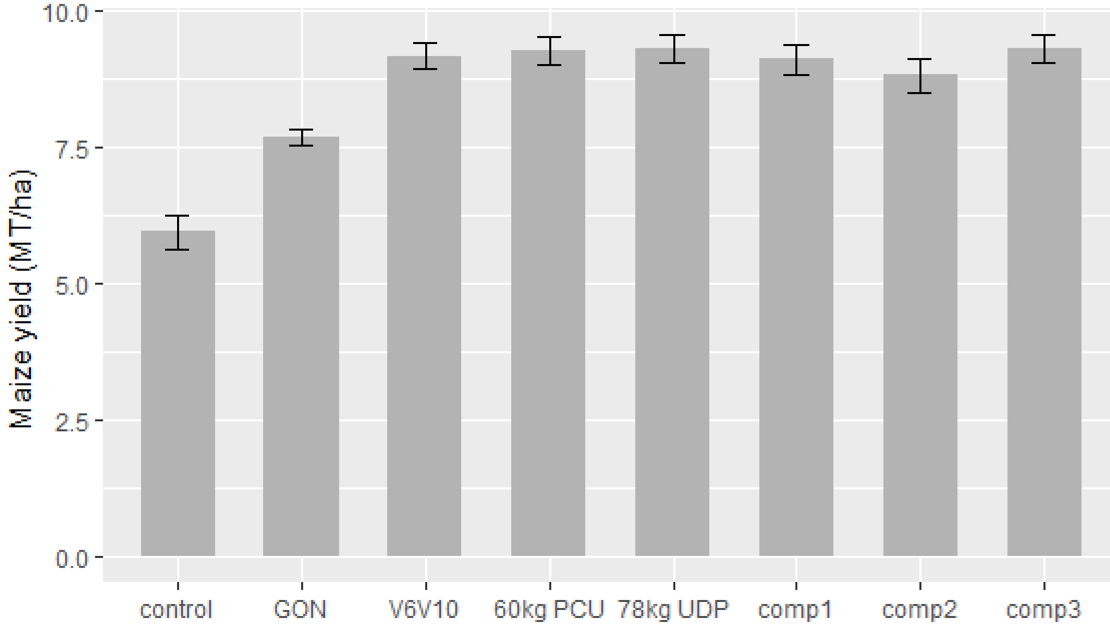

Figure 15. Maize yields in response to various sources and time of nitrogen application from fertilizer trials; comp1, comp2, and comp3 represent different formulation of NPK blends – Complexal 1 (NPK 12-32-16), Complexal 2 (NPK 10-26-26), and Complexal 3 (NPK 20-20-10), respectively.

Comparison of Urea-ES with Other Efficient N Fertilizer Products in Cauliflower: Thirty-three field trials across seven districts were conducted in partnership with the NSAF project in 2019. Urea-elemental sulfur (ES) fertilizer was compared with government-recommended practice (RP) and polymer-coated urea (PCU) in combination with micronutrients Zn and B. Application rates were: F0 (no fertilizer), RP (150:120:100 kg NPK plus 30 mt farmyard manure ha^{-1}), PCU (100:120:100 kg NPK ha^{-1}), and urea-ES (100:120:100 kg NPK ha^{-1}). Zn and B were applied as zinc sulfate (20 kg ha^{-1}) and borax (14 kg ha^{-1}) in selected treatments.

On average (across districts), use of PCU and urea-ES (with Zn and B) increased cauliflower yield by 9% and 14%, respectively. Urea-ES in combination with Zn and B produced about 6 mt higher yield than the government-recommended practice, despite the fact that it included 30 mt of farmyard manure per hectare. These results suggest that S is limiting cauliflower yields. All fertilizer in the PCU treatment was applied at planting.

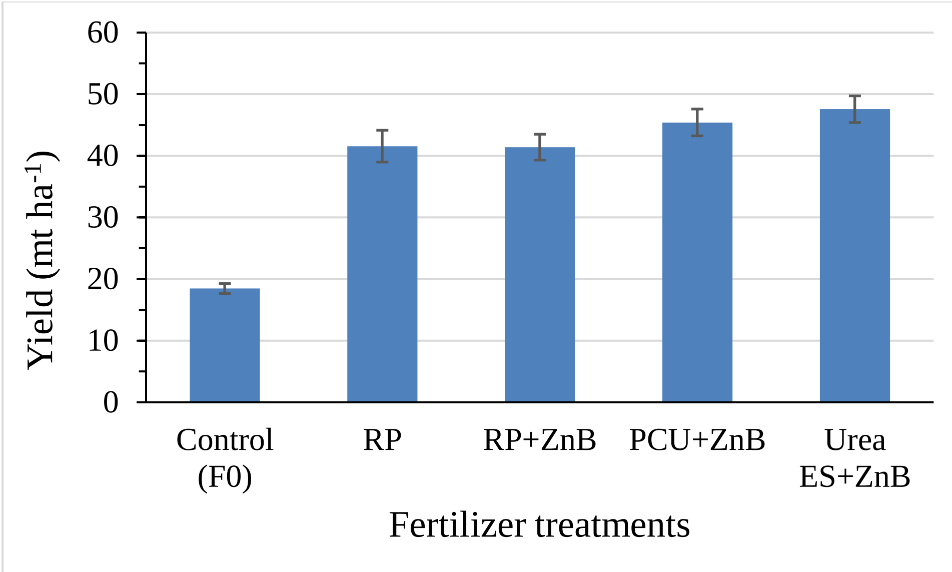

Figure 16. Comparison of cauliflower yields among different N fertilizer treatments: without fertilizer – control (F0), government-recommended practice (RP), PCU, and urea-ES.

C. Developing soil maps for rice farming systems in Buzi (Ongoing)

This ongoing activity uses results from soil analyses conducted under the FAR project in Mozambique to develop soil maps for 12 soil properties in digital format. Additional samplings combined with crop response will be used for the validation process.

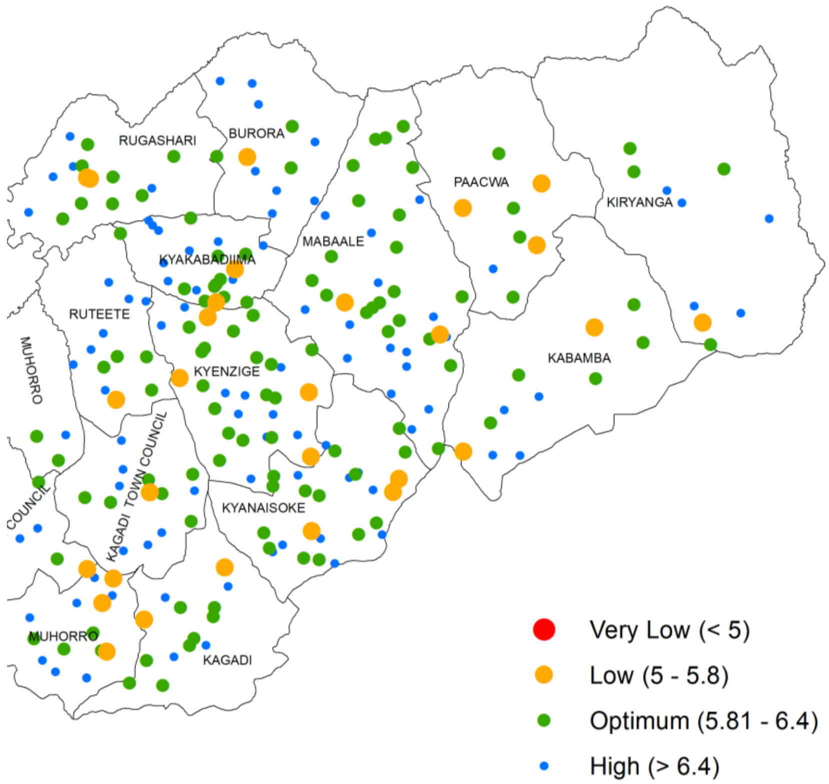

Figure 17. Soil pH for rice farms in Buzi, Mozambique.

D. Validation trials for new balanced fertilizer formulations (linked with Workstream 3) (New)

This activity will leverage results and information generated from the ongoing soil fertility mapping project funded by the West Africa Agricultural Productivity Program (WAAPP)/World Bank in Niger. Under the project, soil nutrient deficiencies and constraints were identified and mapped. The objective of the proposed activity, through field trials, is to verify the reported nutrient deficiencies and evaluate new balanced fertilizer formulations. Ex-ante analysis will be conducted to identify yield potential and yield gaps. The trials are planned for May 2020 but could be delayed by the COVID-19 pandemic.

1.3.3 Wet Chemistry-Spectral Analysis Relationship for Rapid and Reliable Fertilizer, Soil, and Plant Analyses (New)

The proposed activities utilize IFDC's global soil, plant, and fertilizer analyses data and crop responses to develop reliable spectral analytical procedures with high correlation to crop response and/or wet chemistry.

Progress:

A. Wet chemistry-spectral analysis relationship with crop yield and nutrient response (New)

The objective of this research is to provide the evidentiary basis for translating wet chemistry and spectral analyses into robust fertilizer recommendations for focus food crops so that the value of ongoing soil mapping by IFDC and others is valorized to maximum potential. This work forms the evidentiary basis for farm-specific data interpretation as well. Using omission trials to determine individual nutrient response, we will directly correlate wet chemistry and spectral scans of soils from research plots. Multivariate analysis will be employed to understand which soil variables should be included in interpretations. For spectral analyses, machine learning algorithms will be employed to identify the spectral signals that lead to best correlations of response for individual nutrients. X-ray fluorescence (XRF) will be used to quantify nutrients in soil, plant, and fertilizer samples. Bruker has provided both instrument support and data sharing for this activity. Auburn University and Michigan State University will be collaborating for further data sharing under the auspices of Workstreams 1 and 3.

At this moment, the focus is on fertilizer samples that include a wide variety of nutrients and concentrations. The goal is to develop a "global" calibration curve for XRF that performs as well as the traditional wet chemistry analysis. The results for initial correlation of the variables have been very encouraging, with R-square values ranging from as high as 0.99 for Mn and Ni to low of 0.85 for K and Mo (Figure 18). Other elements such as Mg, S, Cl, Ca, Cr, Fe, Co, Cu, Zn, As, Se, and Pb were analyzed. (All of the graph comparisons are available.)

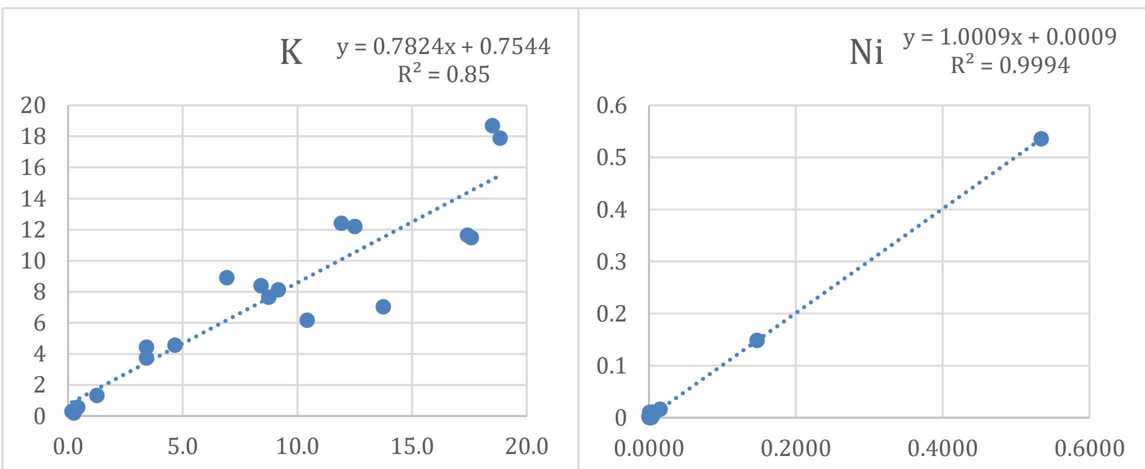

Figure 18. Correlation curves between wet chemistry (x) vs XRF (y) spectral analysis.

B. Evaluation of spectral and wet chemistry methods for detecting changes in soil nutrient status (New)

While spectral analysis of soils is gaining widespread use, it does not accurately determine the availability of some nutrients, such as N and P. Further, spectral methods rely on algorithms that take several related soil properties and estimate nutrient availability. When fertilizers are applied, those related variables might not change, depending on the nutrient. A fundamental feature of the soil test is that it can recognize when a specific nutrient is applied. If spectral methods cannot recognize an increase in nutrient availability due to its application, then the test is not useful to a farmer who risks applying nutrients that are not necessary for his/her soil.

The objective of this activity is to determine how well spectral soil analyses can measure changes in nutrients when supplied as fertilizers. On diverse soils, varying amounts of nutrients (within practical rates) from fertilizer sources will be applied and then the specific nutrients will be measured using both spectral and wet chemistry methods. This will provide valuable insights regarding the proper use of spectral soil analysis for fertilizer recommendations.

We have collected four diverse soils from Kenya and performed preliminary soil analyses to ensure a diversity in soil properties. A first draft of the protocol for spiking with fertilizer nutrients has been prepared. We have identified seven commercial laboratories in addition to IFDC lab that perform either wet chemistry or spectral analyses. We anticipate that the nutrients will be applied to these soils in May.

C. Laboratory standards and standardized methodologies for fertilizers and amendments (New)

Critical for fertilizer recommendation is reliable soil and plant analyses. Unfortunately, laboratories in many developing countries do not follow standard protocols, and quality assurance/quality control (QA/QC) is seldom followed or implemented. This activity addresses these issues by focusing on capacity building, developing training materials, and providing standardized soil and plant samples for QA/QC. As part of this activity, we have assessed laboratories in five West African countries with the objective to help improve the current regional capabilities for the fertilizer analyses by first focusing on the traditional mineral fertilizers and blends. As part of the capacity building effort, Anna Ndiaye Traore, a chemist from Senegal, was trained at IFDC during October-November 2019. Due to the COVID-19 pandemic, some of the assessment has been delayed (e.g., in Nigeria).

With the increasing need to quantify nutrient inputs available in the market, particularly from new fertilizer materials (polymer-coated, slow-release, biofertilizers), plant bio-stimulants and amendments, IFDC continues to be involved with public and private standards and regulatory organizations, such as ISO, the International Fertilizer Association (IFA), and the Association of American Plant Food Control Officials (AAPFCO), to harmonize the methodologies, requirements, and vocabularies. This activity ensures that regulators and control officials have the available information and methodologies to verify the authenticity of the new upcoming products.

Partnership:

Private sector (labs and equipment suppliers), fertilizer associations, Auburn University, and Michigan State University.

1.4 Soil Health and Sustainable Intensification Practices: ISFM, CA, Nutrient Recycling

Poor residue and fallow management, low or no organic waste recycling, and a focus on monocropping (rice, wheat, maize, cassava), combined with soils inherently low in organic matter, can result in increased vulnerability to climatic variability and environmental degradation. Such negative effects of agricultural intensification without integrated soil fertility management (ISFM) and conservation agriculture (CA) practices are evident in the social, economic, and environmental impacts in South Asia, South-East Asia, and SSA. The activities below combine ISFM, CA, and alternative organic amendments, biofertilizers, and bio-stimulants to develop climate-smart cropping systems for rice in Cambodia, Nepal, and Mozambique; for maize in Ghana; and for millet in Niger.

