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

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

Semi-Annual Performance Report

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Cooperative Agreement
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Acronyms and Abbreviations

AAP	Alliance for African Partnership
AAPI	Accelerating Agriculture Productivity Improvement
AFAP	African Fertilizer and Agribusiness Partnership
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
AS	Ammonium Sulfate
ASA	American Society of Agronomy
ATT	Feed the Future Ghana Agriculture Technology Transfer Project
AWD	Alternate Wetting and Drying
B	Boron
BDT	Bangladeshi Taka
BFS	Bureau for Food Security
BPCU	Bio-Based Polymer-Coated Urea
C	Carbon
Ca	Calcium
CA	Conservation Agriculture
CAES	Connecticut Agricultural Experiment Station
CASC	Conservation Agriculture Service Center
Cd	Cadmium
CE SAIN	Center of Excellence on Sustainable Agricultural Intensification and Nutrition
CH_4	Methane
CIMMYT	International Maize and Wheat Improvement Center
CIRAD	Centre de Coopération Internationale en Recherche Agronomique pour le Développement
CN	Concept Note
CO_2	Carbon Dioxide
COMESA	Common Market for Eastern and Southern Africa
COMRAP	COMESA's Regional Agricultural Inputs Program
CRF	Controlled-Release Fertilizer
CSM	Cropping System Model
CSO	Civil Society Organizations
CSSA	Crop Science Society of America
CT	Conventional Tillage
Cu	Copper
CU	University of Colorado
DALRM	Department of Agricultural Land Resources Management
DAP	Diammonium Phosphate
DI	De-Ionized
DSSAT	Decision Support System for Agrotechnology Transfer
DTPA	Diethylenetriaminepentaacetic Acid
ECOWAS	Economic Community of West African States
EDTA	Ethylenediamine Tetraacetic Acid

EIAR	Ethiopian Institute of Agricultural Research
EnGRAIS	Enhancing Growth through Regional Agricultural Input Systems
ES	Elemental Sulfur
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FAR	Food security through climate Adaptation and Resilience in Mozambique
FDP	Fertilizer Deep Placement
FQA	Fertilizer Quality Assessment
FSI+	Fertilizer Sector Improvement Project
FTF	Feed the Future
FTIR	Fourier-Transform Infrared Spectroscopy
FY	Fiscal Year
GARDIAN	Global Agricultural Research Data Innovation & Acceleration Network
GDA	General Directorate of Agriculture
GHG	Greenhouse Gas
GSSAT	Geospatial Decision Support System for Agrotechnology Transfer
HR-TEM	High-Resolution Transmission Electron Microscopy
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IER	*Institut d'Economie Rurale*
IFA	International Fertilizer Association
IFAD	International Fund for Agricultural Development
IFDC	International Fertilizer Development Center
IFEW	International Fertilizer Experts Working
ILRI	International Livestock Research Institute
INERA	*Institut de l'Environnement et de Recherche Agricole*
ISFM	Integrated Soil Fertility Management
K	Potassium
KALRO	Kenya Agricultural and Livestock Research Organization
KEBS	Kenya Bureau of Standards
KeFERT	Kenya Fertilizer Roundtable
KSU	Kansas State University
LandPKS	Land-Potential Knowledge System
LTAR	Long-Term Agroecosystem Research
M&E	Monitoring and Evaluation
MAP	Monoammonium Phosphate
MCC	Millennium Challenge Corporation
MELS	Monitoring, Evaluation, Learning, and Sharing
MERES	Methane Emissions in Rice Ecosystems
Mg	Magnesium
Mn	Manganese
MoALF&I	Ministry of Agriculture, Livestock, Fisheries, and Irrigation
MOFA	Ministry of Food and Agriculture
MSU	Michigan State University
N	Nitrogen
N_2O	Nitrous Oxide
NAC	n-acetyl cysteine
NAI	National Agro Machinery Industries

NARES	National Agricultural Research Extension Systems
NARS	National Agricultural Research Center
NDVI	Normalized Difference Vegetation Index
NH_3	Ammonia
NH_4-N	Ammonium-N
NIFA	National Institute of Food and Agriculture
NML	New Markets Lab
NO_3-N	Nitrate Nitrogen
NSAF	Feed the Future Nepal Seed and Fertilizer Project
NUE	Nitrogen Use Efficiency
OOC	Out of Compliance
P	Phosphorus
PEMEFA	Partnership for Enabling Market Environments for Fertilizer in Africa
POXC	permanganate-oxidizable C
PR	Phosphate Rock
PSDAG	Private Sector-Driven Agriculture Growth
PVoC	Pre-Export Verification of Conformity
RADD	Rwanda Agro-Dealer Development
RAE	Relative Agronomic Effectiveness
RDA	Recommended Dietary Allowance
ReNAPRI	Regional Network of Agricultural Policy Research Institute
RISING	Research in Sustainable Intensification for the Next Generation
RUA	Royal University of Agriculture
S	Sulfur
SAL	Sodium Salicylate
SBPCU	Self-Assembly Modified Bio-Based Polymer-Coated Urea
SEM	Scanning Electron Microscopy
SFT	Soil Fertility Technology
SIIL	Feed the Future Innovation Lab for Collaborative Research on Sustainable Intensification
SIL	Soybean Innovation Lab
SMaRT	Soil testing, Mapping, Recommendations development, and Technology transfer
SOC	Soil Organic Carbon
SOILS	Sustainable Opportunities to Improve Livelihoods with Soils
SOP	Sulfate of Potash
SRI	System of Rice Intensification
SSA	Sub-Saharan Africa
SSBPCU	Self-Assembly and Self-Healing Modified Bio-Based Polymer-Coated Urea
SSSA	Soil Science Society of America
SWAT	Soil and Water Assessment Tool
SWOT	Strengths, Weaknesses, Opportunities, and Threats
TAFAI-Ke	The African Fertilizer Access Index for Kenya
ToR	Terms of Reference
TSP	Triple Superphosphate
UCF	University of Central Florida
UDP	Urea Deep Placement
UDS	University for Development Studies

UF	University of Florida
USAID	U.S. Agency for International Development
USDA	U.S. Department of Agriculture
USG	Urea Supergranules
UTEP	University of Texas at El Paso
WFTO	World Fertilizer Trends and Outlook
WSP	Water-Soluble Phosphorus
WorldVeg	World Vegetable Center
XRD	X-Ray Diffraction
ZARI	Zambia Agricultural Research Institute
ZMAL	Zambia Ministry of Agriculture and Livestock
Zn	Zinc
ZnO	Zinc Oxide
ZnO-NP	Zinc Oxide Nanoparticles

Progress Toward Cooperative Agreement Award Objectives

The International Fertilizer Development Center (IFDC) brings together innovative research, market expertise, and strategic public and private sector partners to identify and scale sustainable solutions for soil and plant nutrition. IFDC is implementing the U.S. Agency for International Development (USAID)-funded Bureau for Food Security Feed the Future project on Soil Fertility Technology Adoption, Policy Reform, and Knowledge Management (BFS-SFT) under a cooperative agreement mechanism with buy-in provisions since March 2015. The project bridges the gap between scientific research and technology dissemination to smallholder farmers. BFS-SFT conducts research with partners from universities, national and international research and development institutions, and the private sector. All the research activities were conducted in partnership with national and international agricultural research institutions and the private sector in a sub-Saharan African (SSA) and Asian country setting.

The BFS-SFT project activities taken up during fiscal year (FY) 2019 focused on the areas as described under the three workstreams in Table 1.

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

Workstream 1 (WS 1)				Workstream 2 (WS 2)			Workstream 3* (WS 3)
Developing and Validating Technologies, Approaches, and Practices				Supporting Policy Reform Processes, Advocacy, and Market Development			SOILS Consortium (Sustainable Opportunities for Increasing Livelihoods with Soils)
Focus Areas				**Focus Areas**			**Focus Areas**
Improving Nitrogen Use Efficiency	Activated Phosphate Rock	Balanced Crop Nutrition	Sustainable Soil Intensification Practices	Documenting Policy Reforms & Market Development	Impact Studies, Assessments	Agro-Economic Studies	Identify holistic solutions, developing a roadmap toward enhancing soil fertility
Cross-Cutting:							
MELS, Knowledge & Data Management Improving the Decision-Making Tools for Cropping System Model for Soil Sustainability Processes University Partnerships, Capacity Building, Workshops							

**From March 2019 onward*

Under Workstream 1, IFDC continued "**Developing and Validating Technologies, Approaches, and Practices**" that address nutrient management issues and advance sustainable agricultural intensification in Feed the Future (FTF) countries.

The major focus of this activity is improving nitrogen (N) use efficiency by minimizing N losses while increasing productivity. This can be accomplished by developing/using alternatives to urea, modified and coated urea products, synthetic and natural coatings, additives/amendments (organic, biofertilizers, bio-stimulants), and nano-materials/nano-micronutrients (phosphate rock [PR], elemental sulfur [ES], zinc [Zn], boron [B]), and implementing innovative practices, such as mechanized fertilizer deep placement (FDP). With N application in Africa already low, increased efficiency of applied N is key to achieving greater productivity and profitability and minimizing environmental impacts. The activities were conducted under field, greenhouse, and laboratory conditions, targeting: (a) development and/or evaluation of more efficient N fertilizers; (b) resolving technology dissemination/scaling constraints to FDP; and (c) promoting climate resilience and minimizing greenhouse gas (GHG) emissions from N fertilizers.

Under Workstream 2, IFDC supported "**Policy Reform Processes, Advocacy, and Market Development**." Relevant research was conducted to support IFDC global activities relating to agricultural policy reforms, advocacy for change, and related efforts to achieve impact in FTF country agriculture. Therefore, the activities included conducting research and analysis for evidence-based policies and supporting reform initiatives for market development, focusing on three broad categories that include documenting fertilizer/input market policy reform processes and engagement with partners to influence policy reforms, conducting impact assessments, and carrying out economic studies.

Under Workstream 3, IFDC supported activities under the **SOILS Consortium**, initiated by IFDC in collaboration with the Feed the Future Innovation Lab for Collaborative Research on Sustainable Intensification (SIIL) at Kansas State University (KSU) with support from USAID-BFS since March 2019. The SOILS Consortium also partners with a host of U.S. academic research partners from Michigan State University (MSU), University of Colorado (CU), Auburn University, and the U.S. Department of Agriculture Agricultural Research Service (USDA-ARS). SOILS Consortium partners further engaged in identifying research activities that offer holistic solutions to developing a roadmap toward enhancing soil fertility in selected countries. This workstream also aimed at providing research solutions and improving capacity building of national-level research partners, especially national agricultural research centers (NARS) in Niger and Ethiopia, in soil fertility-related technologies for further scaling and dissemination in partnership with public entities, such as government programs.

Cross-Cutting Issues, Including University Partnerships and Knowledge Management

Under the awarded agreement, IFDC conducted a range of activities and interventions prioritized by the 2019 annual work plan, including greater partnerships with U.S. universities. A summary of the various associated outreach activities and the methods of disseminating research outcomes and findings are reported in Annexes 1, 2, and 3.

Results – Summary FY 2019

Major results from the workstreams contribute to developing several research products (at different phases of research) because of U.S. government assistance, i.e., higher level outcomes.

During FY2019, we have reported seven unique technologies/approaches and practices developed and further available for scaling and successful dissemination at the farmer level through public and private organizations. Hence, the direct beneficiaries would be farmers and also private firms who are engaged in the production of efficient fertilizers and technologies; and public sector organizations, such as research institutions (national and international), toward better data and scientific knowledge-sharing, including joint publications (20 reported during 2019). The project also produced evidence-based research studies and analysis studies (four) that can generate much interest in improving the enabling environment under which soil fertility-related policies and regulations have been operating in SSA and South Asia. Such studies have been compiled to generate awareness among national-level stakeholders to influence policy reforms. The work also has resulted in consultations conducted with stakeholders that resulted in successful policy platform formation toward advising national governments (e.g., Kenya Fertilizer Platform launch and advising the Government of Kenya on subsidy reforms).

The outcomes from the activities associated with Workstreams 1 and 2 have also further resulted in capacity building of professionals from both public and private sectors as well as farmers in five different locations globally (Nepal, Bangladesh, Ghana, Myanmar, and Thailand) on soil fertility-related technologies and practices that involved farmer-producers, civil society organizations (CSOs), government extension, private firms, and people from research organizations. All of the capacity building programs – especially those associated with demonstrating the effectiveness of new fertilizer technologies conducted at the farmer level – were taken up extensively in the form of field days and crop-field demonstrations involving local farmers in partnership with government extension officials for wider dissemination and further follow up. The capacity building programs aimed at addressing the needs of women farmers and entrepreneurs as well engaging youth in promoting such technologies. This effort was made deliberately, since women farmers in these communities were much more receptive (e.g., in Northern Ghana field days/trials). Most of the training participants were between the ages of 25 and 45 years old in the case of farmers and those from the private sector and CSOs, with more experienced personnel participating from the government organizations.

The activities under Workstreams 1 and 2 also have contributed to the formation of eight successful public-private partnerships toward implementing our research activities – with either laboratory or field testing – and to influencing policy reforms at the country level. A few key partnerships to note are in (a) developing products to enhance nitrogen use efficiency using biodegradable coatings; (b) developing fertilizer applicators for placement of fertilizers to improve efficiencies; (c) field trials and testing of balanced fertilizers with secondary and micronutrient-based coatings; and (d) influencing fertilizer policy reforms to create an enabling environment to improve the fertilizer access and use in partnership with private sector stakeholders.

The above results and associated outcomes are key to achieving the overall project goal of BFS-SFT, i.e., enhance agriculture productivity through improved soil and nutrient management and fertilizer market development, policy reform, and improved regulatory framework in FTF countries.

1. Workstream 1 – Developing and Validating Technologies, Approaches, and Practices

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 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.

Outcomes of Workstream 1: The proposed activities within Workstream 1 are expected to result in (a) increased agricultural productivity; (b) improved soil fertility, soil health, and plant nutrition; (c) increased climatic resilience through increased abiotic and biotic stress tolerance; (d) reduced nutrient losses; (e) greenhouse gas (GHG) mitigation; and (f) overall improved resource use efficiency (nutrients, water, land, and labor). The overall goal is to close the yield gap and produce more with less.

In the 2019 workplan, Workstream 1 activities were categorized as follows:

- Technologies developed, refined, and adapted to improve nitrogen use efficiency
- Activated phosphate rock (PR) evaluation and validation to improve PR reactivity and phosphorus (P) efficiency
- Balanced crop nutrition
- Sustainable intensification practices
- Improving the cropping system model for soil sustainability processes.

A few ongoing activities from the FY2018 workplan (e.g., in Ghana, Myanmar) are also reported in one of the above categories. All reported activities are being conducted in partnership with national agricultural research extension systems (NARES) in FTF countries or areas targeted as FTF countries. The research activities carried out at IFDC headquarters or university partners support and complement field activities. Below is a summary of activities for this reporting period.

1.1 Technologies Developed, Refined, and Adapted for Improving Nitrogen Use Efficiency

The major focus of this activity is improving nitrogen (N) use efficiency by minimizing N losses while increasing productivity. This can be accomplished by developing/using alternatives to urea, modified and coated urea products, synthetic and natural coatings, additives/amendments (organic, biofertilizers, bio-stimulants), nano-materials/nano-micronutrients (PR, elemental sulfur [ES], zinc [Zn], boron [B]), and implementing innovative practices such as mechanized fertilizer deep placement (FDP). The research trials reported here were conducted under on-farm, greenhouse, and laboratory conditions, targeting:

- Development and/or evaluation of more efficient N fertilizers.
- Resolving technology dissemination constraints to FDP.
- Promoting climate resilience and minimizing GHG emissions from N fertilizers.

The research trials reported here were conducted under on-farm, greenhouse, and laboratory conditions to:

- Determine the effects of secondary and micronutrients, coatings, and controlled-release fertilizers on nitrogen use efficiency.
- Quantify the effect of subsurface fertilizer application on improved nutrient use efficiency.
- Evaluate whether fertilizer best management practices can improve stress tolerance.

1.1.1 Development and Evaluation of Enhanced Efficiency N Fertilizers

Developing smart fertilizer products that are climate-resilient, require one-time application, have high N use efficiency, and reduce reactive N and P additions to the environment is one of the major focuses of this sub-activity. Promising enhanced efficiency products available in the market are being evaluated under field conditions in sub-Saharan Africa and South Asia.

1.1.1.1 Developing Enhanced Efficiency N Fertilizers

Along with in-house development and testing, IFDC, through a collaborative partnership with the University of Florida (UF) and the University of Central Florida (UCF), is developing N fertilizers with improved N use efficiency (> 60%). Planned work includes using agricultural wastes, alternative renewable and biodegradable materials, and alternative slower release fertilizers and amendments, such as PR, ES, Zn, B, polyhalites, urea formaldehydes and urea-polymers, as coating materials.

A. Developing Hydrophobic and Controlled-Release Fertilizer

Research activity: Evaluation of renewable materials (soybean oil, castor oil, alginate) as effective coatings for controlled-release fertilizers (CRFs)

Location: IFDC Headquarters laboratories in Muscle Shoals, Alabama, United States

Time period: FY2019

Partners: University of Florida

Details: The use of CRFs is an effective approach to improve nutrient use efficiency and to reduce environmental pollutants. Current CRFs are usually coated with petroleum-based synthetic materials, such as polyolefins, acrylic resin, and polysulfones. However, these are usually difficult to produce on a large-scale and involve either toxic or complicated production processes. Moreover, the raw materials are derived from non-renewable resources and are often nondegradable, resulting in severe environmental pollution, depletion of fossil fuels, and the reduction of energy security. However, most biomaterials, such as cellulose and starch, are hydrophilic and easy to hydrolyze.

To address these challenges, we are evaluating renewable materials (soybean oil, castor oil, alginate) as effective coatings for CRFs. We are applying nanotechnology and chemical grafting techniques to prepare hydrophobic, self-assembling and self-healing bio-based nanocomposite coating materials to encapsulate granular urea. In this effort, three biopolymers will be prepared: bio-based polymer-coated urea (BPCU), self-assembly modified BPCU (SBPCU), and self-assembly and self-healing modified BPCU (SSBPCU). The newly synthesized CRFs are expected to achieve slow and controlled nutrient release using hydrophobic and environmentally friendly coating materials.

This process of producing the first trial of the biopolymer-coated products was tested, and the initial characterization test of peanut shell and liquefied peanut shell was done using a scanning electron microscope (SEM), X-ray powder diffraction (XRD), and Fourier-transform infrared spectroscopy (FTIR) to understand the coating products in terms of surface morphology (Figure 1), roughness, elemental composition, and distribution. Along with the characterization, nutrient release measurements were conducted using an ISO 18644 method and an accelerated method (standard method in China) to plot the percentage N release as a function of time.

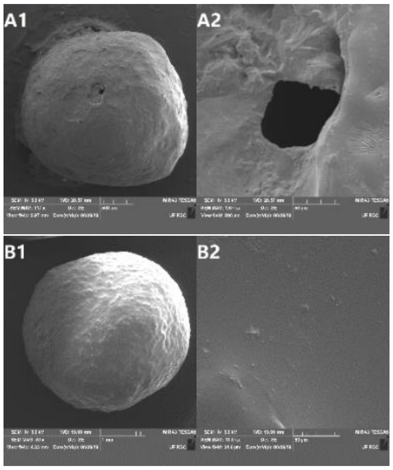


Figure 1. The surface morphologies of BPCU (A1, A2) and SSBPCU (B1, B2) using SEM.

Results: In this study, self-healing modified liquefied peanut shell-coated fertilizers were successfully fabricated to develop a novel CRF. The results demonstrate that SSBPCU had the slowest nutrient release rates, with a longevity of 110-170 days. Both the self-assembling of dopamine and polyamine and the introduction of self-healing SA-modified NHS particles reduced micropores and cracks in biopolymer coating membranes. The self-healing function of SA-NHS was the key to controlling the process of the fertilizer release rate. Thus, the findings from this study provided a novel idea for accurately controlling the nutrient release profile to satisfy plant growth.

Next Steps: IFDC will evaluate those products in greenhouse, volatilization, leaching, and incubation experiments.

Outputs: An initial report was produced and is linked in Annex 3.

B. Improving N Use Efficiency and Delivery of Secondary and Micronutrients

Research activity: (i) Coating urea fertilizers with a multi-nutrient polyhalite material and micronutrients using various binders, additives, and methodologies and (ii) Improving the nutrient use efficiency of the urea fertilizer.

Location: IFDC Headquarters laboratories in Muscle Shoals, Alabama, United States

Time period: FY2019

Partners: Private industry

Details: Ten products (Table 2) were coated and are currently being evaluated under volatilization and incubation studies. In September 2019, a visit from a private industry representative took place at IFDC Headquarters to discuss the current results and possible future collaboration.

Table 2. Treatment list of the coated products for volatilization and full-term incubation study

Treatment	Product
1	Check
2	Urea
3	POLY4
4	Agrotain
5	Urea / Polyhalite
6	Urea / Polyhalite / Starch
7	Urea / Polyhalite / Starch (3 layers)
8	Urea / Polyhalite / Agrotain
9	Urea / Polyhalite / Agrotain / Wax
10	Urea / Polyhalite / $CaCN_2$

Results: From the volatilization experiment, a few samples proved to be effective in reducing ammonia (NH_3) loss. As in Figure 2, the materials coated with three starch layers and the Agrotain products showed a significant difference compare to the other products, such as uncoated urea.

The data curves for urea-N (Figure 3), ammonium-N (NH_4-N) (Figure 4), and nitrate nitrogen (NO_3-N) (Figure 5) are shown below. As shown in Figure 3, all of the treatments follow the same general trendline with a noteworthy distance between the Agrotain-containing products; however, on the fourth day the rest of the urea products did show improvements in urea release. There is a similar difference in the NH_4-N graph from days 2 to 4, demonstrating the slower hydrolysis rate due to the inhibition effects. The data also revealed that the check and POLY4 treatments are set apart from the rest of the treatments in each graph. These two treatments have no added nitrogen, so they are a baseline. Regarding the nitrate graphs, it is reasonable that there is no difference due to the urease inhibitors not affecting the nitrification processes. Interestingly, the three layers of starch product are not performing as seen in the volatilization studies.

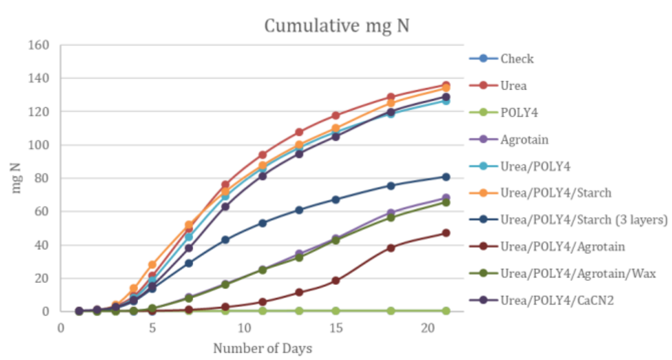


Figure 2. Nitrogen release during volatilization test.