1.4.1 Evaluation of the Synergistic Effect of CA Practices in Combination with ISFM and Activated PR Amendment in Ghana and Niger (Linked with Workstream 3) (New)

The synergistic effects of CA practices and ISFM along with activated PR as a P nutrient source will be evaluated for maize in Northern Ghana (ongoing) and for millet in Niger. The proposed new activity for Niger will be in collaboration with Workstream 3 (SOILS Consortium). It is envisaged that soil amendment with activated PR as a nutrient source, combined with CA and ISFM, will improve rooting and drought tolerance while reducing soil acidification.

Progress:

Ghana*:* During FY2019-20, in partnership with the Africa RISING project, we established eight trials in northern Ghana to evaluate the synergistic effects of CA practices and ISFM along with activated PR as a P nutrient source. The trials were laid out in a split-plot design with the first factor, CA practices (CA vs. non-CA farming systems), randomized on the main plots and the second factor, rates of P fertilizer sources, randomized on the subplots. The P source by rate treatments were (i) activated PR at locally recommended P rate; (ii) activated PR at 75% of locally recommended P rate; (iii) DAP at locally recommended P rate; (iv) DAP at 75% of locally recommended P rate; (v) Togo phosphate rock at locally recommended P rate; and (vi) Control (0 P). At each location, a climate-resilient drought-tolerant maize hybrid was used as the test crop. The trials were harvested in harvested in November 2019 to determine grain and total biomass yields. Post-harvest soil samples were collected in December 2019 to quantify soil organic C (SOC) and N storage following crop harvest.

Results showed synergistic benefits of CA and ISFM practices on maize grain yield (Figure 19). Generally, grain yields from the treatments with CA practices were 30-45% greater than grain yields from the treatments without CA practices. Superimposing various ISFM practices on the treatments with and without CA practices further widened the yield gap between the CA and non-CA treatments for the respective treatments (Figure 19).

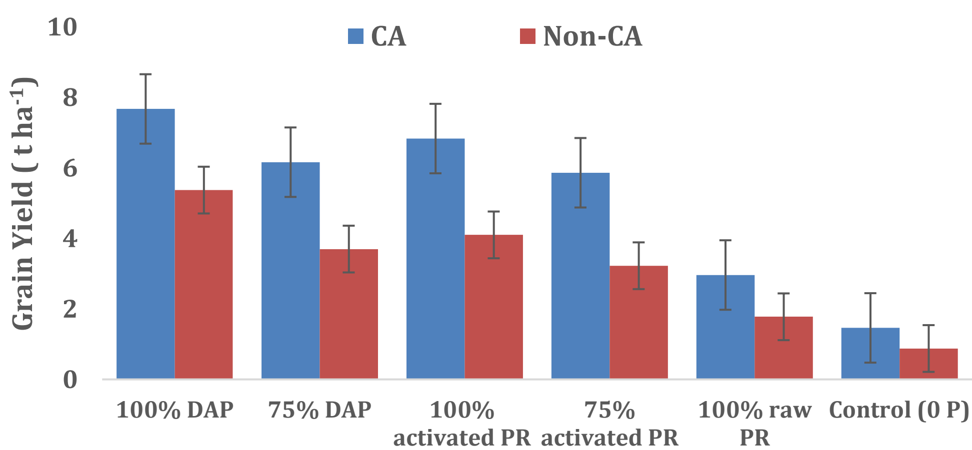

Figure 19. Average grain yield of the rates of P sources tested within CA and non-CA practices.

Due to the COVID-19 pandemic, plant tissue analyses to determine nutrient uptake from selected plots has been put on hold. After determining plant nutrient uptake, we will use economic and statistical models to determine economically optimum activated PR rates for the CA systems. Also, the soil analyses to quantify SOC and N storage following crop harvest are on hold. We planned verification trials to validate the Year 1 results and also to demonstrate the best results to farmers and key stakeholders to educate and build their capacities for climate-resilient maize production in vulnerable soils under a vulnerable climate. These activities are also delayed due to the COVID-19 pandemic.

Niger: The CA-ISFM millet trials that are scheduled to begin in April could be delayed due to the COVID-19 pandemic.

Partnership: Africa RISING Project, INRAN (Niger)

1.4.2 Evaluation of the Role of Legumes in Rice and Maize-Based Farming Systems for Soil Fertility and Health Improvement and Income Generation in Mozambique (Ongoing)

Since most farmers in the target areas (Beira Corridor, Mozambique) have no access to water for off-season cultivation of vegetables, the cultivation of chickpea or other drought-tolerant legume as an alternative crop in rice or maize rotation is being evaluated. Legumes and vegetables are profitable and can catalyze the use of fertilizers by smallholder farmers. Chickpea is a new crop for Beira farmers, requiring close collaboration with extension and research services. Since legumes respond well to P and Ca, activated PR, which provides both P and Ca, will be used as a P source. This activity will complement the ongoing IFDC FAR project in Mozambique.

Farmer harvesting groundnut during the on-farm trial in Mozambique.

Progress:

Evaluating Groundnut Yields in Crop Sequence with Maize: We established 15 on-farm trials with farmers in Buzi to investigate the effect of P (single superphosphate) fertilizers in combination with liquid lime and gypsum products on yield of groundnut. Lime and gypsum application will increase pH and reduce salinity while supplying Ca and S – important nutrients for groundnut. Improved groundnut variety CG7 was planted on November 27-30, 2019. Yield results will be available during the next reporting period.

Cowpea: In collaboration with the SEMEAR project, local seed production of cowpea was initiated on April 10, 2020, on 0.5 ha of land using IT16 and IT18 varieties. We are combining seed multiplication with evaluation of the effect of P fertilizers (triple superphosphate) on grain yield.

Evaluating Chickpea Performance in Crop Sequence with Rice: This activity will be implemented in the winter season starting late April. However, acquiring seeds may be an issue due to the COVID-19 pandemic.

Partnership: Yara Fertilizer Company, Agrodata co-local agro-dealers, District Economic Activities Services, and the USAID-funded SEMEAR project

1.4.3 Increasing Systems Productivity through Agronomic Biofortification with Crop Diversification and Intensification (New)

Intensive rice cultivation in Bangladesh, while helping to secure rice self-sufficiency, has resulted in pest and disease outbreak, declining soil fertility (due to imbalanced fertilization), depletion of groundwater table, etc. In addition, rice monoculture also reduces the production of non-rice crops, erodes biodiversity, and creates nutritional imbalance. Balanced fertilization and crop diversification could help to restore soil fertility and increase system productivity. Balanced fertilization and biofortified varieties can also improve grain quality and human nutrition. Diversification is also considered an effective approach to utilize scarce land and valuable water resources, and it makes agriculture sustainable and environmentally friendly. It offers comparatively high returns from crops by minimizing price and yield risk created by climatic variability and price volatility of agricultural produce while ensuring food and nutrition security, income growth, poverty alleviation, and employment generation.

Progress: This ongoing activity with S nutrition is reported under Section 1.1.1. The new cropping pattern-based field trial will be initiated in July 2020.

Partnership: Field trials will be conducted in partnership with BARI, BAU, BRRI, and SRDI.

1.4.4 Developing a Highly Productive and Sustainable Conservation Agriculture Production Systems for Cambodia (Ongoing)

This ongoing activity quantifies the impact of rice-legume cover crop-based cropping systems under CA with FDP on rice yield and soil organic matter content. It takes advantage of conventional till and no-till paired experiments conducted by Kansas State University since 2011. Changes in soil organic C and N stocks and soil functions of sandy paddy fields under conventional tillage and CA production systems have been assessed. Activities on aspects of cover crop seed production and use of mechanization for effective soil preparation are in progress. The activity will also feature the use of mechanized sowing and FDP under CA practices.

Progress:

Since 2011, a paired-plot design has been implemented in the Stung Chinit irrigation scheme (Santuk district, Kampong Thom province) assessing the performances of conventional tillage (CT) and conservation agriculture (CA) production systems using legume cover crops. The soil is characterized as sandy soil containing more than 70% sand in 0-40 cm depth and classified as Fluvisols/Arenosols in FAO soil taxonomy. The objectives of the study are to: (i) quantify the soil organic C (SOC) and N storage using a diachronic approach based on a paired-plot comparison of paddy fields under CT and CA at different years (2014 and 2018); (ii) assess the changes of three main soil functions (Biofunctool® approach: C transformation, soil structure, and nutrient cycling) between CT and CA; and (iii) simulate SOC and N storage under CT and CA production systems cross-cutting with Section 1.5).

Soil Organic Carbon Buildup and Available Nitrogen: Table 8 shows results of analysis between CA and CT systems. For all paired plots, higher values of potassium permanganate oxidizable C (POXC) are observed under CA when compared with CT. The similar pattern is observed for the soil respiration. These are indications of soil carbon buildup under CA. Available N was also higher in the soil for CA compared with CT. Statistical analysis will be done and a paper written on these results.

Table 8. Assessment of a range of soil parameters under conservation (CA), conventional tillage (CT) management, and native vegetation (NV), and rice yield (November 2019).

Treatment	POXC (mg/kg soil)		Available N (mg/100g)		pH-H20 (1:2.5)		P-Bray II (ppm)		Situresp Abs (T0-T24)		Rice yield 2019 (kg/ha)		
	mean	std dev	mean	std dev	mean	std dev	mean	std dev	mean	std dev	mean	std dev	Increase (kg/ha)
CT L11	721.5	37.4	36.9	6.6	5.20	0.20	26.9	14.7	0.91	0.36	898	686	
CA L12	777.5	36.7	50.9	19.3	4.88	0.23	14.6	7.5	0.88	0.31	1,447	468	549
CT L41	627.2	12.5	27.5	1.1	4.87	0.13	30.9	5.0	0.37	0.31	3,362	405	
CA L42	744.3	116.6	36.5	7.4	4.70	0.25	31.0	19.4	0.71	0.47	3,804	932	442
CT L51	627.9	31.3	35.3	10.2	4.95	0.21	21.9	6.6	0.42	0.26	4,463	717	
CA L52	672.9	64.3	33.9	8.1	4.78	0.41	35.9	8.2	0.60	0.38	4,349	335	-114
CT L61	669.5	63.9	33.9	5.5	5.03	0.29	31.5	14.1	0.69	0.31	3,107	629	
CA L62	753.8	46.8	41.4	6.5	4.73	0.29	20.9	9.1	0.92	0.20	3,630	130	524
CT U51	606.3	60.9	35.2	11.2	5.33	0.21	22.2	8.0	0.18	0.07	1,942	405	
CA U52	677.3	75.0	35.6	11.5	4.83	0.03	41.9	13.9	0.34	0.31	2,686	269	744
CT U61	644.7	42.9	36.9	13.2	5.32	0.21	25.3	16.6	0.31	0.28	3,305	553	
CA U62	761.1	57.4	39.1	10.9	4.67	0.23	26.6	10.3	0.86	0.34	3,439	837	133
NV	751.9	88.4	44.2	9.9	4.74	0.19	17.7	23.7	0.74	0.26			

Rice Yield – Cropping Season 2019: On average under CA management, rice yield was 3,230 kg/ha compared with CT (2,846 kg/ha), an increase of 380 kg/ha (monetary equivalent of $114/ha). The yields under CT and CA management are relatively high when considering the chemical properties of this sandy podzolic soil and the upper position on the irrigation scheme with constraint to conduct an efficient irrigation at the early stage of the rice or complementary irrigation during the wet season (July and August).

Summary of Data for Long-Term Predictions of Soil Health:

The team has been parameterizing the cropping systems, soils, topography, and weather data, and the corresponding yield, and soil health data collected from the plots for long term modeling using the Soil and Water Assessment Tool (SWAT), Agricultural Policy/Environmental eXtender (APEX), and DSSAT models. The training and hiring of a team of graduate students and undergraduates who will do the modeling are being done in synergy with other projects. The modeling team of RUA and ITC will parameterize the several CA and CT crop production systems experiments in Cambodia, including the one in Stung Chinit lowland rice.

The ongoing phase of this activity did not evaluate the mechanized urea deep placement applicator under Cambodian conditions.

Partnership:

Royal University of Agriculture (RUA): Center of Excellence on Sustainable Agricultural Intensification and Nutrition (CE SAIN) and Faculty of Agronomy, Faculty of Agricultural Engineering and Faculty of Land Management and Land Administration, Cambodia
General Directorate of Agriculture (GDA), Department of Agricultural Land Resources Management (DALRM), Conservation Agriculture Service Center (CASC), Cambodia
Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD), France; Innovation Lab for Collaborative Research on Sustainable Intensification (SIIL), Kansas State University

1.4.5 Integrated Best Management Practices for Climate Resilience in Rice-Wheat-Legume System in Nepal (New)

Farmers' fertilizer use in Nepal is unbalanced; they use high, often excessive, amounts of urea compared to other secondary and micronutrients. This poses a huge economic cost to farmers, a subsidy burden to the government, and negative effects on the environment. It also reduces crop yields and soil fertility through mining of secondary and micronutrients. "Smart" fertilizers/technologies that include customized compound fertilizers, subsurface fertilization/FDP, and slow-release N fertilizers in combination with locally available organic amendments and improved genotypes in cereal-legume rotations will be evaluated for climate resilience and sustainable intensification.

Progress:

Four maize demonstration plots were established to compare PCU with government-recommended practice and farmer practice: (i) PCU at 80 kg N/ha, (ii) regular urea at 100 kg N/ha; and (iii) farmer practice. Plots are now under harvest; results will be reported in the next semi-annual report.

Two wheat trials were planned to test compound fertilizers with micronutrients and N-efficient fertilizers) in partnership with university (involving an M.S. student), but wheat sowing time was missed because Mission concurrence not received until the last week of December. Plans are to include these trials in next year's work plan.

Partnership: Agriculture and Forestry University (AFU), International Maize and Wheat Improvement Center (CIMMYT), and NARC

1.4.6 Impact of Nutrient Recycling, Biofertilizers, and Bio-Stimulants on Yield and Soil Health (New)

Organic fertilizers and amendments are essential components of ISFM. Bio-stimulants and bio-regulators can also improve crop productivity through improved crop growth and/or enhanced soil biome activities. The research explores opportunities to increase the quantity and quality of organic fertilizers and the integrated use of inorganic-organic fertilizers to improve soil fertility, soil health, and crop yield.

Progress:

All soils – from conventional tillage, zero-tillage, and organic farms – have been collected and processed. As soon as the graduate student returns (COVID-19 delay), soil incubation studies to quantify soil health (organic matter content, CO_2 emission, nutrient status) will begin. Field studies are scheduled for May.

We also quantified ammonia volatilization loss from organic fertilizer (black soldier fly larvae manure), urea, and ammonium sulfate (Figure 20). Black soldier fly larvae convert poultry manure into high-value pathogen-free organic fertilizer. Results from ongoing lab and greenhouse studies on black soldier fly larvae poultry manure and organic fertilizers produced using vacuum pyrolysis will be presented in the next report.

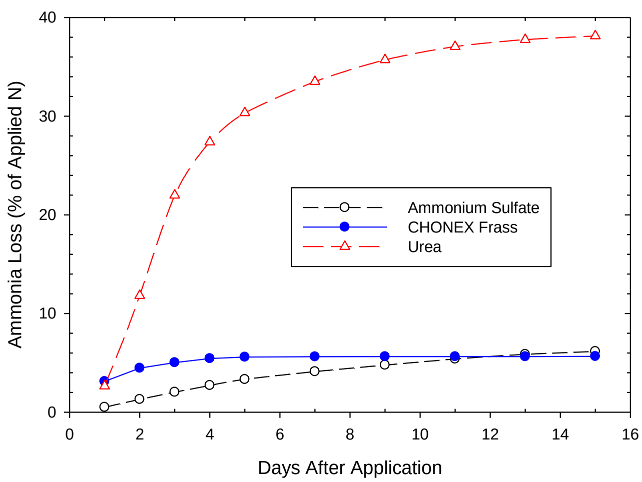

Figure 20. Ammonia volatilization loss from black soldier fly larvae (BSFL) manure is significantly lower than from urea with N application rate of 200 kg N/ha. Losses from ammonium sulfate were similar to BSFL manure. While ammonia losses from urea and ammonium sulfate increased over time, losses from BSFL manure ceased after Day 4 (IFDC 2020).