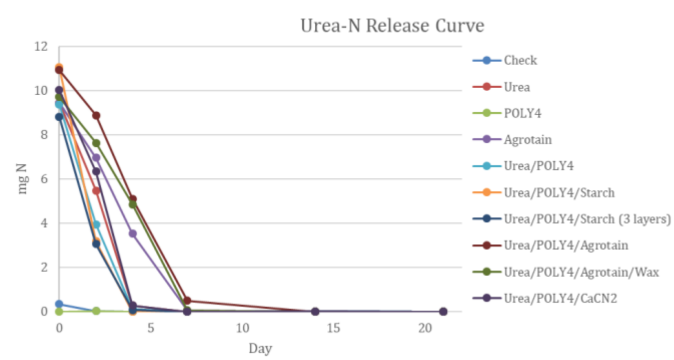


Figure 3. Urea-N release from each treatment.

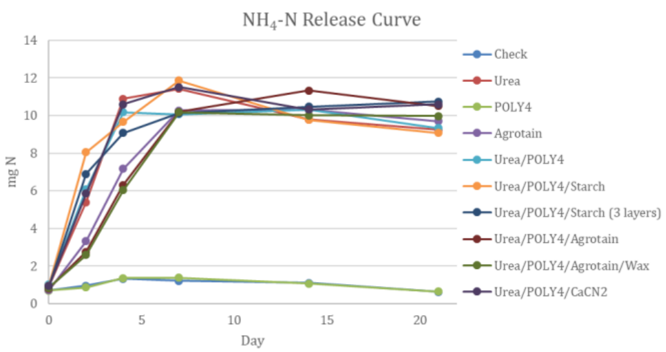


Figure 4. NH4-N-N release from each treatment.

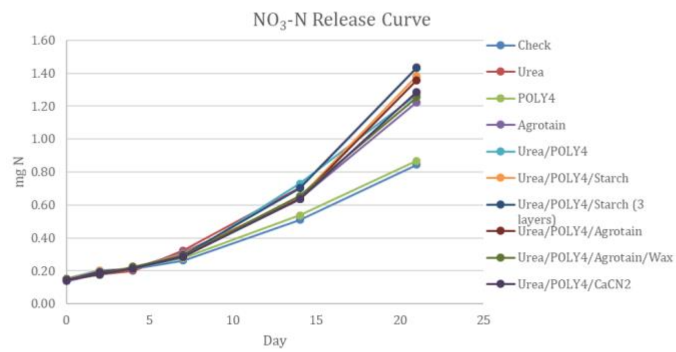


Figure 5. NO3-N release from each treatment.

Output: The incubation experiment is ongoing, and only data for the first three weeks are available.

1.1.1.2 Field Evaluation of Modified Urea-S Products

Several modified urea products, including urea-ammonium sulfate, urea-S, urea-Zn, urea-B, various forms of Agrotain-coated urea, and controlled-release urea products, are already on international markets, including those in Africa and Asia. IFDC has already compared many of these products under laboratory and greenhouse conditions. These products do not require briquetting or special applicators and, like FDP, can be applied at one time. Field trials have been conducted to evaluate yield response and economic returns to these products, compared to urea and FDP in upland crops and lowland rice systems.

A. Urea-Sulfur Evaluation in Bangladesh, Myanmar, and Nepal

Research activity (i): Field trials to determine the optimum rate and efficient source of urea-sulfur fertilizers

Location: Bangladesh

Time period: Field trials were established in November 2018.

Details: Two field trials were established with sulfur-enriched urea fertilizers in sulfur-deficient areas of Bangladesh (Figure 6). At each site, ten treatment combinations from different sulfur (S) sources (Thiogro ES 13%, Thiogro ESS 13%, Thiogro ES 75%, and gypsum) and different sulfur rates (0, 25, 50, and 75 kg S/ha) were laid out in a randomized complete block design with 4 replications in maize. Nitrogen fertilizers (both urea and urea-sulfur) were applied in three equal splits at the final land preparation, 6-8 leaves, and tasseling stages, respectively. For the farmer practice treatment, all fertilizers were applied using the existing farmer practice. Biomass yields (grain and straw), plant height, number of cobs per plant, number of rows per cob, number of kernels per row, and 1,000-grain weight were recorded from each plot. In addition, plant samples (grain and straw) were collected to determine N and S use efficiency, and soil samples were collected to see the effects on soils.

Figure 6. Evaluation of urea-sulfur fertilizers in the North-West part of Bangladesh (sulfur-deficient site).

Results: The addition of sulfur, regardless of the source, increased grain yields significantly compared to farmer practice. Among the different sulfur sources, ES 75% and ES 13% produced relatively higher yields compared to gypsum and ESS 13%. However, the differences in yields among the sulfur sources were below statistical significance. On average, sulfur application increased yields by 1.06 mt/ha (Figure 7). In addition to sulfur, the application of micronutrients (zinc and boron) increased yields by 0.55 mt/ha. Maize yields increased with an increasing sulfur rate up to 50 kg/ha. The highest yield was observed at 50 kg/ha.

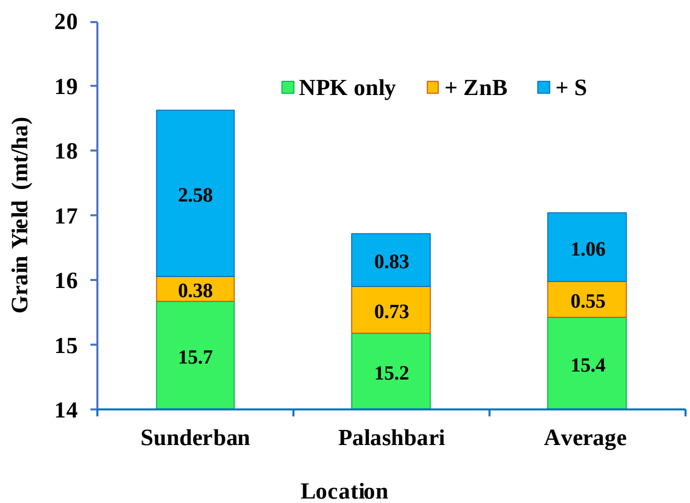


Figure 7. Effects of NPK, S, and micronutrients (zinc and boron) on maize grain yields across two locations in Northern Bangladesh.

Output: Analyses of plant and soil samples are in progress and will be reported in the next reporting period. A link to a more detailed report is in Annex 3.

Sulfur-Enriched Urea Fertilizer Brought Happiness for Rashid

Sulfur-enriched urea fertilizer was applied to maize in a field trial conducted in the sulfur-deficient areas of Northern Bangladesh from November 2018 to May 2019; Mr. Abdur Rashid owns the land. Urea-sulfur (sulfur-enriched urea fertilizer) is a new fertilizer product in Bangladesh. At harvest, plots applied with the new fertilizer produced a robust maize cob with higher relative maturity, kernel height, and shelling qualities. The maize also had a brighter grain color and more weight compared to the plots where farmer practice was applied. Grain yield calculated from crop cut results showed that Rashid produced an additional 2.1 mt/ha of maize by using the sulfur-enriched urea fertilizer compared to his own practice plot. During the harvest in May 2019, the market value of the additional production was approximately Bangladeshi Taka (BDT) 21,017 (US $250).

> "*I have never seen such a robust maize crop in my field as well as in others' fields in my life. I had never imagined such high production of maize using new fertilizer. I want to use this new fertilizer on a regular basis, if available in the market.*" – Abdur Rashid

Rashid's successful maize production inspired and encouraged other farmers in the area. The sulfur-enriched urea fertilizers' performance has been recognized throughout the neighboring farms, and many farmers often come to IFDC's Junior Soil Scientist and request the new fertilizer.

Rashid's family during threshing of trial plots, Sundarban, Dinajpur, Bangladesh

Research activity (ii): Evaluation of sulfur-enriched urea fertilizers and best-bet fertilizer management practices in tomato, cauliflower, and wheat

Location: Nepal

Time period: FY2019

Partners: International Maize and Wheat Improvement Center (CIMMYT) under the Feed the Future Nepal Seed and Fertilizer (NSAF) project

Details: Sulfur-enriched urea fertilizers (Thiogro ES 13% and Thiogro ESS 13%) and best-bet fertilizer management practices were evaluated in 35 tomato, 56 cauliflower, and 48 wheat trials.

Results: Sulfur application enriched urea with 50% less N compared to the government-recommended rate, and it produced similar or higher yields compared to other best-bet N treatments, including polymer-coated urea and urea deep placement (Figure 8).

Treatments

1. 0:0:0 kg NPK/ha
2. 0:0:0 kg NPK/ha + 30 t/ha FYM (organic)
3. 150:120:100 kg NPK/ha + Borax 14 kg/ha + $ZnSO_4$
4. 150:120:100 kg NPK/ha + 30 t/ha FYM (gov't recommended)
5. 100:120:100 kg NPK/ha + Borax 14 kg/ha + $ZnSO_4$ + 30 t/ha FYM
6. 100:120:100 kg NPK/ha (N as polymer-coated urea) + Borax 14 kg/ha + $ZnSO_4$ + no FYM
7. 100:120:100 kg NPK/ha; N application with polymer-coated urea (PCU) + Borax 14 kg/ha + $ZnSO_4$ + 30 t/ha FYM
8. **100:120:100 kg NPK/ha; N application with urea-sulfur fertilizer (ES 13) + Borax 14 kg/ha + $ZnSO_4$ + no FYM**
9. **100:120:100 kg NPK/ha; N application with urea-sulfur fertilizer (ES 13) + Borax 14 kg/ha + $ZnSO_4$ + 30 t/ha FYM**
10. 100:120:100 kg NPK/ha; N application with urea deep placement (UDP) + no FYM
11. 100:120:100 kg NPK/ha; N application with urea deep placement (UDP) + 30 t/ha FYM

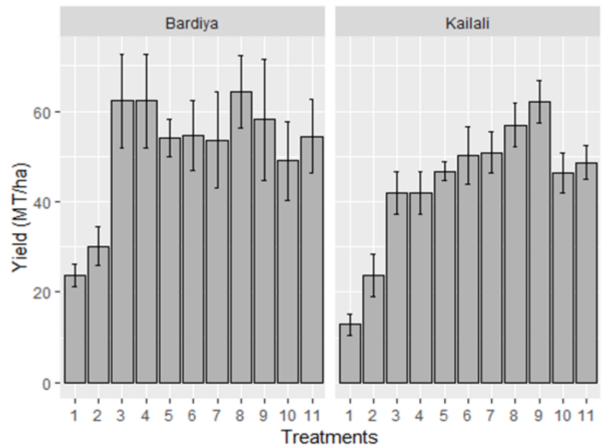


Figure 8. Effects of urea-sulfur fertilizer (ES 13) on cauliflower curd yields compared with different best-bet N fertilizers across two districts in Western Nepal.

Sulfur application increased yields by up to 5 mt/ha. Unlike with cauliflower, the effects of sulfur enriched urea on wheat were not significant compared to other best-bet N management practices (Figure 9). In Nepal, soil analysis data are very limited, and there are no soil fertility maps. These trials confirmed that sulfur is one of the limiting nutrients, and the addition of sulfur could significantly increase the yields of both cereals and vegetables.

Outputs: The data is being processed to prepare scientific papers in partnership with the NSAF project. In addition, an abstract was submitted to the International Nitrogen Initiative Conference that is to be held in Germany in 2020.

Treatments

1. 0:0:0 kg NPK/ha
2. 100:50:10 kg NPK/ha (100% N as PCU, applied at planting)
3. 100:50:10 kg NPK/ha (75% N as PCU, all N applied at planting)
4. 100:50:10 kg NPK/ha (50% N as PCU, all N applied at planting)
5. 100:50:10 kg NPK/ha (25% N as PCU, all N applied at planting)
6. 100:50:10 kg NPK/ha (100% N as regular urea, all applied at planting)
7. 100:50:10 kg NPK/ha (100% N as regular urea, 50% each applied after first irrigation and second irrigation)
8. 80:50:10 kg NPK/ha (100% N as PCU, applied at planting)
9. Gov't recommended rates (100:50:50 kg NPK/ha + 6 t/ha FYM)
10. **100:50:10 kg NPK/ha (100% of urea N from urea Sulphur EES applied at planting)**

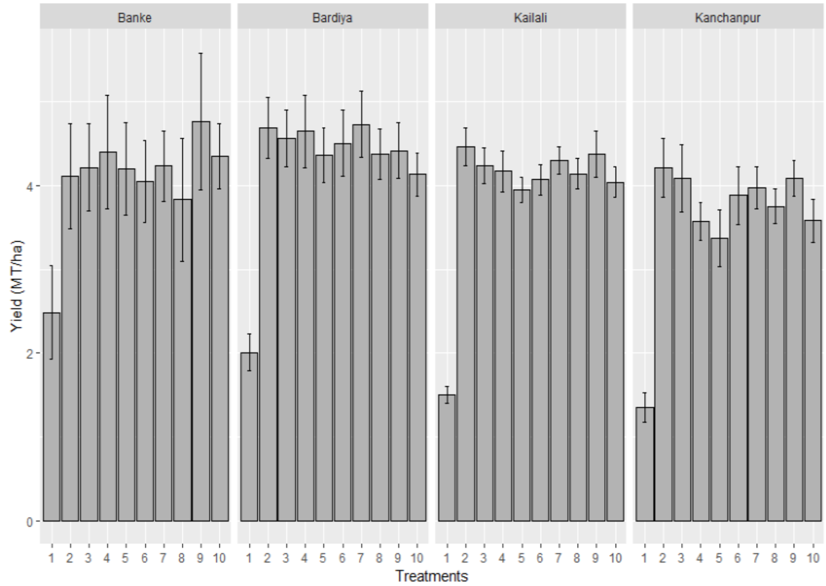


Figure 9. Effects of urea-sulfur fertilizer (ESS 13) on wheat grain yields compared with different best-bet N fertilizers across four districts in Western Nepal.

Research activity (iii): Trials to determine the optimum sulfur rate and most efficient urea-sulfur source

Location: Shan State, Myanmar

Time period: Trials established in June 2019

Details: Four field trials (two S omission and two S rate trials) were established in Shan State (sulfur-deficient areas) following the same experiment protocol as in Bangladesh in November 2018. For the S source trials, three urea-sulfur fertilizers (Thiogro ES 13%, Thiogro ESS 13%, and Thiogro ES 75%) were compared with gypsum and farmer practice. Similarly, for the S rate trial, sulfur rates of 0, 25, 50, and 75 kg S/ha were tested. For both trials, treatments were laid out in a randomized complete block design with 4 replications.

Output: All trials are in progress and will be reported in the next reporting period.

1.1.1.3 Adapting FDP to Intensive Rice Cropping Systems (SRI) in West Africa

IFDC initiated contractual agreements with Institut d'Economie Rurale (IER) in Mali and Institut de l'Environnement et de Recherche Agricole (INERA) in Burkina Faso in order to evaluate the modalities of integrating FDP into the widely promoted system of rice intensification (SRI).

A. Adapting UDP to SRI under Flooding or AWD: Mali and Burkina Faso

Research activity: Adapting urea deep placement (UDP) to SRI under flooding or alternate wetting and drying (AWD) water management systems in three agroecological zones

Location: Burkina Faso and Mali

Partners: IER in Mali and INERA in Burkina Faso

Time period: FY2019

Details: During the dry off-season of 2019, the AWD trials (which were on hold because of the rainy season) were established in Burkina Faso and Mali. The objective was to investigate the synergic effect of AWD and organic matter on the performance of UDP in the SRI system. For AWD, a split-plot design was used, and flooding and AWD were the main plot factors. The following subplot treatments were used:

- T1 = SRI with no mineral fertilizer
- T2 = SRI with half of basal NPK fertilizer recommendation + 72 kg of urea (broadcast) 6 weeks after transplanting
- T3 = SRI with half of basal NPK fertilizer recommendation + UDP (one 1.8 g urea super granule per 4 plants 7-10 days after transplanting = 72 kg urea per ha)
- T4 = SRI with half of basal NPK fertilizer recommendation + 113 kg of urea (broadcast) 6 weeks after transplanting.
- T5 = half of basal NPK fertilizer recommendation, 20 cm x 20 cm spacing, with 1.8 g urea super granule for every 4 rice plants (conventional UDP with transplanting of 3-4-week seedlings, 1-2 plants per hill)

Results: In *Burkina Faso*, the results showed that paddy rice yield was higher under the AWD water regime than when water is supplied continually. The magnitude of the difference between the two water regimes was larger at Di and Bagre but minimal at Bama.

The UDP-related treatments (T3 and T5) performed better under both water regimes. Average paddy yields at Di were 2,690 kg/ha and 3,996 kg/ha with T3 (SRI + UDP) and T5 (conventional UDP), respectively, compared with 1,705 kg/ha for T2 (SRI plus half rate of mineral fertilizer) under continual flooding. Under AWD, yield figures were 4,260 kg/ha and 4,855 kg/ha, respectively, for T3 and T5 compared with 3,253 kg/ha for T2. At Bama, the trend was similar and both T3 and T5 had higher paddy yields than the SRI system receiving half of the recommended basal mineral fertilizer (T2). Biomass data reflected the same trends as paddy yield (data not shown).

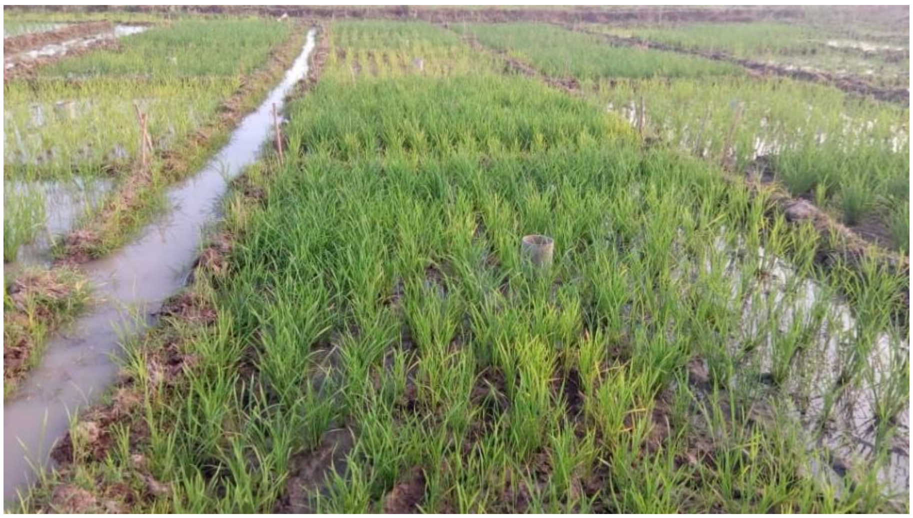


Figure 10. An overview of the AWD trial at the Di site in Burkina Faso.

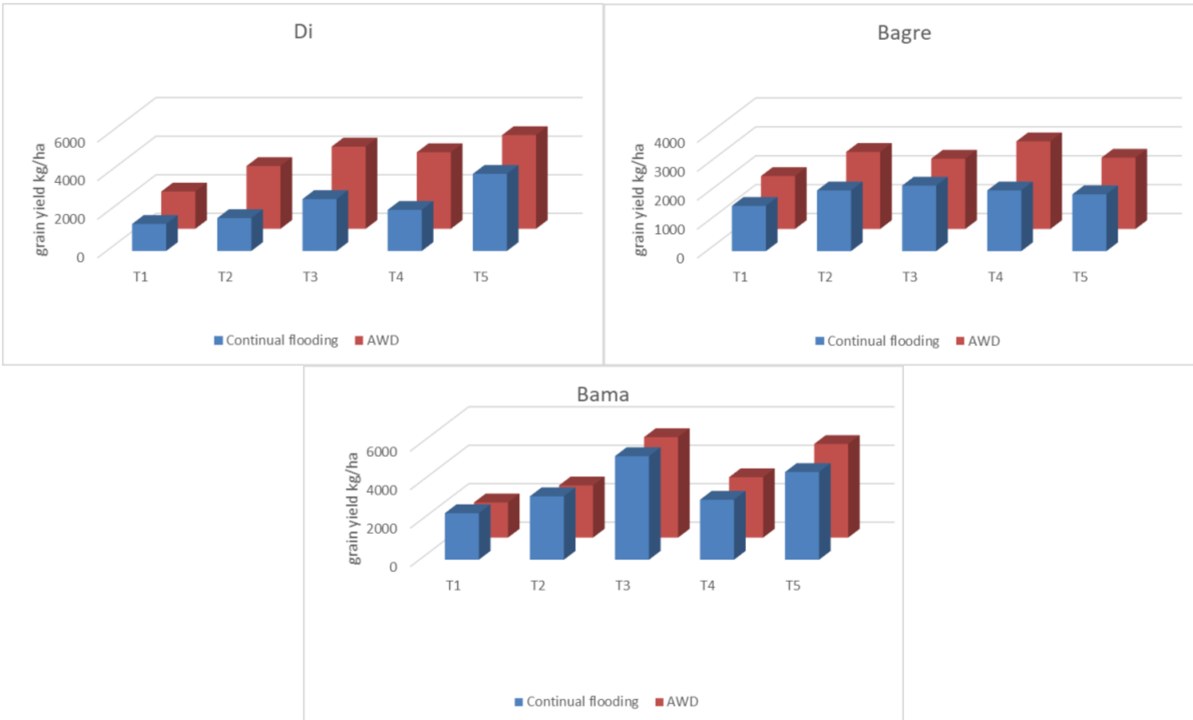


Figure 11. Paddy rice yield as affected by irrigation water regime and fertilizer treatments at different sites in Burkina Faso.

In *Mali*, the AWD trials were established in March 2019 at Baguineda, Niono, and San sites. The rice variety Wassa (120-130 day cycle) was used. Harvesting of plots took place in June 2019 and data collected included number of tillers, number of panicles, and paddy yield. However, the data submitted by IER was very low quality and could not be analyzed. The IER contact scientist is working on reviewing and cleaning the related yield data for resubmission. Thus, no results are presented in the current report.

Output: A link to a more detailed report is in Annex 3.