Partnership: Auburn University, CHONEX, private sector, and farmers

Workstream 2 – Supporting Policy Reform Processes, Advocacy, and Market Development

Summary

Under Workstream 2, IFDC conducts socio-economic research and analysis for evidence-based policies, to support reform initiatives on soil fertility management practices and technologies, including complementary agricultural inputs, toward accelerated farm yields and market systems. The activities associated with this workstream primarily focus on FTF countries; an exception can be made for a non-FTF country to be part of the policy research agenda if there are useful replicable lessons to be learned. The three broad categories under this workstream include document and advocate policy reform processes; conducting evidence-based research and analysis of soil fertility interventions; and conducting socio-economic feasibility studies on scaling up soil fertility and input-based technologies.

2.1 Influencing Policy Reform Processes and Market Development

Activities focus on documenting country-level or regional policy support efforts that provide the necessary impetus to catalyze existing reforms in fertilizer sector. The aim is to create an environment that encourages private sector participation and investment that will result in increased access to input markets by smallholder farm households.

For this purpose, with RFS-SFT support, IFDC partners with organizations and stakeholders at various levels in countries that show high potential for policy change by: (i) engagement of stakeholders through various forums, consultations, and other advocacy modes; and (ii) producing policy briefs and background research evidence to build the capacity of stakeholders on soil fertility-related issues at the country level for wider dissemination.

Highlights for the current reporting period (October 2019-March 2020) include:

- Support of fertilizer sector platform and policy reform processes through consultations and meetings in Kenya.
- Dissemination of fertilizer policy reforms and regulations with Millennium Challenge Corporation (MCC)-Niger's ongoing initiatives.

2.2 Impact Assessment Studies

To support policy reforms for the development of input markets and value chains, this sub-activity primarily focuses on producing evidence-based studies to understand the impacts or effectiveness of technologies related to soil fertility management and the related fertilizer policy reforms and other market-related interventions toward improved access to inputs for small farm households.

Progress made during the current reporting period includes:

- Preliminary results from the assessment of the effectiveness of agro-dealer development/input supplier networks toward improved access to and use of technologies among farmers in Rwanda.

- This also included a rapid assessment of the effect of the COVID-19 shutdown on input supply through the last mile in Rwanda, which was the first country in the region to impose restrictions (see Box)
- Analysis of the best practices and economic costs to control counterfeit fertilizer products and options for fertilizer certification in Kenya.
- New research to study the determinants of fertilizer use in Senegal among small farm households.

2.3 Economic and Market Studies

IFDC's economic studies include: evaluation of various soil fertility-enhancing technologies in terms of economic returns and also financial returns toward scaling; stakeholder analyses and assessment of cost buildups and market margins to identify value chain constraints; and market analysis of the supply and demand of fertilizers.

The activities planned for the FY2020 workplan were initiated in March 2020 and are currently under various stages of implementation. We have also made modifications to accommodate studying the various impacts of the COVID-19 pandemic shutdown in selected Asian and SSA countries; the results will be shared in the FY2020 annual report in October.

Activities that are currently in progress include:

- Documentation of evidence on minimizing market distortions through empirical analysis of data on the fertilizer value chain in Kenya.
- Initiated weekly updates with the *Fertilizer Watch* in the East and Southern Africa region due to COVID-19 shutdown with collaboration from the IFDC-AfricaFertilizer.org (AFO) partnership.
- Documentation of a gender case study on the provision of fertilizers through women input suppliers in Uganda and the implications of the COVID-19 shutdown on input supply.

A detailed summary on the progress of activities during this workplan period (October 2019 – March 2020) follows.

2.1 Influencing Policy Reform Processes and Market Development

2.1.1 Support Fertilizer Platform and Policy Reform Processes in Kenya

A. Stakeholder consultations with KeFERT

Following the launch of Kenya Fertilizer Platform (KeFERT)[1] in June 2019, IFDC was asked to serve as the advisor and coordinator for KeFERT in providing technical advice on soil heath and fertilizer market-related issues. In this regard, regular meetings were held among the stakeholders, followed by few key consultations organized to discuss the issues relevant to fertilizer stakeholders.

Progress:

During FY2020, a series of very successful half-day workshops were held with KeFERT stakeholders. The first workshop on fertilizer product standards and quality was held in September 2019. It was sponsored by the African Fertilizer and Agribusiness Partnership (AFAP) and included presentations by Kenya Bureau of Standards (KEBS).

KeFERT meetings on fertilizer product standards and quality (September 2019)

[1] A public-private initiative to serve the interests of the stakeholders toward preparing an effective roadmap on fertilizer policy reforms and markets in Kenya (https://ifdc.org/kefert/).

During the Kenya Fertilizer Roundtable in October 2018, one of the key priority areas identified by the stakeholders was soil acidity and liming. One great way to encourage the use of lime is through multi-stakeholder knowledge-sharing forums. To advance this, Kenya Markets Trust (KMT), through KeFERT, hosted a workshop to facilitate a technical discussion on liming in January 2020. KALRO and IFDC also presented key findings from empirical research conducted over many years on the following topics: "Overcoming Soil Acidity Constraints through Liming and Soil Amendments in Kenya" and "Liming Rates and Lime Quality."

Farmer applying lime to the fields in Kenya.

Dr. John Wendt, IFDC, highlighted the two key factors that determine the effectiveness: lime type and fineness. Burnt lime (calcium oxide) and hydrated lime (calcium hydroxide) are faster reacting compared to agricultural lime (crushed limestone).[2] The finer the lime, the quicker it reacts. For instance, liquid lime is the finest with the fastest reaction and lowest rate, requiring annual application. Granulated lime, less fine than liquid, has a slightly higher rate and fast reaction, requiring annual application. Agricultural lime, the least fine, has the highest rate, with the greatest initial investment, but it is long lasting. The need for detailed digital soil mapping to plan the liming rates and application in farmers' fields was also discussed.

These meetings allowed for evidenced-based discussion on policy issues and bottlenecks affecting the fertilizer sector and debate among key partners from across the sector (public and private research and development partners). The meetings also served to facilitate partnerships and build consensus to formulate an agenda that supports actions. USAID/Kenya was invited and attended when possible. Additional workshops were planned but are now postponed due to COVID-19; they will be rescheduled as soon as the situation allows.

A summary of action points agreed on by the participants forms the basis for follow-up actions by industry, private sector, and development partners. These discussions are still ongoing but are yielding early results. For example, the discussion on fertilizer product standards, which allowed KEBS to present on the reformed fertilizer standards committee directly, resulted in IFDC Scientist Dr. John Wendt being asked to present to the technical committee on fertilizer product standards in March 2020 to provide input on cadmium levels. An IFDC economist (to be based in Nairobi) will further continue to coordinate and implement the activities on Kenya fertilizer market-related reform processes before the end of FY2020.[3]

B. Participation in the USAID/Kenya Policy Technical Working Group Meetings

USAID/Kenya formed the Policy Technical Working Group (PTWG) in 2019 to coordinate the policy-related activities of USAID implementing partners. The PTWG is coordinated by

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[2] A link to the presentation on "Determining Lime Requirement," by John Wendt, is included in the Annex.

[3] Recruitment for the economist has been initiated but is postponed until after COVID-19 restrictions are lifted.

USAID/Kenya's Africa LEAD Program and USAID Senior Program Management Specialist – Policy and Research, Samson Okumu.

Progress:

- During this reporting period, four PTWG meetings were held in October 2019, November 2019, February 2020, and March 2020.
- Discussions among partners primarily focused on (i) coordination and synergy among USAID implementing partners either geographically, topically, or by government partnership; (ii) learning and dialogue through sharing resources and networks and organizing policy dialogues; (iii) private sector engagement in policy processes; and (iv) special topics, such as opportunities for arid and semi-arid land (ASAL) development, supporting the development of traditional crops to address food security challenges in marginal lands, and engagement of youth.
- Since IFDCs intervention areas are aligned with the proposed priorities of the Kenya Mission on input policies and market systems, public and private sector capacity development, and coordination of thematic policy groups, e.g., KeFERT, the Kenya Mission further encouraged coordination with various implementing partner activities on agro-inputs in Kenya and exploration of opportunities for partnerships.

C. Dissemination of New Fertilizer Regulations in Niger

In 2019, the Government of Niger, with the financial assistance from MCC/MCA-Niger and the technical support of IFDC through the Fertilizer Sector Reform Support Project in Niger (PARSEN) project, started implementing the plan adopted in January 2018 for reforming the domestic fertilizer sector. One important component of this plan is the creation of an enabling regulatory and policy framework. Under this component, fertilizer regulations pertaining to the import, distribution, and control of fertilizers have been signed by the Ministry of Agriculture (October 29, 2019). To complement the above effort, USAID RFS is funding an activity conducted in close collaboration with the IFDC PARSEN project to support the large-scale dissemination of these new fertilizer regulations across the country among the stakeholders, seeking to create an enabling environment for better implementation when the regulations take effect later in the year.

Meeting in Maradi Division with stakeholders to discuss the fertilizer sector reforms

Progress:

The dissemination activity launched in March 2020 to raise awareness among key stakeholders on the new legal framework for fertilizer. The dissemination involved distribution of outreach materials to stakeholders and messaging through mass media channels, involving television and radio. Details of this dissemination activity include:

- ***Distribution of informative materials:***
  - Signed implementing regulations in French have been translated into the local languages of Zarma and Hausa.
  - A joint IFDC PARSEN – MAG/EL DGA field trip was made to the Tillabéri, Dosso, Tahoua, Maradi, and Zinder regions March 18-26, 2020. During this trip, 100 hard copies of the regulations were distributed in each of the five regions to the Governor's office, the Regional Council, representatives of ANIDE (national fertilizer association), Regional and Departmental Directorates of Agriculture (DRA and DDA), the regional branch of the COTEN (national fertilizer technical committee), etc.
  - Because of COVID-19 and the ban on large public gatherings, distribution in the other regions of Niger could not be achieved, and planned meetings with local entities in the regions were replaced with selected briefing meetings with their leaders.
- ***Communication through mass media (TV and radio):***
  - Specialists contracted by IFDC PARSEN have produced two-minute video and audio spots in the Zarma and Hausa languages on the regulations; these are currently under final revision.
  - National Tele Sahel will air the video spot while 15 radio stations have been identified in seven regions to broadcast the audio spots and programs on the regulations.
  - COVID-19 delay effects: contracts with local radio stations have not yet been finalized; data collection surveys covering major stakeholders targeted by the dissemination effort originally planned for the end of April-early May will be done after movement restrictions are lifted.

The dissemination activity will be completed around the end of September, and the major outcome expected is improved knowledge and information among stakeholders through better outreach mechanisms.

2.1.2 Dissemination Event to Support Policy Efforts to Harmonize Fertilizer Quality Regulations in Zambia *(Postponed)*

With support from RFS-SFT funding, a fertilizer quality assessment was conducted through sampling across the fertilizer markets of Zambia in 2016; the assessment identified frequent and severe shortages of macro, secondary, and micronutrients in compound, bulk blends, and straight fertilizers. A learning/dissemination workshop among Zambian fertilizer sector stakeholders, including the Ministry of Agriculture and the private sector, has been planned to share the results.

Progress:

- The workshop could not be conducted during the reporting period, because we have yet to receive the necessary feedback and consent from Zambian Ministry of Agriculture officials. When the Ministry responds, we plan to coordinate the activity with the Mission in Zambia through official concurrence process.
- With the COVID-19 pandemic, *we further plan to postpone the workshop until the FY2021 workplan period*, considering the logistics in arranging such an event.

2.1.3 Policy Briefs on Fertilizer Policies, Reforms, and Market Development

For FY2020, IFDC anticipates four country-level policy briefs to be generated on some of the key issues related to fertilizer access, availability, and technologies[4] in Bangladesh, Niger, Nepal, and Nigeria.

In **Bangladesh**, we planned to document a policy brief identifying characteristics of fertilizer consumption, use, and access through a set of measurable indicators over the last three decades. The proposed brief is to document the existing cost buildups across the fertilizer value chain actors from the port to farm-gate consumers along with market margins involved, to highlight how the existing policies either affect or favor the fertilizer access and supply to small farmers in Bangladesh.

Progress:

- The activity was to begin at the end of March, as we received the concurrence from the Bangladesh Mission earlier this year. We now plan to conduct the activity when the COVID-19 shutdown is lifted in Bangladesh. This will be reported in the next reporting period.
- Since the shutdown, we have initiated a quick survey remotely to document the effects of COVID-19 on input access in rural areas, market participation by farming households during the current harvesting season (Boro), and plans for the next cropping period. Results from the survey will be analyzed and presented in the next reporting period for the FY2020 work plan.

Niger has been undergoing a fertilizer reform process with the assistance of MCC-Niger since FY2018. The proposed policy brief on "*Does Involvement of the Private Sector Improve the*

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[4] All of the policy briefs will be generated from ongoing IFDC project activity or will be initiated as new activities to address key "topics" of interest and relevance to stakeholders in specific countries.

Distribution Efficiency of Subsidized Fertilizers, Especially through the Existing Parastatal CAIMA in Niger?" will be documented to complement the ongoing reform processes in Niger through MCC-related activities.

Progress:

- Concurrence from the Mission was obtained in December 2019.
- After receiving concurrence from the Mission, several dissemination activities through various forums (radio and other mass media) and stakeholder-level consultations were organized in Niger.
- A survey in progress since February will capture the effects of such dissemination on fertilizer sector reforms on stakeholders across the provinces in Niger. The data from the surveys will be analyzed to form the basis of a policy brief that will be submitted at the end of FY2020.

Nepal: A policy brief on "*What is the Impact of Direct Benefit Transfer in India to the Fertilizer Gray Market in Nepal?"* **(Dropped)**

Progress:

- Since concurrence from the Mission was finalized during early part of 2020. Since the on-going USAID funded NSAF project agreed to explore the same, we decided not to duplicate such efforts.

Nigeria: A policy brief on "*How do the Recent Fertilizer Bans (on Urea and NPK) Affect Fertilizer Uptake in Value Chains and Food Security Objectives?*" will be documented for this purpose.

Progress:

- Since the concurrence from the mission was finalized during the early 2020, we expect to initiate this activity during the second half of the FY2020 workplan period.
- The activity will be carried out through the involvement of IFDC's West Africa office in Nigeria with support from IFDC's regional USAID-funded EnGRAIS project.

2.1.4 Partnership for Enabling Market Environments for Fertilizer in Africa (PEMEFA) (Activity Completed)

The activity was initiated in 2015, with the Partnership for Enabling Market Environments for Fertilizer in Africa (PEMEFA), a Michigan State University (MSU)-led consortium to undertake policy research in Africa for advocating reforms. The five members of the "consortium" are MSU, AFAP, the Regional Network of Agricultural Policy Research Institute (ReNAPRI), New Markets Lab, and IFDC. The main objective of PEMEFA is to bring together relevant organizations that can facilitate fertilizer-related policy changes by engaging with policymakers.

Progress:

- The initial set of activities was partly funded under a grant from MSU and generated a set of policy briefs in FY2019 (https://www.canr.msu.edu/fsg/projects/pemefa-intro).
- Currently, there are no activities planned through this consortium due to a lack of funding.