B. Testing of Multi-Nutrient Briquettes in Irrigated and Lowland Rice Systems

Research activity: Trials to test multi-nutrient briquettes in rice systems

Location: Mali and Burkina Faso

Time period: Initiated in July 2018

Partners: IER in Mali and INERA in Burkina Faso

Details: In *Mali*, the testing of multi-nutrient briquettes was initiated in July 2018 (nursery preparation), and rice was transplanted in August 2018. The trials were established at the Niono, Selingué, and San sites for irrigated rice, and at the Sikasso site for lowland rice. Under each rice ecosystem, the following treatments were considered in a split plot design with three replications:

T1 = Control, no fertilizer applied

T2 = Conventional recommendation, basal NPK at land preparation and urea broadcast (6-8 weeks after transplanting), which translates into (126 kg/ha N; 34 kg/ha P_2O_5; 34 kg/ha K_2O)

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, equivalent to 86 kg /ha N, 34 kg/ha P_2O_5, and 34 kg/ha K_2O of nutrients added)

T4 = FDP, two 2.4 g NPK 33-12-8 briquettes for 4 plants (placed 7-10 cm deep 7-10 days after transplanting) equivalent to 99 kg/ha N, 36 kg/ha P_2O_5 and 24 kg/ha K_2O of nutrients added

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 of nutrients added.

Results: Although the trials were concluded in January 2019, only preliminary results are reported (Figure 12) because of a delay in data cleaning and analysis by the IER partner in Mali.

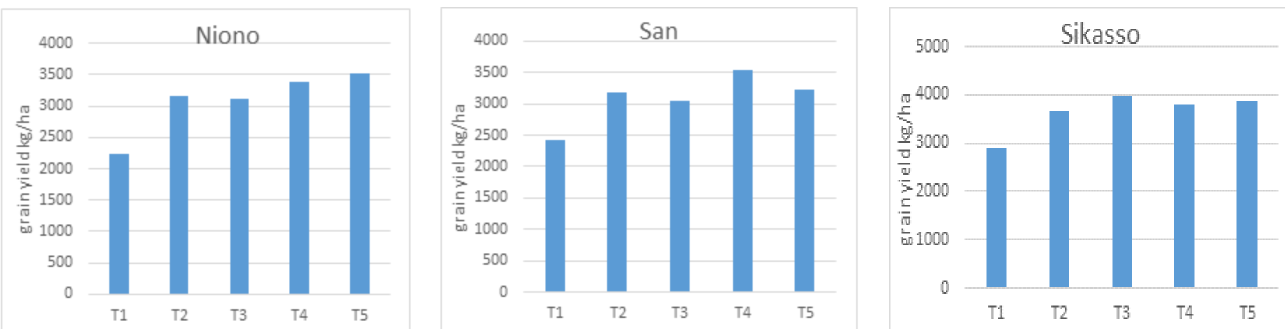


Figure 12. Rice grain yield as affected by fertilizer application treatments at Niono, San, and Sikasso sites in Mali.

In *Burkina Faso*, a similar trial using the same set of treatments was installed this 2019 winter season. No data has been submitted yet. Yield data will be presented in the next report.

No additional multi-nutrient briquette trials are planned for 2020.

Output: Yield data will be presented in the next report.

1.1.1.4 Agronomic and Economic Evaluation of Fertilizer Deep Placement on Vegetables in Mali

Research activity: Vegetable fertilizer trials to evaluate vegetable crop yields and quality as affected by the rate and placement of NPK fertilizer briquettes

Location: Samanko (International Crops Research Institute for the Semi-Arid Tropics [ICRISAT] Agricultural Station), Koutiala (Technology Park of N'golonianasso) and Bougouni (Technology Park of Madina) in Mali

Time period: FY2019

Partners: World Vegetable Center (WorldVeg)

Details: For the off-season crops, eggplant, onion, okra, and tomato were grown on-station at three locations: Samanko (ICRISAT Agricultural Station), Koutiala (Technology Park of

N'golonianasso), and Bougouni (Technology Park of Madina) in Mali. For each crop species, the field layout was a split-plot design with four replicates. The main plot focused on placing the fertilizer at three depths (surface, 5-cm deep, and 10-cm deep) and four subplots for the rate of fertilizer application:

T1 = No fertilizer
T2 = Recommended practice – broadcast incorporated
T3 = Two-thirds of the recommended practice rate as briquettes
T4 = One-half of the recommended practice rate as briquettes

The rates of nutrients applied for the different treatments are shown in Table 3.

Table 3. Rate of nutrients applied per hectare by crop according to the different fertilizer treatments.

Crop	T2	T3	T4
	Nutrients applied per hectare		
Okra	N = 136 kg P_2O_5 = 136 kg K_2O = 136 kg	N = 90 kg P_2O_5 = 90 kg K_2O = 90 kg	N = 60 kg P_2O_5 = 60 kg K_2O = 60 kg
Tomato	N = 170 kg P_2O_5 = 170 kg K_2O = 170 kg	N = 104 kg P_2O_5 = 104 kg K_2O = 104 kg	N = 74 kg P_2O_5 = 74 kg K_2O = 74 kg
Eggplant	N = 212 kg P_2O_5 = 212 kg K_2O = 212 kg	N = 134 kg P_2O_5 = 134 kg K_2O = 134 kg	N = 89 kg P_2O_5 = 89 kg K_2O = 89 kg

All plots received 5 mt/ha of organic manure (Profeba) procured from the local market. Yield data from the off-season vegetable trials are summarized below for the crops for the major sites.

Results: *Tomato* yields varied between sites with higher yields at Bougouni, likely as a result of differences in indigenous fertility of soils at the sites. Contrary to our previous results, there was no significant effect resulting from the depth of fertilizer placement, although deep placement at 10 cm seemed to give higher yields than subsurface placement of fertilizers (Figure 13). Regarding the fertilizer rate treatments, the control without mineral fertilizer had the lowest yields, whereas treatments with a reduced rate of mineral fertilizers applied as briquettes yielded higher than the recommended practice (T2) in most cases. Except at the Bougouni site, which had an overall higher yield level, T4 (placement of half of the recommended fertilizer as briquette) performed equally well or better than the other fertilizer treatments (Figure 13).

For *eggplant*, the trend was basically the same as that reported with tomato except at the Bougouni site. Treatments with reduced rates of mineral fertilizer applied as briquettes (T3 and T4) produced yield greater than or equal to yield of T2, the recommended practice (data not shown).

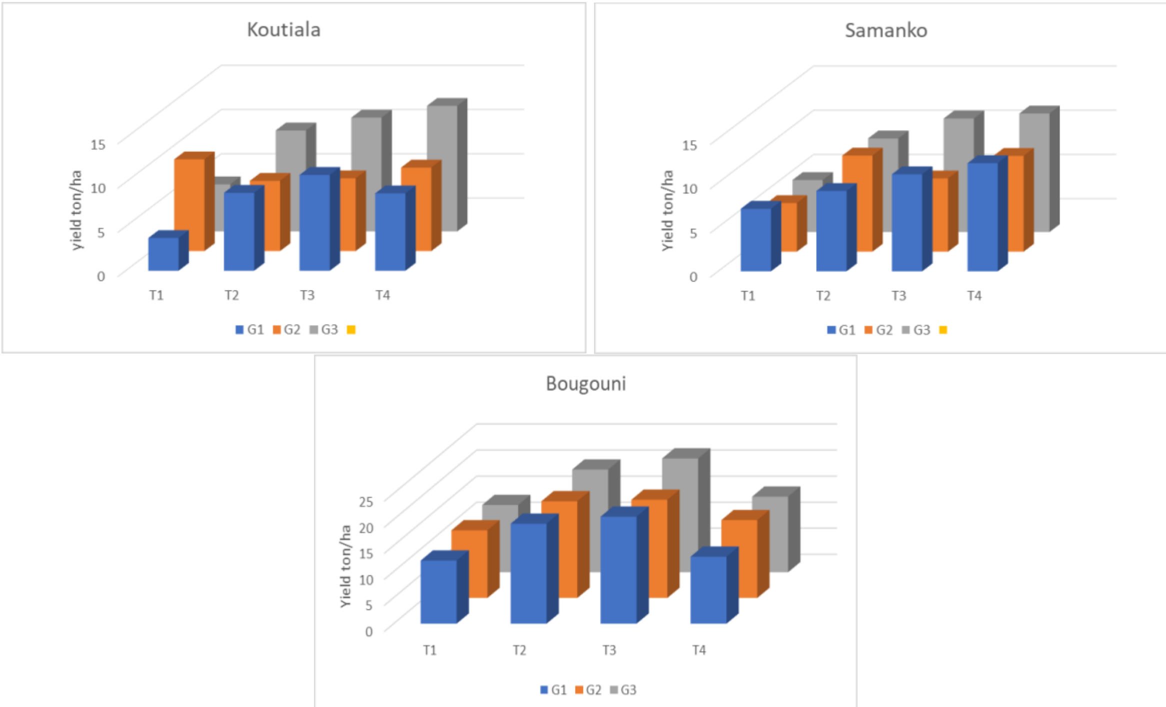


Figure 13. Tomato yield as affected by rate of fertilizer, types of fertilizer, and placement depth at different sites in Mali.

With *onion*, the fertilizer rate treatment was not significant at Koutiala, and differences between fertilizer treatments and the control were only slight at the other sites. However, deep placement of fertilizer as a briquette seemed to induce higher crop response, especially at Bougouni and Koutiala sites (Figure 14).

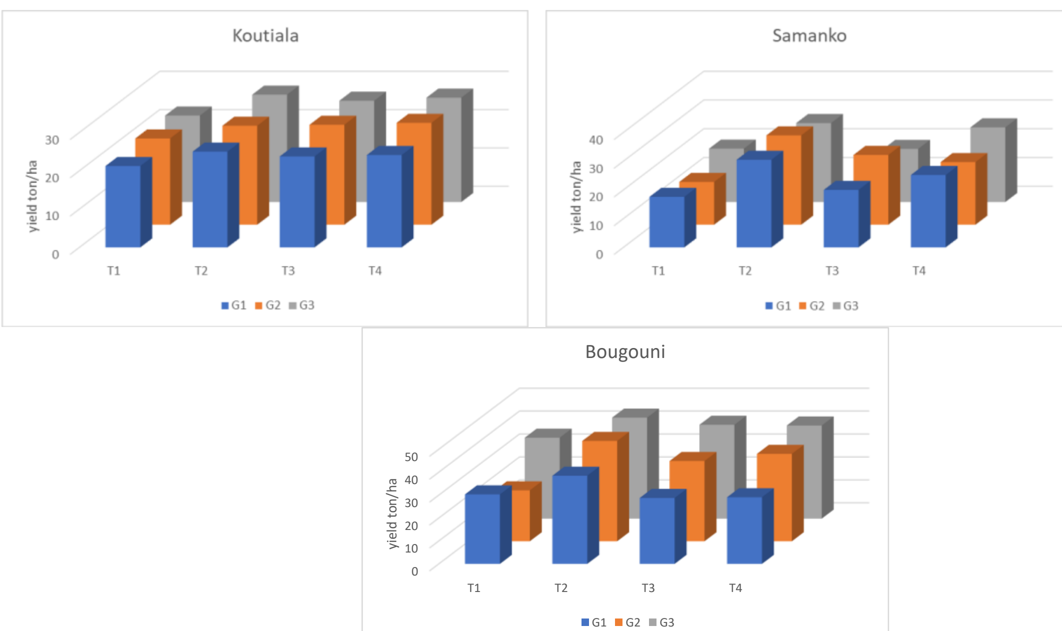


Figure 14. Onion bulb yield as affected by rate of fertilizer, type of fertilizer, and placement depth at different sites in Mali.

With *okra*, the results showed comparable performance between the recommended practice and treatments with reduced rates of fertilizer applied as briquettes at Koutiala and Samanko. The depth of placement was not significant either.

Output: A link to a more detailed report is in Annex 3.

1.1.2 Scaling Fertilizer Deep Placement Technology through Mechanization

While the benefits of FDP are well-documented, scaling has been slow. To date, the primary model for fertilizer deep placement has been compacting urea and urea-containing fertilizers at the agro-dealer level into briquettes and applying these briquettes either by hand or mechanically. Viable options to address these challenges include:

- A better production and distribution model, with briquettes being produced at or near a fertilizer distributor and then distributed to agro-dealers using briquetting machines
- Subsurface application of granular urea and multi-nutrient granular fertilizers using mechanized applicators

A. Combined Mechanical UDP Applicator and Rice Transplanter

Research activity: Development of an automated mechanical UDP applicator attached to a rice transplanter

Location: Mississippi State University

Time period: November 2019 (completion)

Partners: Mississippi State University Agricultural and Biological Engineering (ABE) Department

Details: An automated mechanical UDP device is being attached to a rice transplanter to facilitate combined application of briquettes along with the transplantation of rice seedlings.

Results: More information is provided below, and a link to a more detailed report is in Annex 3.

Automated Mechanical UDP Applicator Combined with a Rice Transplanter

In developing countries, UDP application is done by hand or through a mechanical rod. An automated mechanical applicator will benefit farmers not only in Asia and Africa, but also in the United States. Since there is not a rice transplanter available in the United States, a transplanter was procured from India.

The objective of this project is to develop an automated mechanical UDP device as an attachment to a rice transplanter. This will facilitate the combined application of urea supergranules (USG) or mega granules with rice seedling transplantation.

The UDP applicator is being designed and fabrication is ongoing in the Mississippi State University ABE workshop. The drawing has been prepared. There are two hoppers and four urea briquette placement rows. The four-row applicator is fed briquettes by two tank hoppers. One tank hopper will feed two applicators. The transplanter plants eight rows. Briquettes will be placed in four rows (between two rice plant rows). So, each briquette row will feed two rice plant rows. Each hopper will feed the briquettes to two placement hoses. A single placement hose is currently fitted on the transplanter. The project is ongoing and is expected to be completed by November 15, 2019.

Partner Organization: Mississippi State University

Transplanting unit (left) and the UDP application device with the hopper attached to the transplanter (right).

B. Direct-Seeded Mechanized Applicator

Research activity: Development and evaluation of a direct-seeded mechanized applicator for rice and maize

Location: Myanmar

Time period: FY2019

Partners: Fertilizer Sector Improvement (FSI+) Project, Myanmar; National Agro Machinery Industries (NAI), India

Details: A direct-seeded mechanized applicator developed by NAI has been shipped to Myanmar for FDP evaluation on rice and maize in Myanmar.

Results: Results will be presented in the next reporting period.

Mechanization of Fertilizer Deep Placement

Fertilizer deep placement or subsurface application under flooded and upland conditions has resulted in a 15-35% increase in rice, maize, wheat, and vegetable yields, with a 20-80% reduction in nutrient losses. Subsurface granular urea application approaches the efficiency of deep-placed briquettes and can be combined with NPKs to further improve efficiency. Mechanization for subsurface application of fertilizer briquettes or granular fertilizer would resolve labor constraints, a major bottleneck for the adoption of deep placement technology. Based on input from IFDC, a mechanized applicator for direct-seeding (rice, maize, and wheat) and FDP (granular and briquettes) was developed by NAI. Since 2018, the applicator has been evaluated in Myanmar, and modifications have been made to improve its performance on a wide range of soils used for growing rice and maize. During the next six months, the seeder/deep placement applicator will be tested on farmers' fields by a local Inputs and Service Provider. Based on the above trials, additional modifications will be made, if needed.

NAI will produce improved versions of the seeder/deep placement applicators for field trials in Nepal, Myanmar, Cambodia, and India. These applicators could have a significant impact on improving fertilizer use efficiency, crop yield, and farmer profitability.

Partner Organization: FSI+ Project, Myanmar; NAI, India; and BFS

One-time seed and subsurface fertilizer applicator

C. Modification to Manual Plunge-Type Applicator

Research activity: Modification to the current manual plunge-type briquette applicator to permit application of granular urea and other NPKs at two different rates

Location: Kenya

Time period: FY2019

Details: A modification was made to the current manual plunge-type briquette applicator to permit application of granular urea and other NPKs at two different rates. Further modifications will be made to permit continuous adjustable volume applications.

Next steps: The applicator is due to be tested in late 2019. If the modifications are robust in field testing, we will cost the key pieces for molding and extend field testing in 2020.

1.1.2.1 High-Capacity Briquette Machine

Research activity: Development of a prototype high-capacity, robust briquette machine

Location: Kenya, Uganda

Time period: FY2019

Details: Blueprints for a more robust briquetting machine were created in Kenya, with key modifications, including a more robust cooling system and better bearings and other key parts. These modifications should ensure continuous operation better than the current briquetting machine, which requires downtime after four hours to cool.

Next steps: Prototype is now under construction in Uganda.

1.1.3 Climate Resilience and Mitigating GHG Emissions

Fertilizers play a unique role of both emitting and sequestering greenhouse gases and improving crop resilience to abiotic and biotic stresses. The reported activities highlight the resilience feature of FDP technology in improving crop yields under unfavorable environments and mitigating GHG emissions.

The resilience trials were conducted for at least two seasons and completed during FY2018-19. These include:

- Trials in submergence-prone areas in northern Ghana
- Trials in submergence-, drought-, salinity-, and soil acidity-prevalent areas in Bangladesh
- Trials in submergence- and salinity-prone areas in Myanmar
- Trials in drought-prone areas in Nepal

1.1.3.1 Resilience Trials in Stress-Prone Environments

Research activity: Evaluating the benefits of deep placement (granular and briquettes) compared to conventional fertilizer management on yields of local versus stress-tolerant rice varieties.

Location: Bangladesh, Myanmar, Nepal, and Ghana

Time period: Trials were completed during FY2018 and FY2019.

Details: Trials were conducted to illustrate the adaptation feature of deep placement in unfavorable environments – submergence-, salinity-, and drought-prone areas – and to determine optimum N rates and application methods that increase yields and profits.

Results: Activities and results are complete and were reported in the BFS-SFT Semi-Annual Report covering October 2018-March 2019.

Outputs: Four journal articles evaluating subsurface fertilizer application in Northern Ghana have been published and one manuscript is under peer review. Links are provided in Annex 3.

1.1.3.2 Quantification of GHG Emissions of Various N Sources under Greenhouse Conditions

Research activity (i): Quantification of GHG emissions of various N sources under greenhouse conditions to evaluate the effect of inhibitors, coatings, and additives in reducing N losses and GHG emissions and improving fertilizer use efficiency

Location: Greenhouse at IFDC Headquarters

Time period: FY2019

Details: GHG emissions (carbon dioxide, methane, nitrous oxide, ammonia, and nitric oxide) were quantified under greenhouse conditions from urea, enhanced efficiency N fertilizers, organic sources, and methods of application under varying water regimes (50% and 75% field moisture capacity and flooded soils).

Results: These results confirmed that UDP, while increasing grain yields and NUE, does not have negative effects on the environment in rice cultivation or in wheat. Similarly, UDP performed well under the direct-seeded rice condition. Detailed results were presented in the BFS-SFT Semi-Annual Report covering October 2018-March 2019.

Outputs: Three manuscripts were prepared and submitted for journal publication. One journal article was published. Links are provided in Annex 3.

Research activity (ii): Preliminary in-house research to evaluate GHG emissions in a controlled environment with a new instrument testing different sources of fertilizer

Location: Greenhouse at IFDC Headquarters

Time period: FY2019

Details: The setup for this experiment comprised five different treatments in three replicates totaling 15 pot systems. The five treatments were: hydrated organic material, dry organic material, urea, urea formaldehyde, and check. In these experiments, GHGs such as carbon dioxide (CO_2), nitrous oxide (N_2O), ammonia (NH_3), methane (CH_4), and moisture were evaluated to test the instrument's response and to compare the emissions from different fertilizer sources.

Results: The experiment is ongoing. In Figure 15, the CO_2 emissions have been quantified to show the three main products that had higher CO_2 emissions: hydrated organic material, dry organic material, and urea. As for N_2O, dry organic material showed significantly higher emissions compared to the other treatments (Figure 16). Over time, the emissions from each of the products in this experiment "level out"; this is to simulate the same effects that occur when fertilizers are exhausted in the field.

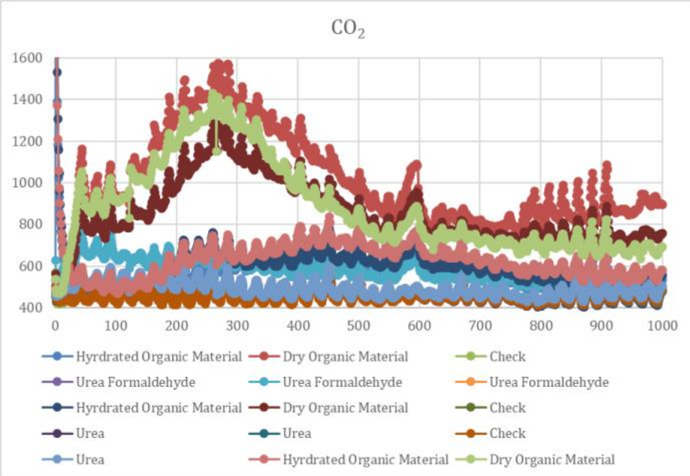


Figure 15. Real-time CO_2 emissions.

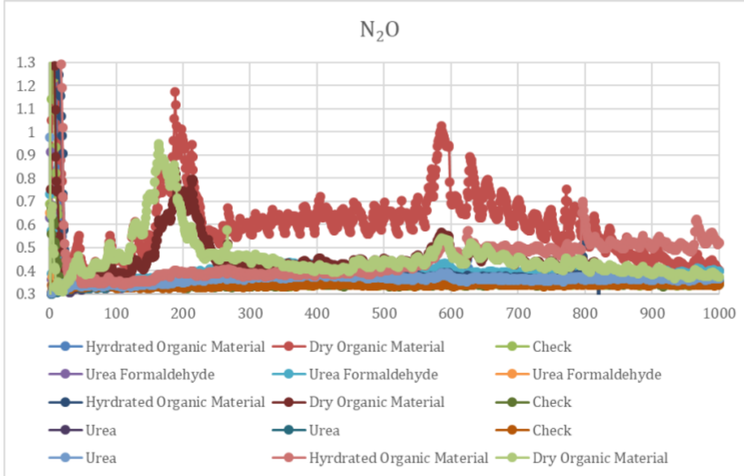


Figure 16. Real-time N_2O emissions.

In addition to the greenhouse gas emissions being collected and recorded, we have also maintained the moisture content of the soil so that the conditions being tested accurately reflect the intended fertilizer use. This experiment is active and on its third month of progress. Most of the fertilizers' emissions have subsided. This is due to the fertilizers being broken down and "used" just as they would be if applied to a crop field.

The importance of testing and quantifying a fertilizer's emissions is to stem the concern of its nutrient efficiency and environmental effects. If we can test and quantify the amount of nutrients lost to the environment, it becomes possible to improve fertilizer efficiency in the field. Conducting this experiment provides very valuable information for both scientists and farmers, as it provides analytical values to be tested and compares real-time fertilizer emission values.