2.2 Impact Assessment Studies

2.2.1 Determinants of Small Farmer Demand for Fertilizers in Senegal (Modified)[5]

This new activity was included in the FY2020 workplan as a partnership activity to complement the requirements of the newly initiated Feed the Future Senegal Dundël Suuf, which is part of the larger Feed the Future Enhancing Growth through Regional Agricultural Input Systems (EnGRAIS) Project for West Africa, and the Global Food Security Strategy.

In Senegal, despite the government subsidy programs, fertilizer adoption is still low but highly variable across crops and production systems. To improve fertilizer use for food security and agricultural sustainability, its consumption needs to be understood. This research aims to study determinants of fertilizer demand in two agroecological areas of Senegal. The main goal of this study is to understand the determinants of fertilizer use in Senegal. Specifically, this involves characterization of fertilizer consumption (including adoptions rates, profiling) based on rigorous econometric analysis of factors affecting fertilizer demand and understanding the potential yield gaps among smallholders due to inefficient fertilizer adoption methods.

Activities:

Detailed household data will be collected from 300 small farmers located in the Senegal River Delta region, where a national-level rice and vegetable crop-based system for self-sufficiency program is implemented through irrigation, and in the southern Peanut Basin (Njoro), where other high fertilizer consumption crops (peanut, maize, cotton) are grown, mostly under rainfed systems. The study will be conducted by three BAME researchers and graduate students, with advice and participation from IFDC's Regional Economist based in Senegal.

The outputs from this research include:

- Research report based on qualitative and quantitative analysis.
- Policy brief identifying factors that enhance programs promoting fertilizer use in small-scale farms.
- A clean and complete household database.

Progress:

- Preliminary discussions with ISRA-BAME researchers have been completed, and a detailed research outline has been prepared
- Survey and sampling are underway and will be finalized in the coming weeks.
- Field research and surveys are expected to begin once the COVID-19 shutdown ends in Senegal.

[5] Previously, the activity planned under 2.2.1 was the "Assessment of Ongoing Fertilizer Distribution (Through Subsidies) and Implications Toward Better Design in Burkina Faso"; this activity was dropped after consultations with the regional EnGRAIS project to complement their new initiative in Senegal.

2.2.2 *Effectiveness of Agro-Dealer Development Programs Toward Sustainable Input Supply and Technology Transfer in Rwanda (Ongoing)*

This activity was initiated with the Agribusiness-Focused Partnership Organization (AGRIFOP), a local Rwandan civil society organization, and in partnership with AGRA-Rwanda, involving capacity building of agro-dealer programs in Rwanda.

The purpose of the assessment is to profile and document the contribution of agro-dealer development programs toward establishing sustained agricultural input networks and making inputs available, accessible, and affordable to smallholder farmers in Rwanda since 2010. For this assessment, 150 agro-dealers from 10 districts in all four provinces (east, west, north and south) were sampled based on their participation in to various agro-dealer capacity building initiatives provided by donor programs (COMRAP, AGRA, USAID); it includes those who are still in business, those who never received any such skills training, and those who left the input business operations despite training. Ten focus group discussions among 210 farmers were also held to determine farmers' access to inputs through agro-dealers and the knowledge gained through such channels.

The preliminary observations indicate that the demand for agro-inputs has increased in Rwanda due to agro-dealer networks and strengthening through programs. There are currently more than 1,500 agro-dealers supplying inputs throughout the country; of those, 60% are trained and are still in business. The average distances traveled by the farmers to agro-dealer shops has decreased from 20 km (in 2009-10) to less than 3 km. The effect of trained dealer network with accreditation has also resulted in a reduction in input prices by around 30% and an increase in sales of suppliers by 50%. The effect of financial institutions on credit delivery also has increased. The focus group discussions also indicate reduced transaction costs with the increased number of dealers and access to improved technologies, especially new varieties of seeds and fertilizers.

Progress

- On receiving concurrence from the USAID Mission in Rwanda, surveys were drafted, pre-tested, and implemented among agro-dealers to document their sales, geography, participation in input subsidy, and accreditation programs. Focus group discussions were then held among farmers to determine the depth of input access and use from November 2019 to January 2020.
- Preliminary observations from the assessment were shared with Mr. Jean Damascene Nyamwasa, Agricultural Productivity Team Leader, USAID/Rwanda Mission, during a meeting on February 17, 2020 (*see section 4.2 under cross cutting themes*). The full data is being coded and analyzed for reporting in September 2020.
- Final analytical report along with policy implications will be submitted by FY2020 end.
- A dissemination workshop to share the findings of the assessment is planned for early next FY2021.

COVID Shutdown in Rwanda – Some Preliminary Observations on Last-Mile Operations

The final survey stages also coincided with the COVID-19 pandemic, and with Rwanda being the first country in the region to shut down all operations in mid-March 2020, we had a small window of opportunity to do a rapid assessment on the impact of the shutdown on input access and last-mile operations in Rwanda at the end of March 2020.

Box: Rapid Assessment of COVID-19 Effect on Agro-Input Availability in Rwanda (March 25, 2020)[6]

The first case of COVID-19 in Rwanda occurred on March 8, 2020. On March 21, the government implemented measures to limit the spread of the disease. Rwanda was one of the first countries to implement a country-wide shutdown to control the COVID-19 pandemic affecting the population. While Rwanda and other countries in the region agreed to facilitate the movement of agricultural goods, including agro-inputs, as essential goods, the initial days of the shutdown impacted market actors in many ways. For example, last-mile actors, such as agro-input suppliers, have had to adjust to this new reality of enforcing practices to avoid the spread of COVID-19 while ensuring safe delivery of products to the farming community. In Rwanda, the COVID-measures also coincided with the beginning of agricultural season B (March to May).

The following are highlights of how COVID-19 measures undertaken by Rwanda in March 2020 have affected last-mile input supply:

Farmers wait in line in front of the shop to get inputs

Agro-dealer Ange Ngabonziza wears a mask while completing a sale

[6] This a summary of insights drawn from observations of last-mile input retail shops immediately after COVID-19 measures were implemented (March 8) and complete shutdown (March 21) occurred. This does not represent the current functioning of input retail sales, as the COVID-19 measures have since been modified.

Sales operations in input shops with COVID-19 measures since the beginning of March

- The government started providing essential food for citizens under lockdown and fixed prices to avoid price gouging (since March 17).
- Input retail shops adopted strict social distancing measures to provide safe access by farmers through:
    - Providing hand-washing stations, commonly called ***Kandagira Ukarabe*** (meaning **Step and Wash Your Hands**), which are mandatory in each agro-dealer shop.
    - Requiring customers to line up in front of the shop at least 1 meter apart and enter the shop one at a time, keeping the same distance from the counter staff.
    - Wearing face masks while completing sales.
- Most small-scale farmers pay in cash, but mobile money transfer and bank transfer payments to agro-dealers have increased significantly (>40% since mid-March), encouraged by the government.
- Money transfers through mobile phones among agro-dealers, hub-agro-dealers, and wholesalers have increased by around 80%, with a significant increase in online orders, texts (SMS), and voice calls to input suppliers in town, thus reducing the mobility of agro-dealers from rural to towns to access inputs.
- A few challenges exist. For example, to access fertilizers, the retail shops must purchase through wholesale input suppliers in town. However, the wholesale traders have stopped accepting mobile or electronic payments through banks because of fraud concerns. Discussions to resolve this issue, through a collaborative effort by trader associations and cooperatives with MINAGRI's input subsidy program, were undertaken.

Input sales trend immediately after the COVID-19 shutdown on March 21

Overall, the COVID-19 measures introduced in March in Rwanda did not affect the flow of agricultural goods into Rwanda, since trucks were still operating from the ports of Mombasa and Dar es Salaam despite the usual challenges faced on the roads (corruption and other unnecessary delays caused by law enforcement officials, especially in border areas). Very few instances of border restrictions were observed, e.g., Burundi was denying any entry from the Rwandan side. All agro-dealer shops are officially open for business countrywide. Output food trade is also allowed, and the traffic police facilitate the movement of trucks, allowing only the driver and his assistant to be in the vehicle.

- Some wholesalers in Kigali reported increase in sales, because agro-dealers ordered large quantities, prior to the COVID-19 shutdown, to meet the demand for the current agricultural season.
- Traders also feared that the government might extend the lockdown beyond March or that a stock shortage might occur, since importers would not be able to procure inputs as easily from China, India, Europe, and South Africa. The traders anticipated increased shortages of vegetable seeds and pesticides, while fertilizer-based traders and firms indicated ample stocks and storage before COVID-19.

- The Rwanda Agriculture Board (RAB) is supporting seed companies in providing tractor services for land preparation this season and for processing seeds produced in the previous season.
- Looking at the current local production in season 2020, Rwanda expects to have sufficient seeds for low and middle altitude ecologies, but imports will still be needed for high altitude crops. RAB is supporting seed companies in providing tractor services for plowing this season and for processing seeds produced in the previous season.
- Fertilizer companies had ample stores prior to the outbreak. ETG and Yara Rwanda Ltd. reduced their prices (15 RWF on DAP and urea and 20 RWF on NPK) to increase the agro-dealers' margin due to increased transport costs, but prices at the farmer level remained the same. There was no change in retail seed prices at this point.
- Demand for veterinary products increased, although not as much as agricultural products. People have reduced their consumption of animal products, such as milk, meat, and eggs, because they are expensive and perishable. Thus, farmers are not inclined to buy expensive animal feed.
- Wholesalers reported an increase in sales for all agricultural and veterinary products, although customer traffic decreased. People are ordering by phone, and companies send products by trucks that supply foodstuffs in Kigali. Payment is made through mobile money transfer and bank transfer.

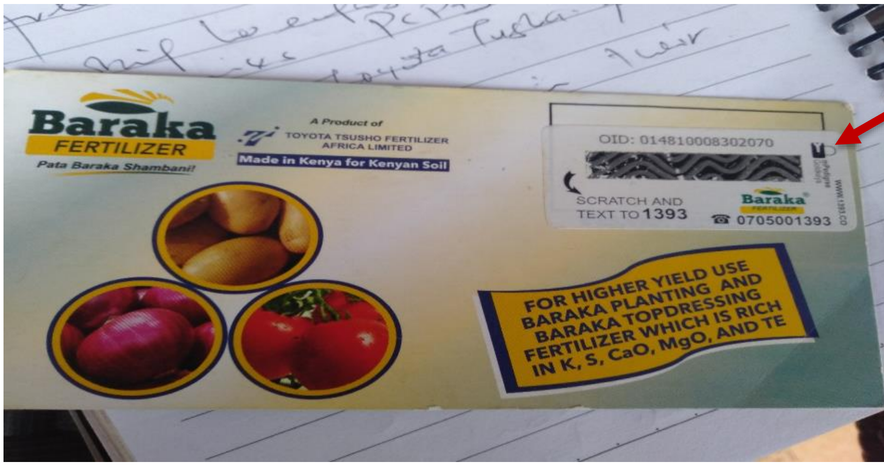
2.2.3 Assessment of Video-Based Extension Approaches to Disseminate Agricultural Technologies and Practices in Northern Ghana – (Postponed)

This new activity was included in the FY2020 workplan to understand the effectiveness of knowledge management and information dissemination efforts to hasten the adoption of new agricultural technologies with the recently concluded USAID-funded Feed the Future Ghana Agriculture Technology Transfer (ATT) project in Ghana.

Since we have not yet received concurrence from the regional mission in Ghana to conduct this field research evaluation, we have further postponed this activity for implementation during the FY2021 workplan period.

2.2.4 Analyze Impact of Counterfeit Fertilizer Products and Options for Fertilizer Certification in Kenya (New)

Counterfeits not only result in an inferior product to farmers and reduce the profitability of fertilizer use (which is already the most expensive input), but they also dilute the brand reputation of fertilizer companies, many of which are investing in balanced fertilizers (crop- and soil-specific blends) that significantly increase yields and profits for farmers. IFDC undertook a "Fertilizer Quality Analysis" activity in 2016-2017, which included an investigation and analysis of sealed fertilizer bags sold through the private sector in Kenya. A recent issue noted by fertilizer blenders was the presence of counterfeit fertilizers. These are fertilizers of unknown origin that are sold in bags branded as Kenya's leading fertilizer companies. This was highlighted as an issue during the Kenya Fertilizer Roundtable and in subsequent Fertilizer Association of Kenya (FAK) and Fertilizer Platform meetings.



Anti-counterfeit stickers for product verification via Scratch Cards and SMS

Progress:

Our preliminary interviews with a fertilizer company in Kenya (e.g., Baraka Fertilizer Blends sold through Toyota Tsusho) have highlighted the benefits on using “brand protection through anti-counterfeiting measures,” such as using SMS/scratch-off labels (e.g., mPedigree) similar to those used in the pharmaceutical and seed sectors. Customers can confirm the authenticity of a bag of fertilizer by scratching off the label to reveal a code, which is sent via SMS to a number that then confirms the authenticity of the code/bag.

We plan to undertake an analysis of the extent and costs to the economy of fertilizer counterfeits and produce options for fertilizer certification using best practices available to control counterfeits in other agricultural inputs, such as seeds and animal and human health-related sectors (pharmaceuticals delivery). This would allow us to develop a detailed action plan for private and public sectors to address counterfeits, including strengthening of the existing regulatory systems. We expect to complete this activity immediately after the COVID-19 shutdown ends in Kenya and the draft will be submitted during the end of FY2020 workplan period.

2.3 Economic and Market Studies

2.3.1 Minimizing Market Distortions in Fertilizer Supply in Kenya – An Economic Analysis (Effects of Tariff and Non-Tariff Barriers [NTB] on Trade)

IFDC recognizes that while cost buildup studies provide useful information on constraints along value chains, there are aspects of fertilizer market flows, such as marketing margins at different stages of the value chain, that may be difficult to capture. Examples include the delays at borders, ports, along the roadways and border crossings due to tariffs and procedures (NTBs) that often distort trade and increase transaction costs. The key implications of such tariffs are often reflected in fertilizer prices and sometimes have resulted in a few quality-related issues (i.e., providing low-quality fertilizer blends, etc.).

The activity will generate necessary evidence by analyzing the supply chain where distortions occur and the type of policies needed to correct such distortionary impacts on fertilizer pricing and availability in Kenya.

Progress

- Initial consultations have been held with MoALF-Kenya and other stakeholders to understand the situation through KeFERT forums (as in 2.1.1 A) to understand the implications for landlocked countries in the East Africa region.
- Discussion held with Policy Economist from Tegemeo University in February 2020 toward collaborating for the research study originally planned to begin March. The activity could not be initiated due to COVID-19 shutdown in Kenya.
- We further plan to include a rapid assessment of tariff and non-tariff barriers imposed on fertilizer access, especially in landlocked countries in the East Africa region, due to COVID-19 as a part of the Fertilizer Watch beginning in April 2020.

2.3.2 Fertilizer Watch Reports in East and Southern Africa (NEW from April'20 onwards)[7] – (Modified)

As an immediate response to the COVID-19 pandemic, IFDC and our ongoing fertilizer marketing initiative, AfricaFertilizer.org (AFO), plan to launch a Weekly East and Southern Africa COVID-19 Fertilizer Watch starting Thursday, April 23. This weekly one-page document will specifically track the impact of COVID-19 interventions on the delivery and use of fertilizers in African countries and, in doing so, will allow public and private sectors and development partners to monitor agricultural production and food security in the region. IFDC has already launched the COVID-19 Fertilizer Watch in West Africa and intends to launch an Africa-wide Watch shortly.

The West Africa Fertilizer Watch has been greatly appreciated by private sector businesses all along the value chain, public sector and development partners responsible for policy and food security interventions, including Government Ministries, Regional Economic Communities, IFA, and the African Union as a valuable tool to monitor actions and analyze data to help in decision-making related to fertilizer availability and use.