1.1.4 CO_2 Mitigation Role of Enhanced Efficiency Fertilizers and Practices

Ouputs: A publication entitled "Quantifying CO_2 Release from Different Nitrogen Fertilizer Sources and Application Methods and Opportunities for Carbon Sequestration" is being developed and will be completed during FY2020.

Results from the study on "The Long-Term Effect of UDP Application on Soil Organic Matter and Carbon Sequestration" will be highlighted during the American Geophysical Union meeting in December 2019.

1.2 Activated Phosphate Rock

All commercially available phosphatic fertilizers contain 100% water-soluble P (WSP). The hypothesis of the proposed research is that 100% WSP is inefficient, both in terms of application efficiency as well as production efficiency. High solubility ensures immediate availability of P for plant uptake. However, high solubility results in leaching losses in coarse-textured soils and under high-intensity rainfall events. More importantly, WSP entering the soil solution P pool is rapidly converted to labile P, active P, or stable P pools, and can be rendered unavailable in acidic soils through fixation by iron and aluminum oxides and in alkaline soils as calcium phosphate precipitation. The plant availability of P is strongly affected among labile (more available), active, and stable P (less available) pools. The efficiency of P fertilizers from initial application is only

10-20%. On the other hand, phosphate rock (PR) is relatively less soluble; its direct application is limited to highly acidic soils (pH < 5.5) as solubility increases under acidic conditions (it is preferable for use with perennial crops).

In contrast to WSP and PR, the use of activated PR is neither constrained by soil type nor crop species. Activated PR is produced by compressing or granulating phosphate rock with low amounts of WSP. The activation processes (granulation or compression) add little to production costs. WSP fertilizers, by contrast, require enormous investments in excess of $1 billion. They are also limited to regions with very large deposits and, through an expensive acidulation process, also produce large amounts of phosphogypsum, which is a disposal challenge. The ability to convert national deposits of PR into less expensive, yet effective, phosphate products can greatly reduce the need to import soluble P fertilizers, which are the most expensive of the NPK nutrient fertilizers.

1.2.1 Complete and Analyze Ongoing Field Trials

1.2.1.1 Activated Phosphate Rock Trials in Ghana (Year 2)

Research activity: Follow-up trials on activated PR in maize and soybean to validate results obtained during the Year 1 PR field study

Location: Savanna (Sudan and Guinea savanna) agroecological zones of Ghana

Time period: FY2018-FY2019

Details: Previous greenhouse studies using soils with different physio-chemical characteristics and multiple crops suggest that activated phosphate rock (a combination of a modest amount of diammonium phosphate [DAP] or monoammonium phosphate [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. During FY2018-19, we began evaluating the effectiveness of "activated" PR products under field conditions to validate the greenhouse results. The activated PR products were evaluated on soil-P-deficient sites of varying soil pH levels. Maize and soybean cropping systems were used in 15 and six sites, respectively, for the evaluation.

During FY2019, we established follow-up activated PR trials to validate the results obtained during the Year 1 field study. As with the Year 1 study, we are using maize and soybean as test crops. For maize, the trials are being conducted in soils with strongly acidic, moderately acidic, and near-neutral pH levels; the soybean trials are being done in soils with near-neutral pH levels.

Results: Results of the Year 1 field trials confirmed the findings of the greenhouse studies. For maize production, the effects of soil pH on P availability observed from the raw PR were eliminated when the activated PR products were used because yields were similar regardless of the soil pH. The relative agronomic effectiveness (RAE) indicated that, in the acid soil, the activated PR products were more effective (~4 % more) than DAP, with the raw PR product being ~33% as effective as DAP. However, in the near-neutral soil pH, the activated P products were ~79% as effective as DAP, and the PR product was <3% as effective as DAP. Thus, incorporating a modest amount (20%) of WSP into the PR increased its effectiveness, in terms of grain yield, by about twofold in acid soils and more than threefold in near-neutral soil. Similarly, for the soybean crops, the RAE indicated that, on average, the activated PR products were ~80% as effective as triple superphosphate (TSP) and the PR product was ~35% as effective as TSP. As much as these results were consistent with the results of the greenhouse studies, these were results from only one year of field evaluation and needed to be repeated for validation.

The Year 2 follow-up trials are currently ongoing in the field and are expected to be harvested during November and December 2019.

Next steps: Next steps include harvesting trials to determine grain yield and conducting plant tissue analyses to determine nutrient uptake from selected plots. Economic and statistical models will be used to determine economically optimum activated PR rates.

Output: Year 2 results will be reported. A stakeholder workshop will be held to discuss the two-year trials and determine a way forward for fertilizer production/importation for farmers in the regions. A publication will be developed.

1.2.1.2 Activated PR Trials in Kenya

Research activity: Continuation of activated PR field trials

Location: Western Kenya

Time period: FY2019

Details: Activated PR trials were run at four sites: two on wheat (Narok and Uasin Gishu) and two on maize (Bungoma and Kisumu). All treatments contained 93 kg N, 50 kg P_2O_5, 10 kg K_2O, 10 kg S, 0.2 kg B, and 0.4 kg copper (Cu)/ha (soil-applied). The distinguishing treatments were the P sources, as follows:

1. DAP
2. Togo PR
3. Activated PR (80/20 ratio of P_2O_5 from Togo PR and DAP, respectively)
4. Same as 3, but with 9.1% urea in the DAP/PR granules
5. Togo PR + DAP (80/20) but applied as an uncompacted powder
6. Control (no P)

The wheat sites employed a Latin square design. Yields (Table 4) show that at Uasin Gishu no significant differences were observed between any of the treatments, and yield levels were relatively high. At Bungoma, the rather unusual result was the under-performance of DAP relative to other treatments. This result is difficult to explain, but one possible reason may be increased Cu deficiency induced by the more soluble P source, DAP. While Cu was applied in this trial, it was previously shown that soil-applied Cu (which was employed in these treatments) had no effect in addressing Cu deficiencies. To better judge the effects of activated PR, it is advised to repeat this trial using a foliar Cu source, both to address Cu deficiencies and to control rust.

Table 4. Wheat yields from activated PR trial.

Treatment	Wheat yield (mt/ha)			
	Uasin Gishu		Bungoma	
DAP	3.87	a	0.93	a
Togo PR	4.15	a	2.32	b
DAP:PR	3.84	a	2.05	b
DAP:PR w 9.1% urea	3.56	a	2.22	b
Togo PR + DAP (not compacted)	3.82	a	2.24	b
No-P control	3.54	a	2.28	b

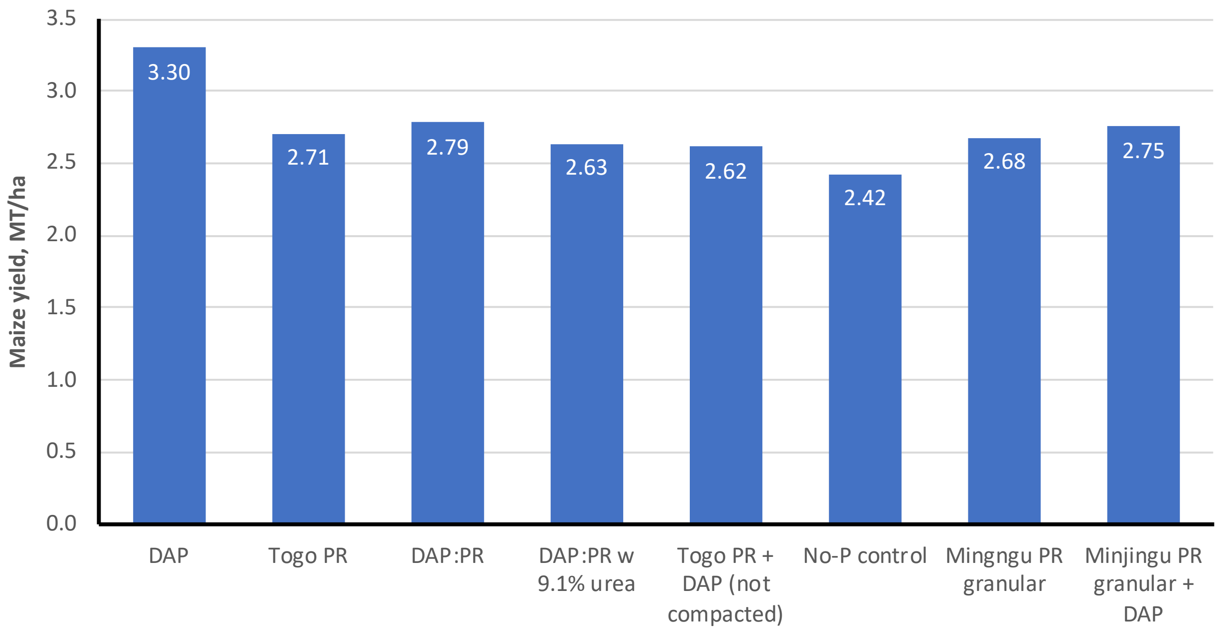
Note: Means followed by the same letter are not significantly different at $p \leq 0.05$.

The PR trial was also run on maize in Bungoma and Kisumu, along with other trials, which are reported elsewhere. In these trials, we employed a single-row design, with each 6-m row representing a treatment. This was an experimental design to ascertain whether treatment differences could be determined in smaller experimental areas. To avoid interactions, fertilizers were placed within rows, and rows were separated by 1 m to minimize between-row effects.

The site at Kisumu failed due to several factors, including a severe armyworm attack, drought, and a windstorm, which randomly affected parts of the field. At Bungoma, no significant differences between treatments were observed, and yields were reduced due to intermittent drought; no rainfall was received the month following basal fertilizer application and the month following topdress application. Apart from the above treatments, two additional treatments were included: granular Minjingu PR (from Tanzania) and granular Minjingu PR mixed in an 80/20 P_2O_5 ratio with granular DAP.

At Bungoma, a significant block effect was observed ($p<0.001$), with one responding less to DAP than the others. Even considering this block effect, treatment effects were significant only at $p = 0.08$, with DAP significantly outperforming some treatments in some blocks and performing the same in others; all other treatments were statistically indistinguishable. Overall averages across blocks are shown in Figure 17. Given the severity of the drought, we believe that root access to all P treatments was restricted through most of the season. The trial still sheds some light on how activated PR treatments might perform under water stress.

PR trials continue in Kenya at five sites for maize and three sites for wheat.



Treatment means were not statistically different at $p \leq 0.05$.

Figure 17. Maize yields in activated PR trial, Bungoma.

Next steps: Harvest for the trials began in October 2019 and will be reported in 2020.

1.2.2 Activated PR Demonstrations

Research activity: On-farm demonstrations to show the agronomic effectiveness of activated PR to farmers, agro-input dealers, agricultural extension officers, and key stakeholders

Location: Savanna agroecological zones of northern Ghana

Time period: FY2019-2020

Details: Greenhouse and field studies have shown that activated PR could be as effective as water-soluble phosphorus (WSP) regardless of soil pH or crop; activated PR is also more effective than raw PR applied directly to crops. We hypothesized that the modest amount of WSP contained in activated PR would supply the crops' early P requirement, which would enhance the crops' root development to deplete P and Ca^{2+} in the dissolution zone. This reaction was expected to increase P availability from the PR. The results support the hypothesis that P availability from the PR was enhanced by activation with a modest quantity of WSP.