Through this weekly Fertilizer Watch and for the coming months, IFDC wants to ensure that fertilizers are moving freely across the region, from ports and plants to farms, and that sufficient fertilizers are reaching the farmers in time for planting so that productivity and food security needs are met. We expect that, as the agricultural season evolves, other related indicators and data will need to be tracked and we will update the Fertilizer Watch accordingly. The East Africa COVID-19 Fertilizer Watch will pertain to the following countries: Ethiopia, Kenya, Uganda, Rwanda, Burundi, Tanzania, Mozambique, Zambia, Zimbabwe, Malawi, and South Africa, covering the major consuming countries and fertilizer trade corridors in the region. The weekly reports on fertilizer access-related measures will be collected from stakeholders in the fertilizer value chain and documented for wider public outreach.

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[7] Previously, the activity planned under 2.3.2 was to document a set of indictors of consolidated measures across various fertilizer access factors influencing policies, markets, research and development, and regulatory aspects in Niger. The activity has been modified to accommodate the weekly reports on fertilizer supply and other market-related constraints in the East and Southern Africa region due to COVID-19 and to accommodate emerging needs.

2.3.3 Women's Access to and Use of Fertilizers in Field Crops and Vegetables – Case Study on Fertilizer Supply by Women Input Retailers in Uganda

For various reasons, female farmers use less fertilizer than male farmers. Studies show that female farmers are as efficient as male farmers, but they produce less because they control less land, use fewer inputs, and have less access to important services, such as extension advice. The outcome of this effort is to generate a series of country-level case studies that offer best practices for IFDC and others, incorporating technologies that are "gender neutral" to those that are "gender aware" and eventually "gender transformative."

Progress

- Discussions were held with IFDC colleagues in Uganda in February about conducting a case study on the role of last-mile women input suppliers in improved access to fertilizers in the southeastern region of Uganda.
- The activity will be carried out in collaboration with the Uganda National Agro-Input Dealer Association (UNANDA).
- Questions regarding the impact of COVID-19 pandemic shutdown on the women input dealers also will be captured as a part of the survey.

Deliverables:

- The final descriptive case study on the role of women agro-input suppliers in improving fertilizer access in Uganda will be generated.

Workstream 3 – Sustainable Opportunities for Improving Livelihoods with Soils (SOILS) Consortium

Summary

Coordination and alignment of activities have been a significant component to the work plan of the SOILS Consortium. Research activities have been developed and are underway in Niger and Ethiopia.

The research activities in Niger (3.1) focus on enhancing resilience to food insecurity and conflict through land-use planning, soil rehabilitation strategies that involve developing the capacities of in-country research institutions, and collaboration through effective partnerships in producing research evidence.

The activities to be implemented in Ethiopia (3.2) focus on developing improved soil fertility-enhancing tools and management practice to address productivity issues associated with key cereals and legumes with national and international agricultural research partners for effective scaling.

The activities and accomplishments outlined in the following sections below fit within a unified agenda that was developed in collaboration with lead soil fertility partners. As each of these activities was developed, significant input was also received from the other partners to either collaborate with these activities or to align plans by donors.

3.1 Enhance Resilience to Food Insecurity and Conflict through Land-Use Planning, Soil Rehabilitation, and Capacity Building

Three related research activities have been developed and are underway in Niger. These activities are applicable to regional aspects of soil fertility management and land-use planning.

3.1.1 Remote and On-the-Ground Land-Use Suitability Analysis to Guide Decision-Making in Niger

The objective is to develop land-use planning maps in Niger that provide land capability classifications (LCC) to guide commune and/or individual level decision-making about appropriate land management. These maps will provide guidance on whether livestock, crop, fodder, rangeland, conservation, or other land management practices are the most suitable to sustainably intensify smallholder systems.

Progress:

Revised high-resolution base maps at 12.5 M resolution have been developed. Remote sensing validation/testing work should occur during April-August, with field data incorporation from IFDC and MSU/ICRISAT/LandPKS planned for June-August (see MSU timeline below). Remote sensing validation report/update will be available following validation from imagery in May. Field validation report/update by August (contingent on the MSU/ICRISAT/LandPKS field-sampling schedule in Section 3.1.2).

Partners:

Jason Neff, University of Colorado; Jeff Herrick, USDA Agricultural Research Service (ARS)

Deliverables:

- The initial overlay for LCC has been completed by December 1, 2019.
- Partial validation of LCC with remote sensing data was completed by February 1, 2020.
- Validated LCC map of the target Zones of Influence will be completed by June 1, 2020 (contingent upon the delivery of field data from partner organizations).

Impact of COVID-19:

- There may be delays in the validation timeline if the field studies led by MSU as outlined below are delayed.

3.1.2 Remote Sensing and Improved Use of Soil Data, Niger

Remote sensing will be used to aid in the identification of at-risk soil areas to help select agronomic methods best suited for the soils. Use of LandPKS will be done in conjunction with the annual cropping work, meshing crop production work with site-specific soils data.

Progress:

MSU-ICRISAT-LandPKS: The LandPKS training/workshop was planned for virtual implementation in April; however, due to connectivity issues, PowerPoint presentations will be shared with the trainees followed by a virtual meeting in May. The subsequent ground survey in Dosso, Niger, is planned for late June/early July following the incorporation of IFDC's Supported Crop Fertilization for Sustainable Agriculture in Niger (AFRAD) project data. By the end of April, there will be a training/workshop report (sensitizing Niger scientists [INRAN et al.]

and extension on the use of LandPKS and draft soil hardness maps with ICRISAT). INRAN scientists will have a major role in this training and field data collection as well.

MSU Economic Profitability Assessment: The economic profitability assessment based on the Niger Living Standards Measurement Study (LSMS, a panel survey conducted by Niger/World Bank, so data already collected) is currently in preparation for analysis. Insights on technology profitability will be derived from this survey in June/July. There will be some preliminary insights on the prevalence of factors associated with farmers' use of various soil fertility management and soil/water conservation practices by late April.

Partnership:

Sieglinde Snapp, Nicole Mason-Wardell, and Vicki Morrone, Michigan State University
Vincent Bado, Anthony Whitbread, Murali Gumma, ICRISAT
Niger Agricultural Research Institute
Ekwe Dossa, IFDC

Deliverables:

- Protocol developed for ground truth exercise with LandPKS application to verify and fine tune remote-sensing maps of soil hardness.
- Implementation of this protocol at one location in Niger, building on ICRISAT and INRAN research sites and maps as a proof of concept on how to develop actionable decision-making guides.
- List of soil categories in Niger, based on soil status classification by parent material and hardened layers present through literature review and the ground truth exercise.
- Current farmer soil fertility management and soil water conservation practices documented and mapped, and key soil, demographic, and socio-economic determinants identified.

Impact of COVID-19:

- The in-person training has been changed to a virtual training. Further timeline delays may develop if planned field activities are impacted in the coming months.

Note: This activity also crosscut with "Validation Trials for New Balanced Fertilizer Formulations" in Workstream 1.3.2.

3.1.3 LandPKS Collaboration with Auburn University

This activity provides general support of the LandPKS platform. The goal is to improve the soil taxonomic unit descriptions and subsequent management information, with focus on lateritic soils, for the LandPKS app to support the Niger activities and the use of LandPKS more broadly.

Progress:

FAO and World Reference Base (WRB) databases have been used to improve soil taxonomic unit descriptions of the soils of Niger and other regions in the LandPKS app.

Editing has been provided to the LandPKS app to link soil classifications to land management information.

Partnership: Joey Shaw and Beth Guertal, Auburn University

Deliverables:

While the basics of the LandPKS soil inventory program are developed, FAO and WRB databases will be used to improve soil taxonomic unit descriptions of the soils of Niger and other regions. These taxonomic descriptions are correlated to map units that provide a foundation to LandPKS. Once these descriptions are developed, the specific soil characteristics and properties will be described to improve the inventory and interpretive value of the taxonomic descriptions. Specifically, there is a need to create unique descriptions for each of the ~170 group/sub-group combinations. Given the not-infrequent contradictions between FAO's group and sub-group descriptions, this will require a fair bit of careful expert consideration.

In the second portion, existing data will be evaluated (FAO, WRB, Soil Taxonomy, peer-reviewed literature, etc.) to further develop management considerations and strategies for the soil taxonomic units. LandPKS also needs to have continued editing to improve the readability (for target audiences – extension and farmers with some education in the developing world) and information value. This editing is designed to provide a strong link between the soil information obtained from the LandPKS program (what the farmer or extension professional sees on their phone) and how that translates to agronomic and land management information for the grower. This could include, but is not limited to, specific cropping system, tillage, soil fertility, or crop selection recommendations.

3.2 Enhancing Productivity and Food Security in Ethiopia through Improved Soil Fertility Management

Following the "Joint Summit on Soil Fertility to Scale" in Addis Ababa, Ethiopia, May 23-24, 2019, and work plan meetings, a proposal on "Targeting Fertilizer Source and Rate in Ethiopia" was developed by ICRISAT, IFDC, and the National Agricultural Research Council Secretariat (NARCS). From December 2019 to April 2020, research activities on development of the teff model and evaluation of crop production and fertilizer use trends were conducted.

3.2.1 Targeting Fertilizer Source and Rate in Ethiopia

The goal of this activity is to produce a model for prediction of responses to different nutrient combinations and rates, with emphasis on K, S, Zn, and B, that improves upon current fertilizer targeting, using soil critical values only. The model will consider multiple variables, including soil analysis values, soil properties such as soil pH, soil texture, and soil organic carbon, soil classification, landscape position, crop, weather (at least rainfall), and agroecology and link to crop response. The intended use of the model is within a dedicated decision support tool (DST) and within the Ethiopian Soil Information System (EthioSIS). The ultimate outcome is better targeting of fertilizers (rate and source) to specific crops and areas of Ethiopia, resulting in increased yield and more economic fertilizer use.

Progress:

A unified Fertilizer Trial Protocol has been developed with the Ethiopian Institute of Agricultural Research (EIAR). These research activities have just been approved for implementation by the SOILS Consortium Leadership Team.

Partnership:

Tilahun Amade (ICRISAT), John Wendt (IFDC), Mulugeta Demiss (SOILS Consortium), Ethiopian Institute of Agricultural Research (EIAR), Regional Agricultural Research Institutes (RARIs)

Deliverables:

Unified fertilizer trial protocol that includes core fertilizer treatments and minimum supporting parameters. The collaborative model and joint planning with the national system on common protocols will provide access to large datasets coming from the various institutions, including EIAR, the four RARIs, universities, CGIAR centers, donor-funded large projects including CASCAPE, and SOILS Consortium investments. Moreover, the Excellence in Agronomy (EiA) team is now considering the Ethiopian fertilizer research as a use case to test broader concepts and investments. Targeted and gap filling field trials on teff (200 sites), wheat (100 sites), and sorghum (100 sites).

Historical data from fertilizer response trials relevant to the objectives of this research will also be reviewed, with the intent of integrating such data into our model. Special attention will be paid to collect data from EthioSIS, EIAR, RARIs, universities, and CGIAR centers that have a set of minimum characteristics that would allow integration. The data may also be used to identify representative sites, monitor changes over time, and identify responsive and non-responsive spots within the landscape and thus augment the newly generated data for developing decision tools and fertilizer recommendation domains.

Impact of COVID-19:

The implementation of field trials may be delayed if the pressure from COVID-19 persists and overlaps with the cropping season.

3.2.2 Decision Support Systems for Improved Access to Information and Farming Practices

Site- or farming system-specific management recommendations that build from existing data are critical to sustainably intensifying Ethiopian cropping systems as the foundation for food and nutrition security and economic growth. However, critical knowledge gaps exist for Ethiopia's most important crop, teff. During the past five months, Dr. Mulugeta Demiss, Visiting Scientist from the Ethiopian Agricultural Transformation Agency, has been developing a teff model, which will be included within the DSSAT suite of crop models.

The goal of this activity is to develop a teff model that simulates effect of soils, weather, genotype, water management, fertilizer rates and sources, and effect of such management factors as plant population and sowing date.

Progress:

During December 2019 to April 2020, the teff model was developed, with ongoing testing with independent data in progress (Figure 21). Teff model to be released with the next DSSAT version. Greenhouse trials are quantifying the effects of N response, plant population, and flooding/waterlogging on growth, development, and nutrient status of teff (Figure 22).

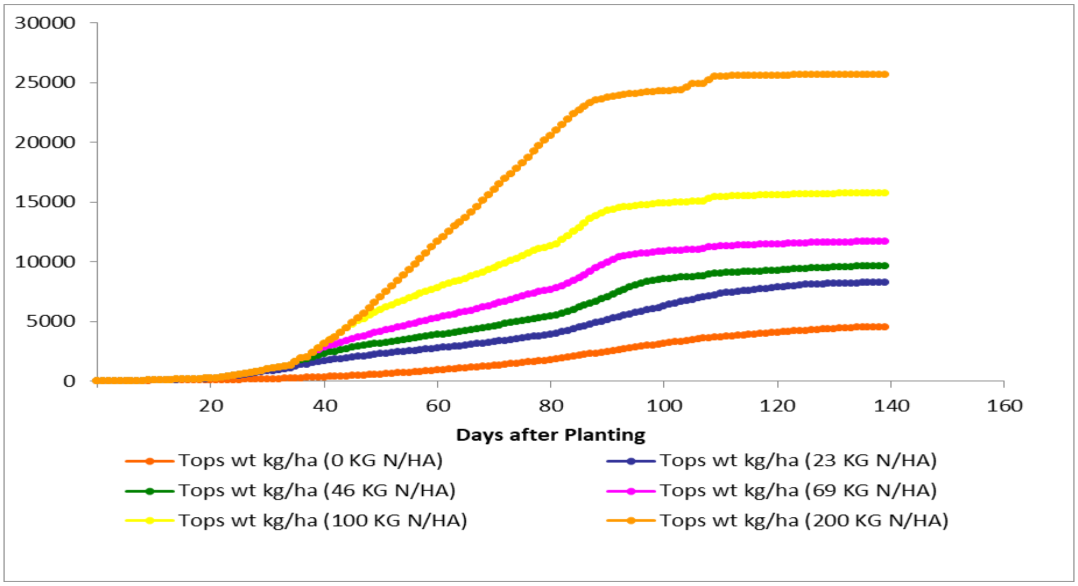


Figure 21. Simulating effect of N fertilizer rates on teff biomass.

Figure 22. Response of N rates (left) and plant population (right) on teff.

Collection of additional data for model validation and application from the 200 teff field trials planned under the "Targeting Fertilizer Source and Rate in Ethiopia" activity.

Partnership: Mulugeta Demiss (SOILS Consortium), NARCS, universities.

Deliverables:

Teff model included within DSSAT suite of models.
Publications on development and applications of the teff model.
Additional greenhouse and field research to improve our understanding of genotype, environmental, and management effect of teff.
Compilation of soil, weather, and management data to evaluate the teff model.

Impact of COVID-19:

The outcome of field model validation could be compromised by the pandemic.

3.2.3 Quantifying Effect of Rainfall and Fertilizer Use on Crop Production in Ethiopia

Water and nutrients are in general the most critical determinants of crop yields. The goal of this activity is to assess the yield trends of the three major crops (teff, maize, and wheat) across years and locations in the two major regions of the country (Amhara and Oromia) and identify the effect of different yield-limiting factors.

Progress:

Fifteen years of data on crop production and fertilizer use trend data from the central statistics agency was compiled, analyzed, and interpreted. Results indicate that area coverage and production of these three crops vary across location and year. Production of the three crops showed an increasing trend every year. The average national productivity of teff, wheat, and maize increased by 85%, 78%, and 132%, respectively, from 2004/05 to 2018/19. But the annual increments were 5-8%. Though there is progress, the current productivity of these crops – 1.8, 2.8, and 4.0 mt/ha for teff, wheat, and maize, respectively, is far less than their potential, and there is a big productivity gap. Productivity is affected by rainfall pattern and amount, amount of fertilizer used, and their interaction (Figure 26). Therefore, climatic variability must be considered in the targeted use of fertilizer and other improved technologies to improve productivity in decision-making at the farm level.

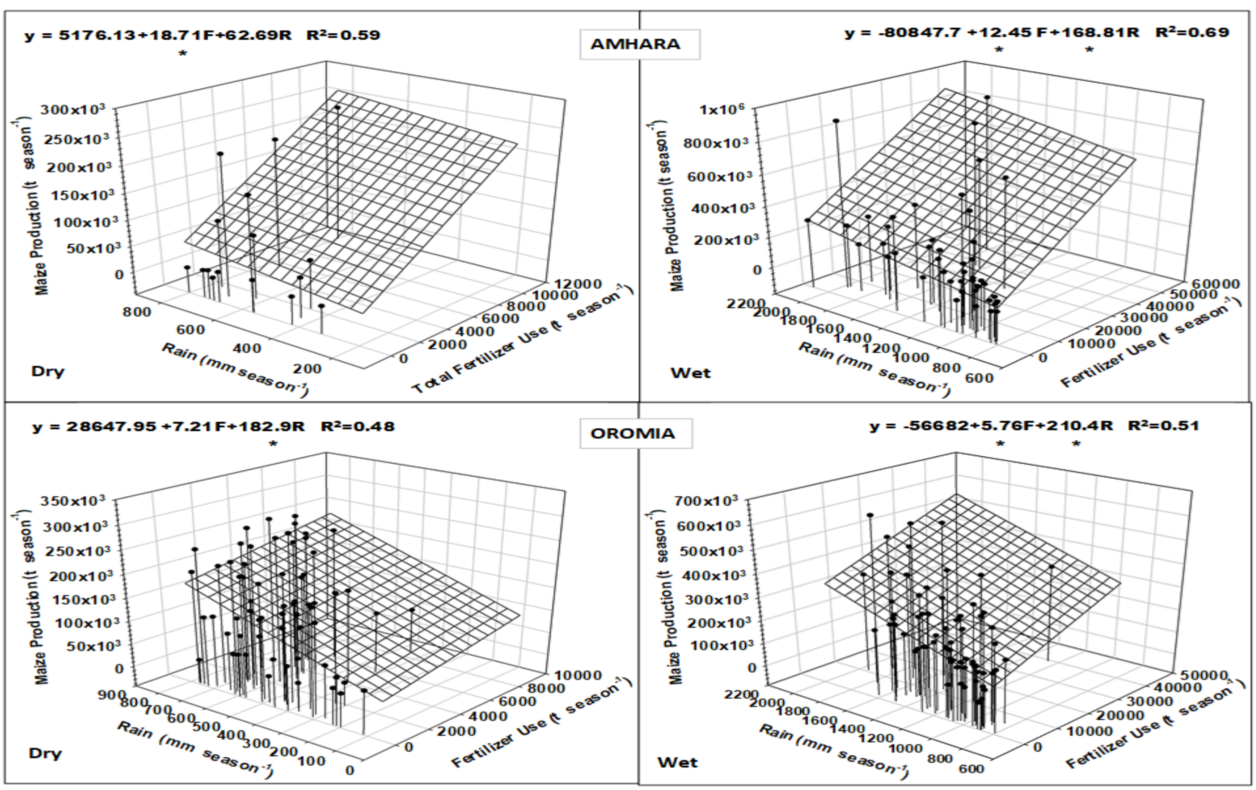


Figure 23. Maize production as influenced by rainfall and fertilizer use during wet and dry seasons in Amhara and Oromia.

Deliverables: A draft manuscript is under preparation.

4. Cross-Cutting Across Workstream Themes: Data, Outreach, and Knowledge Management

4.1 Centralized Database and Improving Decision-Making Tools for Soil Sustainability Processes

Since March 2019, IFDC, in partnership with the University of Florida, has used and adapted the database platform developed for the global Agricultural Model Intercomparison and Improvement Project (AgMIP). Within this partnership we are also improving the existing soil dynamics model in the DSSAT Cropping System Model using the soils and agronomic data generated by IFDC over past years. The geospatial addition to the DSSAT software, GSSAT, originally developed by IFDC, will be refined, and evaluated using spatial soil data from Ghana, Burkina Faso, and Ethiopia (under Workstream 3). The database and decision support tools will help in making timely and reliable recommendations on fertilizers, sowing dates, and other management inputs covering a wide range of biophysical and socioeconomic conditions.

Accomplishments:

- A centralized database platform has been established with a total of 468 experiments (17,560 records) from Bangladesh, Myanmar, USA, and Northern Ghana available on the platform (http://database.ifdc.org:9000/cropsitedb). Platform expansion is in progress to provide new features to import, export, search, visualize, and maintain different kinds of data.
- Improvements to the DSSAT Cropping System Model include: (i) soil carbon (C) balance precisely tracks all soil C and N state variables during computation of organic matter decomposition processes (including emissions of CO_2), organic matter application events, and tillage events; (ii) evaluation of nitrous oxide emission; and (iii) a generic fertilizer routine allowing users to create custom blends of fertilizers and evaluate the effect of urease and nitrification inhibitors and controlled-release fertilizers.

4.1.1 Develop IFDC Centralized Database Using AgMIP Database Template (Ongoing)

The objective of this center-wide initiative is to collect all research and development data in standard accessible formats, collate all data and analyses, and make it available through the IFDC website. The IFDC data management and sharing services will be organized based on the principles of FAIR, i.e., easily findable, accessible, interoperable (compatibility of systems), and reusable. The IFDC database will be compatible with CGIAR and USDA data platforms. Data interoperability will also allow capture of older datasets, which are often archived in distributed locations, diverse formats, and do not use a consistent vocabulary. IFDC envisages that this approach will also facilitate the reuse of these data for quantitative analyses, including for use in modeling activities and synthesis for recommendations and policy reforms. The effort will avoid poor documentation and even loss of data due to the lack of a centralized system.

Progress:

The platform was implemented using four pieces of software: (i) CropsiteDB API, used to collect and distribute site-based datasets in AgMIP's model-ready format; (ii) Navi API, used to look up global administrative-level information; (iii) Checkpoint API, used for user access and page navigation control; and (iv) Interchange, responsible for the web interface, delivering a responsive user friendly interface. These pieces of software were integrated using a heterogeneous set of technologies and patterns, like PostgreSQL and MongoDB databases; Java, Scala, and JavaScript languages; and the standard file format JSON (JavaScript Object Notation).

As a result, research and development data were stored in a standard accessible format, collating all and making them available through the website. A total of 468 experiments (17,560 records) from Bangladesh, Myanmar, University of Tennessee, and Northern Ghana are available on the platform (http://database.ifdc.org:9000/cropsitedb) (Figure 24).

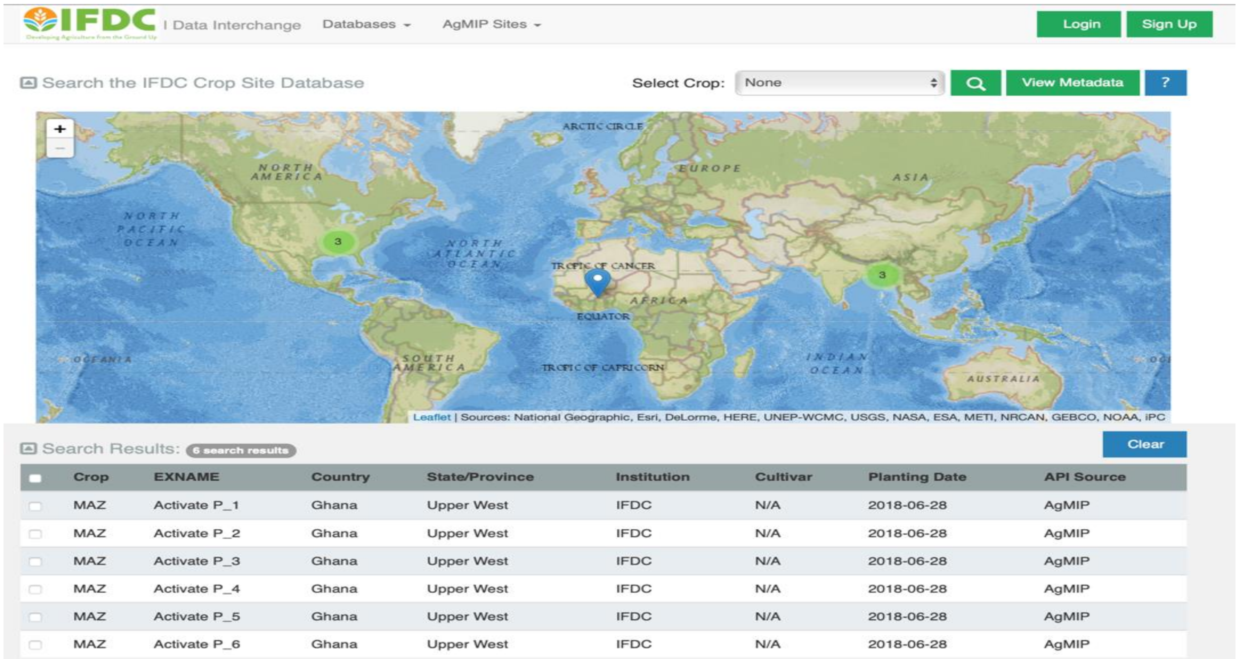


Figure 24. IFDC Crop Site Database

The platform expansion is necessary to provide new features to import, export, search, visualize, and maintain different kinds of data (weather, papers, documents, manuals, and raw data). In addition to other technologies, Docker and Kubernetes are being used to improve the system, for automatic deployment, scaling, and management. The current software is being transformed into microservices and containers, making the platform expandable and replicable (Figure 25).

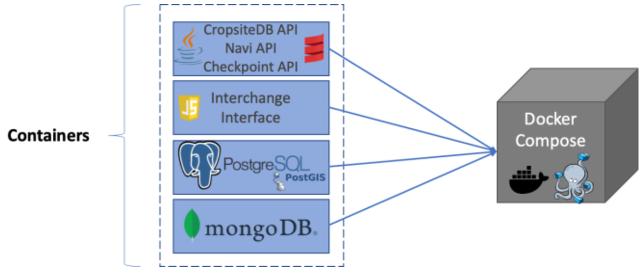


Figure 25. Docker solution and implementation architecture.

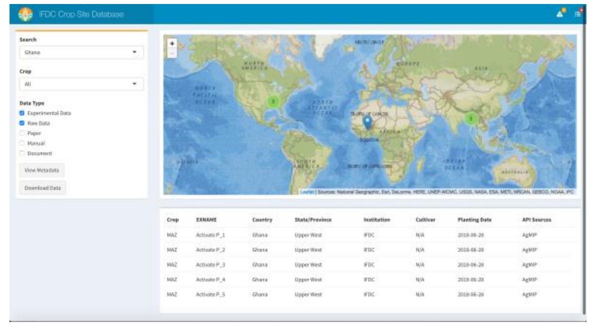


Figure 26. Under development Interface.

A new user interface is under development (Figure 26) to reflect the expansion and allow users to manage access privileges, upload, and select different types of data and information, as needed.

Partnership: University of Florida, AgMIP (in-kind), IFDC (cost-share)

Outcome: Improve storage, analyses, and sharing of data within IFDC and full public access to all non-confidential data and results

4.1.2 DSSAT Cropping System Model Improvement and Application (Ongoing)

Crop simulation models are widely used for fertilizer recommendations, yield gap analysis, and climate change impact, adaptation, and mitigation. However, the performance of models can be questionable in low fertility soils with low soil organic matter content and multiple nutrient deficiencies. The University of Florida (UF) is collaborating with IFDC to improve our ability to model impacts of fertilizers and soil fertility on environmental and agronomic outcomes. Model improvements as part of this collaboration were done using the Decision Support System for Agrotechnology Transfer (DSSAT, dssat.net). In addition, the GSSAT (GIS-based DSSAT) will be updated to use the most recent DSSAT software and the database expanded to include more georeferenced data from IFDC projects.

Progress:

1. Implementation of a complete daily and seasonal soil carbon balance routine to ensure that the model precisely tracks all soil C and N state variables during computation of organic matter decomposition processes, organic matter application events, and tillage events. Emissions of CO_2 from decomposition of organic matter is now a standard output in DSSAT. This work will be included in the next release of DSSAT.
2. A generic fertilizer routine has been implemented in DSSAT that allows fertilizer characteristics to be read from a file, thus allowing a user to create custom blends of fertilizers. This external file provides fertilizer content of NO_3, NH_4, urea, P, K, S, Ca, and Mg; as well as factors to describe urease inhibitors, nitrification inhibitors, and slow- and controlled-release fertilizers. These changes have been fully implemented and will be included in the next release of DSSAT, although evaluation of fertilizer characteristics is ongoing using data collected by IFDC for urease inhibitors and slow-release fertilizers.

3. We have sketched out a conceptual model for predicting the mobility of soluble phosphorus in soil and thus be able to predict the effect of P management and sources on P use efficiency and P losses. This model will be developed for implementation in DSSAT as part of Year 3 deliverables for this collaboration.
4. We are in the process of evaluating a new greenhouse gas emissions model in DSSAT, which computes emissions of N_2O and NO. The routines have been tested with limited data, and we are collecting additional IFDC and LTAR datasets for further testing and evaluation.
5. UF and IFDC are collaborating on improvements to GSSAT, a gridded DSSAT modeling platform developed by IFDC that computes yield forecasts on a regional to country-level scale. GSSAT is one of the tools that will be used by SOILS Consortium partners in Ethiopia.

Partnership: University of Florida, SOILS Consortium partners in Ethiopia and Niger

Outcome: Wide application of improved decision support tools in agricultural decision-making – fertilizer recommendations, planting windows, etc.

4.2 Workstream 2: Cross-Cutting Activities

A. IFDC-SFT Meetings with the Missions

1. *Meetings with the USAID/Kenya Mission* were held several times during the reporting period. Following initial discussions in April and August 2019, the SFT point of contact David Charles and Samson Okumu met with Latha Nagarajan and Alexander Fernando (IFDC East and Southern Africa Regional Director) to introduce SFT and discuss Kenya activities through the concurrence process and how IFDC could support mission priorities.
   - IFDC met with USAID/Kenya implementing partners to discuss soil fertility priorities and presented a concept note for potential activities to be funded through Mission buy-ins in November 2019. These were discussed later in November 2019 with Samson Okumu.
   - In December 2019, during the visit of IFDC's President and CEO Albin Hubscher to Kenya, a meeting was held with Samson Okumu and David Charles from the Mission. The Mission indicated that their programming was focused on market systems development, and while they appreciated that USAID implementing partners showed interest and relevance for IFDC's activities, IFDC should try to obtain funding from their current implementing partners, many of which have grant and partnership opportunities.
2. Mr. Jean Damascene Nyamwasa, team leader for the agricultural productivity in the Mission, Latha Nagarajan (IFDC), and Jean Bosco Safari (AGRIFOP, an implementing partner) met with the Rwanda Mission point of contact in February 2020 to report on the assessment on the effectiveness of input suppliers in technology transfer in Rwanda and share few key observations from the assessment (https://ifdc.sharepoint.com/:p:/s/Communications/EXpnZ2KDRktGvoG_LM1hYBMBCALtuN_vxq_hWaJd1L34KQ?e=IeQiXf).
3. *Meeting with the USAID/Bangladesh Mission*, February 5, 2020: Ishrat Jahan and Abdullah Mohammed met with the Bangladesh Mission FTF coordinator Dr. Osage and Mr. Mehdi Hassan, Economist, and made a presentation on the "Status and Update of the Soil Fertility Technology Adoption, Policy Reform, and Knowledge Management Activity in Bangladesh," on February 3, 2020 (https://ifdc.sharepoint.com/:p:/s/Communications/EYamkIrSdkhIrMeZ_vfmDhkBn920lUuvbCcrwNCQQZofVg?e=kuFvvl). The Mission requested feedback on the soil fertility

technologies in Bangladesh that need further evaluation and technologies that have significant scaling potential with the private sector.

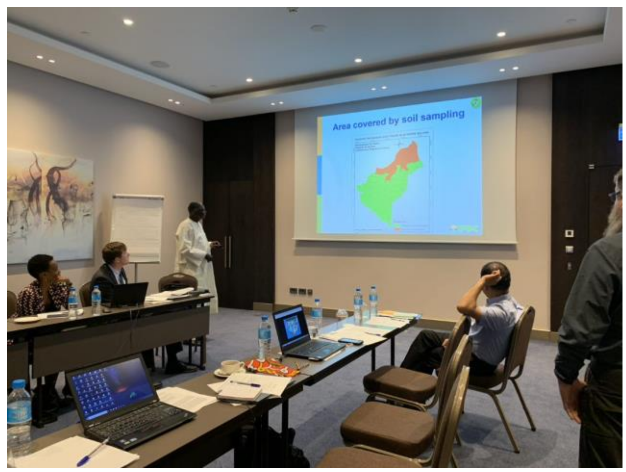
4. *Meeting with the USAID/Niger Mission* with Dr. Idrissa Issoufi, the Niger Mission contact, was held in November 2019 to discuss the activities to be undertaken in Niger through the SFT project across the workstreams and obtain the necessary concurrence for implementation.

4.3 Workstream 3: Cross-Cutting Activities

A. Niger Partners Meeting, November 21-22, 2019, in Niamey, Niger

Purpose: The purpose of this meeting was to build on the recommendations developed during the "Joint Partners Summit on Soil Fertility" held May 2-3, 2019, in Niamey, Niger, and to refine a joint action plan for integrated investments in soil and land-use planning from USAID, MCC, and World Bank. A Common SOILS Agenda was drafted that outlines ongoing activities that meet the recommendations of the summit and proposes new activities to fill gaps.

Soils-C Partners Meeting, Niamey, Niger.



Presentation given at the Partners Meeting, Niamey, Niger.

Field visits to INRAN millet trials and soil profiling sites in Niger

Output:

This meeting refined and finalized the Joint Action Plan for integrated activities in soil and land-use planning in Niger as the full action plan and identified new SOILS activities to fill gaps. The gap filling prioritized research that is currently being implemented and is described in Section 3.1.

A follow-up meeting is tentatively scheduled for June (in person, if COVID-19 regulations permit, or via video call) to share progress.

B. Consultation meeting with Ministry of Agriculture, Ethiopia; Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ); and the Bill & Melinda Gates Foundation

This consultation was part of the "Supporting Soil Health Interventions in Ethiopia: Opportunities for Accelerating Impact" meeting held in Addis Ababa, Ethiopia, on February 6-7, 2020.

Group 1 participants discuss questions assigned during Soil Heath Intervention group work session.

Consultation Workshop on Supporting Soil Health Interventions in Ethiopia in session.

Output:

Opportunities for strengthening the national research and development (R&D) framework on the development of soil health and agronomy content to align with requirements of the national and regional agricultural advisory systems and related initiatives, such as FarmStack and other key national initiatives, was developed and a report created. This meeting was followed by a March 10-13 meeting to harmonize treatments between the SOILS proposal and EIAR nationwide omission trials.

The above meetings together with the Ethiopia Summit (May 2019) guided the creation of the Ethiopia Research Activities (outlined above) and coordinated these activities with NARCS (Birru), Gates (Christian Witt), GIZ (Steffen Shultz), Excellence in Agronomy Platform (Bernard Vanlauwe), and Africa RISING (Peter Thorne).

C. Recruitment of SOILS Consortium Post-Doctoral Fellow, Muscle Shoals

The recruitment process for post-doctorate fellow under SOILS Consortium began in July 2019 with the position being filled by Dr. Mulugeta Demiss since May 1, 2020.

Table 9. Workstream 1: Developing and Validating Technologies, Approaches, and Practices (RFS-SFT/FY2020)

Workstream 1		Country	Activity Summary	Progress (October 2019-March 2020)	Partnership
1.1	**Improving Nitrogen Use Efficiency**				
1.1.1	Development and Evaluation of Enhanced Efficiency N Fertilizers	Global	1. Developing enhanced efficiency N fertilizers using Zn (nano and bulk), as coating material for urea. Coated products formulated, characterized, and evaluated under greenhouse conditions.	New products for field evaluation. New-capped products under greenhouse evaluation. Publication.	University of Central Florida, TERI (cost shared)
		Bangladesh, Ghana, Nepal, Myanmar (FY2018 Funds)	2. Field evaluation of existing enhanced efficiency N fertilizers (urea briquette, urea with elemental S) for improved yield, reduced N pollution	Field trials (completed and ongoing). Reports	BARI, Africa Rising, cost shared (OCP, NSAF, Shell)
1.1.2	Scaling Fertilizer Deep Placement Technology for Granular and Briquette Fertilizers	Bangladesh, Kenya, HQ, Myanmar (FY2018 Funds)	Developing fast and flexible mechanized/manual applicators for fertilizer deep placement for upland and lowland conditions with the option of combined planting.	Field evaluation. Feedback to manufacturers.	Private sector, BRRI, Mississippi State University
1.1.3	Climate Resilience and Mitigating GHG Emissions (Crosscutting with Knowledge Management)	Bangladesh (ONGOING)	1. Mitigating GHG emissions from rice-based cropping systems through efficient fertilizer and water management	Publications and modeling data from past trials.	Krishi Gobeshona Foundation, IRRI, BAU, BRRI
		Bangladesh (ONGOING)	2. Increasing fertilizer use efficiency and resilience in saline soils for rice	Rice at ripening stage. Lab analysis in progress.	BRRI, Khulna Agricultural University, SRDI
		Burkina Faso and Mali	3. Adapting balanced subsurface fertilizer management (NP, NPK briquette) to intensive rice cropping systems (SRI)	AWD-SRI and multi-nutrient briquette results from Mali completed and reported.	NARES

Workstream 1		Country	Activity Summary	Progress (October 2019-March 2020)	Partnership
1.2	**Improving Efficiency of Phosphatic Fertilizers**				
1.2.1	Activated Phosphate Rock Trials Under Greenhouse and Field Conditions	Ghana, Kenya, HQ (ONGOING)	Activated PR evaluated under greenhouse and field conditions	Yield results reported. .	Private sector, UDS, SARI, and local agricultural extension agents
1.2.2	Validating and Promoting Activated PR Using Local PR Sources and Producers (Crosscutting with Workstream 3)	Ghana, Niger, Angola (NEW)	PR and activated PR demonstrations conducted on soils of varying pH to further validate the role of activated PR as an alternative to WSP fertilizers	Seven on-farm demos completed in Ghana with three field days for each location. Angola trial in progress. Niger planting by June, likely to be delayed by COVID-19.	Private sector, NARES
1.2.3	Alternative Activation Process for Enhanced Efficiency P Fertilizers	HQ (NEW)	Alternatives to water-soluble P fertilizers with beneficiation by calcination and grinding.	Range of calcined and ground products prepared. Lab characterization in progress.	Private sector
1.3	**Balanced Crop Nutrition for Site-Specific Fertilizer Recommendation**				
1.3.1	Efficient Incorporation of Micronutrients into NPK Fertilizers and Evaluation of Multi-nutrient Fertilizers	Kenya, Ghana, HQ (ONGOING)	1. Micronutrient rates, sources (S, Zn, B, Cu), and nutrient omission trials in cereals and vegetables - crop yields and nutrient acquisition.	GH trial on Zn and organic manure completed and published. Zn, and B trials completed and reported for Western Kenya. Ghana residual S trials completed.	KALRO (in kind), NARC (in kind), SARI
		Bangladesh (ONGOING)	2. Balanced fertilization through secondary and micronutrients (compound fertilizers) in maize (acid-prone area)	Two maize trials planted in December 2019.	BARI, SRDI
		HQ, Kenya (NEW)	3. Promoting the commercial and experimental use of efficient micronutrient coatings	Products for characterization. Greenhouse study completed and reported	NARES, private sector, university partners

Workstream 1		Country	Activity Summary	Progress (October 2019-March 2020)	Partnership
		Mozambique (NEW)	4. Repeat on-farm omission trials (severely affected by cyclone Idai) in Buzi district to quantify the effect of key nutrients, including secondary and micronutrients, to close rice yield gaps	360 plots in 40 farmer-fields established. Due to February 2020 flooding; continued with only 15 fields. Conducted field days incorporating COVID-19 measures.	FAR project, Yara, farmers' associations, agro-dealers, District Economic Activities Services
1.3.2	Facilitate Site- and Crop-Specific Fertilizer Recommendations for Increased Economic and Environmental Benefits from Fertilizer Use	Ghana (ONGOING)	1. Generate site- and crop-specific balanced fertilizer recommendations - nutrient omission trials in Ghana	115 maize trials completed. Analyses of harvest data in progress.	Soybean Innovation Lab (SIL) - University of Illinois, UDS, Shell
		Nepal (NEW)	2. Update fertilizer recommendations for cereals and vegetables in Nepal	Maize and cauliflower trials completed and reported.	NSAF Project (cost shared), NARC
		Mozambique (ONGOING)	3. Develop soil maps for rice farming systems in Buzi	Preparation of maps. Additional sampling.	FAR Project
		Niger (NEW)	4. Validation trials for new balanced fertilizer formulations (crosscutting with Workstream 3)	Ex-ante data collection.	NARES, SOILS Consortium
1.3.3	Wet Chemistry-Spectral Analysis Relationship for Rapid and Reliable Fertilizer, Soil, and Plant Analyses	Global (ONGOING)	1. Wet chemistry-spectral analysis relationship to crop yield and nutrient response. Current activity focused on fertilizer samples a wide variety of nutrients and concentrations.	Calibration curves for XRF vs. wet chemistry 18 elements (excluding N and P) developed.	Bruker (equipment), NARES
		Kenya, HQ (NEW)	2. Evaluation of spectral and wet chemistry methods for detecting changes in soil nutrient status	Soil samples collected.	Local labs
		HQ/Global (ONGOING)	3. Working with partner organizations to improve methodologies and lab standards for fertilizers and amendments	24 lab assessments in 5 West African countries. Staff training. Delays due to COVID-19.	ISO, IFA, AAPFCO

Workstream 1		Country	Activity Summary	Progress (October 2019-March 2020)	Partnership
1.4	**Soil Health and Sustainable Intensification Practices: Integrated Soil Fertility Management, Conservation Agriculture, Nutrient Recycling**				
1.4.1	Evaluation of the Synergistic Effect of CA Practices in Combination with ISFM and Activated PR Amendment in Ghana and Niger (crosscutting with Workstream 3)	Ghana, Niger (2019-2020) (ONGOING)	Performance maize (Ghana) and millet (Niger) under CA versus non-CA and amendments - activated PR	8 trails in Northern Ghana completed and yields reported. Establishment of Niger trials will also be delayed	Africa RISING, NARES
1.4.2	Evaluation of the role of Legumes in Rice-Based Farming Systems in Mozambique for Nutrient Improvement, Soil Health, and Income Generation	Mozambique (NEW)	Promoting beans and vegetables in crop sequences with maize to improve farmer income and catalyze the use of fertilizers by smallholder farmers	Established 15 on-farm trials. Field days.	FAR Project, USAID-SEMEAR project, Yara Fertilizer Company
1.4.3	Increasing System Productivity Through Agronomic Biofortification with Crop Diversification and Intensification	Bangladesh (NEW)	Increasing system productivity through agronomic biofortification with crop diversification and intensification	S nutrition trials completed.	BARI, BAU, BRRI, SRDI.
1.4.4	Developing a Highly Productive and Sustainable Conservation Agriculture Production System for Cambodia	Cambodia (ONGOING)	Assessing changes in soil organic C and N stocks and soil functions of sandy paddy fields under conventional tillage and conservation agriculture production systems	Soil health parameters analyzed and reported. Impact on rice yield quantified. Data prep for modeling.	RUA-CE SAIN, GDA, DALRM, CASC, CIRAD, SIIL-KSU (university partnership)
1.4.5.	Integrating Best Management Practices for Climate Resilience in Rice-Cereal-Legume System in Nepal	Nepal (NEW)	Improving crop performance through balanced fertilization using customized compound fertilizers in rice-cereal-legume system	Four maize demo plots established and harvested.	NARC, AFU
1.4.6	Impact of Nutrient Recycling, Biofertilizers, and Bio-stimulants on Yield and Soil Health	Global, HQ (ONGOING)	1. Effective recycling of nutrients using biological, chemical, and physical processes for improving soil fertility, soil health, crop yield, and nutrient use	Representative soil samples collected. Characterized organic amendment.	Private sector, Auburn University, farmers

Table 10. Workstream 2: Supporting Policy Reform Processes, Advocacy, and Market Development (RFS-SFT/FY2018)

	Title/Activities	Country	Progress (October 2019-March 2020)	Partnership
2.1	**Document Policy Reforms and Market Development**			
2.1.1	Kenya Fertilizer Platform (KeFERT) Public-Private Dialogue and Coordination	Kenya (ONGOING)	Participation in USAID-Kenya Mission on Policy Working Group among Implementing partners	MoA, FAK, AGRA, private firms, KMT, One Acre Fund, Tegemeo, AFAP
2.1.2	Dissemination Event to Support Policy Efforts to Harmonize Fertilizer Quality Regulations in Zambia	Zambia (NEW)	Postponed – stakeholder response pending.	MoA Zambia, private firms
2.1.3	Policy Briefs on Fertilizer Policies, Reforms, and Market Development	Global (ONGOING)	• Policy brief in Niger initiated and in progress. • Policy brief on Nepal is dropped • Policy brief in Nigeria will be completed during the FY2020 end. • Policy brief on access to inputs by farmers in Boro season due to COVID shut down in Bangladesh in progress	PARSEN, MCA-Niger, NSAF, EnGRAIS
2.2	**Impact Assessment Studies**			
2.2.1	Assessment of Ongoing Fertilizer Distribution (Through Subsidies) and Implications Toward Better Design in Burkina Faso Modified as: Determinants of small farmer use of fertilizers in Senegal	Senegal (NEW)	• Activity modified for Senegal: • New activity on determinants of small holder use of fertilizers added.	EnGRAIS, ISRA-BAME
2.2.2	Impact of Agro-Dealer Development in Technology Transfer and Input Use and Access	Rwanda (ONGOING)	• Meeting with USAID Mission-RW to apprise the prelim survey results • Data analysis and draft reporting will be submitted in September'20 • Rapid assessment on COVID lockdown on last mile	AGRIFOP, AGRA-Rwanda
2.2.3	Assessing the Impact of Audio-Visual Based Extension Approach Toward Dissemination of Agricultural Technologies and Practices- Case of Soil Fertility Technologies in Northern Ghana	Ghana (Postponed)	• Postponed for FY2021 due to concurrence related issues	University of Illinois, UDS

Title/Activities		Country	Progress (October 2019-March 2020)	Partnership
2.2.4	Analyze the Impact of Counterfeit Fertilizer Products and Options for Fertilizer Certification in Kenya	Kenya (NEW)	• To be initiated in April. • Draft report toward end of FY2020.	KeFERT platform members, OCP-Kenya
2.3	**Economic Studies**			
2.3.1	Minimizing Market Distortions (Subsidies, Taxation, Logistics/Cost Build-Up) Economic Analysis/Assessment	Kenya (NEW)	• To be initiated in April • Draft report toward end of FY2020	Tegemeo, IFDC-AFO, AGRA, KeFERT
2.3.2	Identifying Characteristics of Fertilizer Consumption, Use, and Access (TAFAI-Niger) – Analyzing/Understanding Determinants of Fertilizer Use by Nigerien Farmers- Modified as FERTILIZER WATCH for Eastern and Southern Africa - as a part of COVID response –	East and Southern Africa (MODIFIED)	• Analytical reports – Fertilizer Watch in East and Southern Africa since April 2020 onward and will continue until September 2020. • Weekly reports publication in progress since April'20	IFDC-AFO
2.3.3	Gender Series on Women's Access and Use of Fertilizers: Case in Uganda – documenting women entrepreneurs (input suppliers and women farmers in Uganda)	Global (ONGOING)	• To be initiated in April onward. • Preliminary discussions held in February with REACH project in Uganda.	IFDC projects and interventions in Uganda

Table 11. Workstream 3: Sustainable Opportunities for Improving Livelihoods with Soils (SOILS) Consortium

Workstream 3		Country	Activity Summary	Progress (October 2019-March 2020)	Partnership
3.1	**Enhance Resilience to Food Insecurity and Conflict through Land-Use Planning, Soil Rehabilitation, and Capacity Building**				
3.1.1	Remote and On-the-Ground Land-Use Suitability Analysis to Guide Decision-Making in Niger	Niger	Develop land-use planning maps in Niger that provides land capability classifications (LCC) to guide commune and/or individual level decision making about appropriate land management.	Revised high-resolution base maps at 12.5 M resolution have been developed.	University, Colorado, USDA-ARS
3.1.2	Remote Sensing and Improved Use of Soil Data	Niger	Remote sensing will be used to aid in the identification of at-risk soils areas and use this to help select agronomic methods best suited for the soils. Use of LandPKS will be done in conjunction with the ley-annual cropping work, meshing crop production work with site-specific soils data.	Training workshop on LandPKS postponed to May. IFDC's AFRAD project data being incorporated leading to ground survey in June/July. Economic profitability assessment based on the Niger LSMS is currently in preparation for analysis.	Michigan State University, Colorado University, ICRISAT-Niger, INRAN, SOILS Consortium, IFDC-Niger
3.1.3	LandPKS Collaboration with Auburn University	Niger	Provide general support of the LandPKS Platform and improve the soil taxonomic unit descriptions and subsequent management information, with focus on lateritic soils, for the LandPKS app to support the Niger activities and the use of LandPKS more broadly.	FAO and WRB databases have been used to improve soil taxonomic unit descriptions of the soils of Niger and other regions in the LandPKS app. LandPKS app to link soil classifications to land management information.	Auburn University
3.2	**Enhancing Productivity and Food Security in Ethiopia through Improved Soil Fertility Management**				
3.2.1	Targeting Fertilizer Source and Rate in Ethiopia	Ethiopia	Produce a model for prediction of responses to different nutrient combinations and rates, with emphasis on K, S, Zn, and B, that improves upon current fertilizer targeting using soil critical values only	A unified Fertilizer Trial Protocol has been developed with EIAR. These research activities have just been approved for implementation	SOILS Consortium, ICRISAT, EIAR

Workstream 3		Country	Activity Summary	Progress (October 2019-March 2020)	Partnership
3.2.2	Decision Support System of Improved Access to Information and Farming Practices	Ethiopia	Sustainably intensify cropping systems using DSS and existing data for site- or farming system-specific management recommendations.	Teff model development. GH trials established for knowledge-gap research.	SOILS Consortium, EIAR
3.2.3	Quantifying Effect of Rainfall and Fertilizer Use on Crop Production in Ethiopia	Ethiopia	Assess the yield trends of the three major crops (teff, maize, and wheat) across years and locations in the two major regions of the country (Amhara and Oromia) and identify the effect of different yield-limiting factors	15 years of data on crop production, fertilizer use, and weather compiled, analyzed and interpreted. Manuscript prepared.	SOILS Consortium

Table 12. Cross-Cutting Activities: University Partnerships, Workshops, and Trainings FY2020

Theme/Activities	Countries	Partnership	Progress (Oct'19-Mar'20)
I. Collaboration with U.S. Land-Grant Universities*			
1.1.1 Developing Enhanced Efficiency N Fertilizers	Global	University of Central Florida	Dual-capped Zn nanoparticle coatings were formulated, characterized and sent to IFDC for coating of urea
1.1.2 Scaling Fertilizer Deep Placement (FDP) Technology for Granular and Briquette Fertilizers	Global	Mississippi State University	Prototype developed combined with rice transplanter. Delays due to COVID-19
1.2.1 Activated Phosphate Rock Trials under Greenhouse and Field Conditions	Northern Ghana	Soybean Innovation Lab, University of Illinois	Soybean field trials established on near-neutral soils and harvested.
1.4.4 Developing a Highly Productive and Sustainable Conservation Agriculture Production System for Cambodia	Cambodia	Kansas State University	Soil health parameters analyzed and reported. Impact on rice yield quantified. Data preparation for modeling
1.4.6 Impact of Nutrient Recycling, Biofertilizers, and Bio-Stimulants on Yield and Soil Health	Global	Auburn University	Representative soil samples collected. Student involvement delayed Cotton field trials begin this summer.
1.5.1 Develop IFDC Centralized Database Using AgMIP Database Template	Global	University of Florida	Database established and data uploaded http://database.ifdc.org:9000/cropsitedb Platform expansion to include new features.
1.5.2 DSSAT Cropping System Model Improvement and Application	Global	University of Florida	Carbon balance, and generic fertilizer module completed. Evaluating GHG emission model with IFDC and LTAR datasets. Training program postponed due to COVID-19.

Theme/Activities	Countries	Partnership	Progress (Oct'19-Mar'20)
Workstreams 1 and 2: Strengthening MELS Capacity in IFDC – PhD Training for an IFDC M&E Field Staff Member	Global	University of Georgia	In progress
3.1.1 Remote and On-the-Ground Land-Use Suitability Analysis to Guide Decision-Making in Niger	Niger	Colorado University	Revised high-resolution base maps at 12.5 M resolution have been developed.
3.1.2 Remote Sensing and Improved Use of Soil Data, Niger	Niger	Michigan State University	Training workshop on LandPKS postponed to May. Economic profitability assessment based on the Niger LSMS is currently in preparation for analysis
3.1.3 LandPKS Collaboration with Auburn University	Niger	Auburn University	FAO and WRB databases have been used to improve soil taxonomic unit descriptions of the soils of Niger and other regions in the LandPKS app.
**Note: All university partnerships involve graduate students/post-doctoral fellows and faculty expertise.*			
II. Outreach: Trainings/Workshops			
A. Workshops			
2.1.1 Support for Policy Reform Processes in Kenya – KeFERT Consultations and Meeting	Kenya	BFS/MoA/AFAP	Will be during June-July 20
2.1.2 Dissemination Event to Support Policy Efforts to Harmonize Fertilizer Quality Regulations in Zambia	Zambia	BFS/MoA-Zambia/AFAP	Postponed to FY2021
B. Training Programs			
International Training Program on Technology Advances in Agricultural Production, Water and Nutrient Management	USA	IFDC, BFS	Postponed to 2021
International Training Program on Assessing Crop Production, Nutrient Management, Climatic Risk and Environmental Sustainability with Simulation Models	University of Georgia	University of Florida, University of Georgia, DSSAT Foundation	Postponed to December 2020
GSSAT Training (Job Fugice, Upendra Singh, Sampson Agyin-Birikorang, John Wendt, Willingthon Pavon)	West Africa	NARES, University of Florida, local universities	Postponed to 2021

Annex

Publications

Agyin-Birikorang, S., I. Tindjina, C. Boubakary, W. Dogbe, and U. Singh. 2020. "Resilient Rice Fertilization Strategy for Submergence-Prone Savanna Agro-Ecological Zones of Northern Ghana," *Journal of Plant Nutrition*, 43:7, 965-986, https://doi.org/10.1080/01904167.2019.1702209

Baral, B., K. Pande, Y. Gaihre, K. Baral, S. Sah, and Y. Thapa. 2020. Farmers' Fertilizer Application Gap in Rice-Based Cropping System: A Case Study of Nepal. *SAARC Journal of Agriculture*, 17(2):267-277. https://doi.org/10.3329/sja.v17i2.45311

Dimpka, C.O., J. Andrews, J. Sanabria, P.S. Bindraban, U. Singh, W.H. Elmer, J.L. Gardea-Torresdey, and J.C. White. 2020. "Interactive Effects of Drought, Organic Fertilizer, and Zinc Oxide Nanoscale and Bulk Particles on Wheat Performance and Grain Nutrient Accumulation," *Science of the Total Environment*, 722. https://doi.org/10.1016/j.scitotenv.2020.137808

Dimpka, C.O., J. Andrews, J. Fugice, U. Singh, P.S. Bindraban, W.H. Elmer, J.L. Gardea-Torresdey, and J.C. White. 2020. "Facile Coating of Urea With Low-Dose ZnO Nanoparticles Promotes Wheat Performance and Enhances Zn Uptake Under Drought Stress," *Frontiers in Plant Science*, https://doi.org/10.3389/fpls.2020.00168

Gao, Y., D. Wallach, B. Liu, M. Dingkuhn, K.J. Boote, U. Singh, S. Asseng, T. Kahveci, J. He, R. Zhang, R. Confalonieri, and G. Hoogenboom. 2020. "Comparison of Three Calibration Methods for Modeling Rice Phenology," *Agricultural and Forest Meteorology*, 280:107785. https://doi.org/10.1016/j.agrformet.2019.107785

Kaeomuangmoon, T., A. Jintrawet, C. Chotamonsak, U. Singh, C. Buddhaboon, P. Naoujanon, and G. Hoogenboom. 2019. "Estimating Seasonal Fragrant Rice Production in Thailand using a Spatial Crop Modelling and Weather Forecasting Approach," *The Journal of Agricultural Science*, 157(7-8):566-577. https://doi.org/10.1017/S0021859619000881

Siddique, I.A., A. Al Mahmud, M. Hossain, M.R. Islam, Y.K. Gaihre, and U. Singh. 2020. "Movement and Retention of NH4-N in Wetland Rice Soils as Affected by Urea Application Methods," *Journal of Soil Science and Plant Nutrition*, 20:589-597. https://doi.org/10.1007/s42729-019-00148-2

Book Chapters

Hoogenboom, G., C.H. Porter, K.J. Boote, V. Shelia, P.W. Wilkens, U. Singh, J.W. White, S. Asseng, J.I. Lizaso, L.P. Moreno, W. Pavan, R. Ogoshi, L.A. Hunt, G.Y. Tsuji, and J.W. Jones. 2019. "The DSSAT Crop Modeling Ecosystem," IN K. Boote (ed.), *Advances in Crop Modelling for a Sustainable Agriculture*, pp. 173-216, K. Boote (ed.), Burleigh Dodds Science Publishing. https://doi.org/10.19103/AS.2019.0061.10

Pray, C.E., L. Nagarajan, A. Naseem, and J.R. Anderson. 2020. "Chapter 3: Investing in Innovation," IN *Harvesting Prosperity: Technology and Productivity Growth in Agriculture*,". pp. 95-146, K. Fuglie, M. Gautam, A. Goyal, and W. Maloney (eds.), World Bank. https://openknowledge.worldbank.org/bitstream/handle/10986/32350/9781464813931.pdf?sequence=6&isAllowed=y

Singh, U., and C.H. Porter. 2019. "Improving Modeling of Nutrient Cycles in Crop Cultivation," IN K. Boote (ed.), *Advances in Crop Modelling for a Sustainable Agriculture*, pp. 69-99, Burleigh Dodds Science Publishing.

Policy Briefs

Nagarajan, Latha, Anwar Naseem, Carl Pray. 2020. "Seed Policy Reforms in Zambia," Published in Agrilinks on March 9 2020. https://www.agrilinks.org/post/seed-policy-reforms-zambia

Nagarajan, L., A. Naseem, and C.E. Pray 2019. Policy Brief on "Contribution of Policy Change on Maize Varietal Development and Yields in Kenya," http://ru-ftf.rutgers.edu/policy_briefs.html

Presentations

Demiss, Mulugeta. 2020. "Developing Teff Model in DSSAT and Teff's Response to Different Growth Factors Study," IFDC Webinar, February 11, Muscle Shoals, AL. https://ifdc.sharepoint.com/:b:/s/Communications/EdYa6-vPjsJCtqPMcMy3KQUBpU4IBiGQcM8DzMbik2OGzA

Nagarajan, Latha, Anwar Naseem, and Carl Pray. 2019. "Input Policy for Agriculture-Led Growth: A Case Study of Maize Seed Policies in Kenya," presented at the USAID BFS-funded Rutgers University Policy Research Consortium Listening Session meetings, October 28, 2019, Washington DC. https://ifdc.sharepoint.com/:p:/s/Communications/Ee56re6Ag3JBjeWvAJMIZ3cB4bMqOlHOAgO4M5lwZ4FT9Q?e=aopB3d

Nagarajan, L., and A. Thigpen. 2019. "Reaching the Unreached through Resilient Market Systems," presented at the AIARD meeting, with a theme of resilience. http://www.aiard.org/uploads/1/6/9/4/16941550/aiard_lightning_talks_nagarajan_thigpen_ifdc.pdf. June 2019, Washington D.C.

Singh, U. 2019. "Smart Fertilizers and Technologies for Next-Generation Nutrient and Water Management," presented at the International Conference on Soil and Water Resources Management for Climate Smart Agriculture, Global Food and Livelihood Security. November 5-9, NASC, Pusa, New Delhi, India.

Singh, U. 2019. "New Avenues and Opportunities for Indo-U.S. Collaborative Research with Special Reference to Nano fertilizers," presented at the Next Generation Biologically Synthesized Nano Fertilizers for Seed Coating and Foliar Application conference organized by The Energy Research Institute (TERI-Deakin Nanobiotechnology Centre) in collaboration with IFDC, September 5-9, New Delhi, India. https://ifdc.sharepoint.com/:b:/s/Communications/Ee_JA_Tc8uFFjeUt4bcyTvYBTAgZTrLhKoAWaYa8AHekow?e=yR4IVf

Stewart, Z.P. 2020. "Market Place: Introduction to the SOILS Consortium. Supporting Soil Health Interventions in Ethiopia: Opportunities for Accelerating Impact," Gates, GIZ, EIAR, February 6-7, Addis Ababa, Ethiopia.

Wendt, J. 2020. “Determining Lime Requirement,” presented at a workshop hosted by KEFERT on lime impact study dissemination workshop of Kenya Markets Trust (KMT), January 5th, 2020, Nairobi, Kenya. https://ifdc.sharepoint.com/:b:/s/Communications/EQ4qsbmhta1AmCV09qo-jtsBVR_1l5qVNlr57d3WJaPncQ?e=EjXuKz

Trainings

Two farm-level trainings on Urea-S research trial conducted December 26, 2019, and December 29, 2020 in Bangladesh.
Topic: Trials Objectives, Trial Establishment Approaches and Methodologies and Research Management. Participants: 14 farmers (12 male and 2 female) and 2 SAAOs.

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