During FY2019-2020, we established seven on-farm demonstrations designed to show the agronomic effectiveness of activated PR to farmers, agro-input dealers, agricultural extension officers, and key stakeholders in the fertilizer value chain. The specific demonstration locations and the crops utilized for testing are presented in Table 5. 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: (a) Planting Field Day, (b) Green Field Day, and (c) Brown Field Day.

Results: Results will be reported in 2020.

Next steps: Brown Field Days and harvesting are scheduled for November 2019.

Table 5. Locations and test crops for the activated PR demonstrations

Location	Latitude	Longitude	Crop	Planting Date	Expected Harvest Date
Mankpan	8.8994 N	0.1224 E	Maize	7/15/2019	11/7/2019
Jeffisi	10.719 N	2.2281 W	Maize	7/18/2019	11/10/2019
Kpachie	9.4791 N	1.4335 E	Maize	7/22/2019	11/14/2019
Chuchuliga	9.3514 N	0.7276 E	Maize	7/24/2019	11/16/2019
Kulmasa	9.8250 N	2.5161 W	Maize	7/30/2019	11/22/2019
Yendi	9.4325 N	0.0042 W	Soybean	8/12/2019	11/10/2019
Pusu Mamongo	10.738 N	0.8521 E	Soybean	8/15/2019	11/13/2019

1.3 Balanced Crop Nutrition (Cross-Cutting with Workstream 2.3)

Balanced crop nutrition is addressing all deficient nutrients and soil pH constraints. 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 response. In recognition of these wide-scale deficiencies and subsequent crop responses, blenders capable of adding these nutrients to fertilizers have sprung up throughout sub-Saharan Africa and Asia. Providers of compound fertilizers, such as Mosaic, OCP, and Yara, are collaborating to address these deficiencies as well.

IFDC activities highlight the importance of balanced fertilization and fertilizers and the most cost-effective and efficient ways of delivering these nutrients to maximize productivity, profitability, and nutrient use efficiency. All field trials include the collection of soil data, weather data, 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

Activities focus on the improved delivery, distribution, and efficiency of nutrients (N, P, K, Zn) 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.

1.3.1.1 Laboratory, Greenhouse, and Field Evaluations of Various Rates, Sources, and Methods of Zn Delivery

Zn deficiency is widespread, affecting both crop yields and human nutrition. As interest in multi-nutrient fertilizers increases, incorporating Zn efficiently into fertilizer compounds and blends has become an increasing priority. The objectives of these evaluations are to study the effects of different Zn types, rates and formulations with macronutrients on crop development, yield, and nutrient acquisition in different crops under laboratory, greenhouse, and field conditions.

A. Greenhouse Trial Evaluating the Effects of Zn on Sorghum Yield and Nutrient Use Under Drought Conditions

Research activity: Evaluating the effect of zinc oxide nanoparticles on sorghum performance, nutrient acquisition, and grain fortification under drought stress

Location: IFDC greenhouse in Muscle Shoals, Alabama, United States

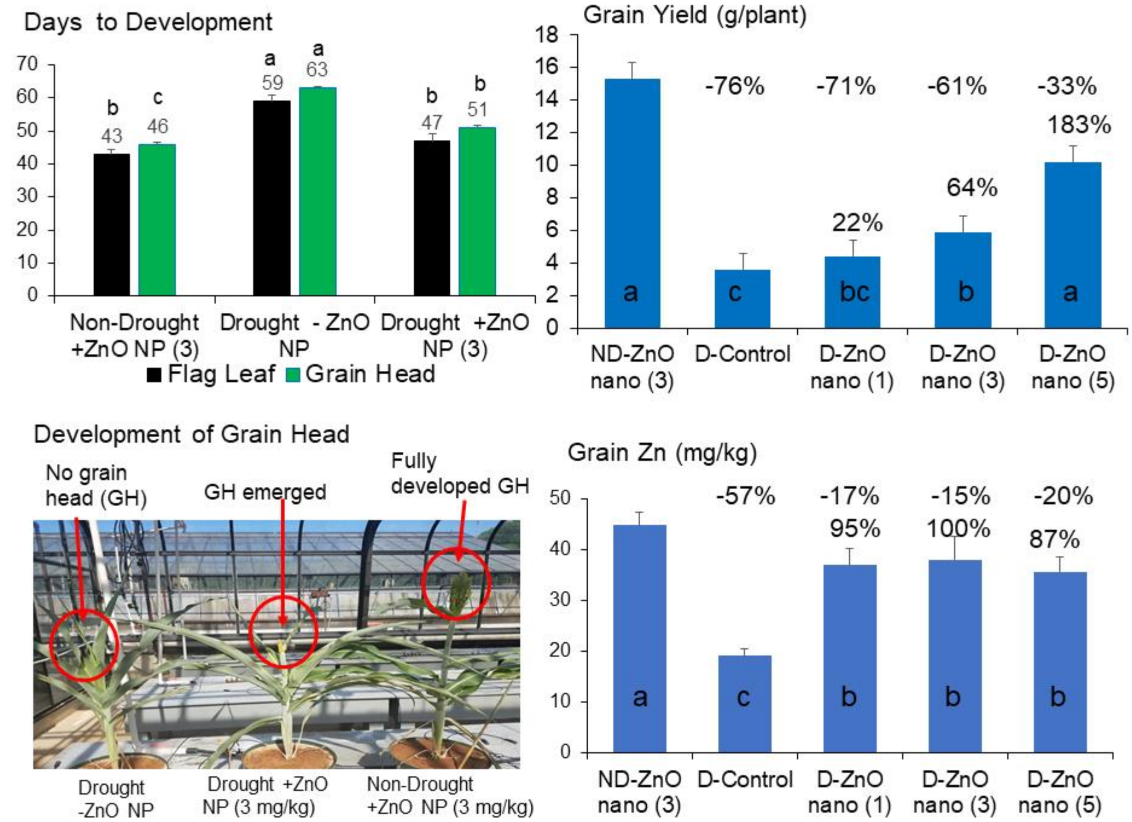
Time period: Winter-Fall 2018

Funding (if cost shared): USAID BFS-SFT and USDA NIFA grant on the applications and implications of nanotechnology in agriculture

Partners: The NIFA grant partners included scientists at the Connecticut Agricultural Experiment Station (CAES) and the University of Texas at El Paso (UTEP).

Details: Soil (sandy loam; pH 6.87; 0.92% organic matter content; and a diethylenetriaminepentaacetic acid (DTPA)-extractable Zn level of 0.1 mg/kg, which is well below the critical soil Zn level of 0.5-1.0 mg/kg for most crops) was amended with zinc oxide nanoparticles (ZnO-NPs) at 0, 1, 3, and 5 mg Zn/kg in 8-liter pots. Three sorghum seeds were planted per pot, which was thinned down to one seedling after emergence. Approximately a month after sowing, the plantlets were exposed to drought stress by maintaining the soil at 40% field moisture capacity. A non-drought treatment with the Zn amendment at 3 mg/kg was also set up, rounding the treatments to five. All pots received similar NPK fertilization, and each treatment was in three replicates. Subsequently, vegetative growth (tiller number, panicle number, and plant dry biomass) and reproductive (grain) yield were monitored. Upon maturity, plants were harvested, and plant tissues were analyzed for their nutrient contents as affected by drought and Zn fertilization.

Data analyses showed that flag leaf and grain head emergence were delayed 6-17 days by drought, but the delays were reduced to 4-5 days by the addition of ZnO-NPs. Drought significantly ($p < 0.05$) reduced (76%) grain yield; however, ZnO-NP amendment under drought improved (22-183%) grain yield. Drought inhibited grain N translocation (57%) and total (root, shoot, and grain) N acquisition (22%). However, ZnO-NPs (5 mg/kg) improved (84%) grain N translocation compared to the drought control and restored total N levels to the non-drought condition. Shoot P uptake was promoted (39%) by drought, while grain P translocation was inhibited (63%); however, ZnO-NPs lowered total P acquisition under drought by 11-23%. Drought impeded shoot uptake (45%), grain translocation (71%), and total potassium (K) acquisition (41%). ZnO-NP amendment (5 mg/kg) applied to drought-affected plants improved total K acquisition (16-30%) and grain K (123%) compared to the drought control. Drought lowered (32%) the average grain Zn concentration; however, ZnO-NP amendments improved (94%) grain Zn under drought.



Note: Different letters in bars represent significant differences for each variable across the treatments. Negative percentages are for comparisons with ND; positive percentages are for comparison with D.

Figure 18. Effects of drought and Zn (as ZnO-NPs) fertilization on plant development (flag leaf and grain head emergence), grain yield, and grain Zn concentration under non-drought (ND) and drought (D) conditions.

Results: Key results are highlighted in Figure 18. This study represents the first evidence of drought stress mitigation in full-term plants solely by exposure to ZnO-NPs in soil. The ability of ZnO-NPs to accelerate plant development, promote grain yield, fortify edible grains with critically essential nutrients (such as Zn), and improve N acquisition under drought stress has strong implications for increasing cropping systems' resilience, sustaining human/animal food/feed and nutrition security, and reducing nutrient losses and environmental pollution associated with N fertilizers.

Output: One study was published and a link is available in Annex 3.

Zinc Fertilization Can Improve Grain Quality for Human Nutrition under Drought Conditions

Partner Organization: The Connecticut Agricultural Experiment Station; University of Texas at El Paso

Zinc is a commonly deficient nutrient in human diets globally. Its deficiency in humans is linked to deficiency in soils and plants, especially in populations primarily dependent on plant diets. Zinc deficiency can be exacerbated by drought. **But can zinc fertilization contribute to human nutrition under water-limiting conditions through the transfer of zinc from soil to the grain of crops such as sorghum?** According to sources, a serving (192 g) of sorghum grain supplies only 22% of the daily recommended dietary allowance (RDA) of zinc for adult humans. Through our reseach, we have demonstrated that sorghum grain can be enriched with zinc under normal water conditions. Enriched grains in ideal conditions can provide up to 60% of the daily RDA. However, a drought event in the absence of zinc fertilization could reduce the daily RDA to 36%. Notably, zinc fertilization under drought could increase grain zinc content to 50% of the daily RDA.

An interesting insight from this study is that grain crops grown under drought stress and fertilized with zinc can supply up to 50% of the daily human zinc RDA, representing a significant zinc enrichment that could be important in human health.

Zn Fertilization Can Improve Grain Quality for Human Nutrition Under Low Water Supply

Zinc Content (mg/kg) of Sorghum Grain Determined Experimentally				
Zinc (medium) + Water (adequate)	- Zinc + Water (low)	Zinc (low) + Water (low)	Zinc (medium) + Water (low)	Zinc (high) + Water (low)
44	19	35	37	38
Percent Daily Zinc RDA Supplied by Water and Zinc Treatment*				
Zinc (medium) + Water (adequate)	- Zinc + Water (low)	Zinc (low) + Water (low)	Zinc (medium) + Water (low)	Zinc (high) + Water (low)
60% RDA	36% RDA	48% RDA	50% RDA	52% RDA

*Zinc treatment (mg/kg soil): 1 = low; 3 = medium; 5 = high.

B. Low ZnO Nanoparticles Exposure Promotes Wheat Development and Grain Yield Under Drought Stress

Research activity: Greenhouse study to (i) determine if zinc can mitigate drought stress on development, grain yield, and Zn and N uptake of wheat; (ii) understand differences when urea is coated or not coated with the Zn; and (iii) determine whether using less Zn as nanoparticles can generate comparable effects as bulk Zn.

Location: IFDC greenhouse in Muscle Shoals, Alabama, United States

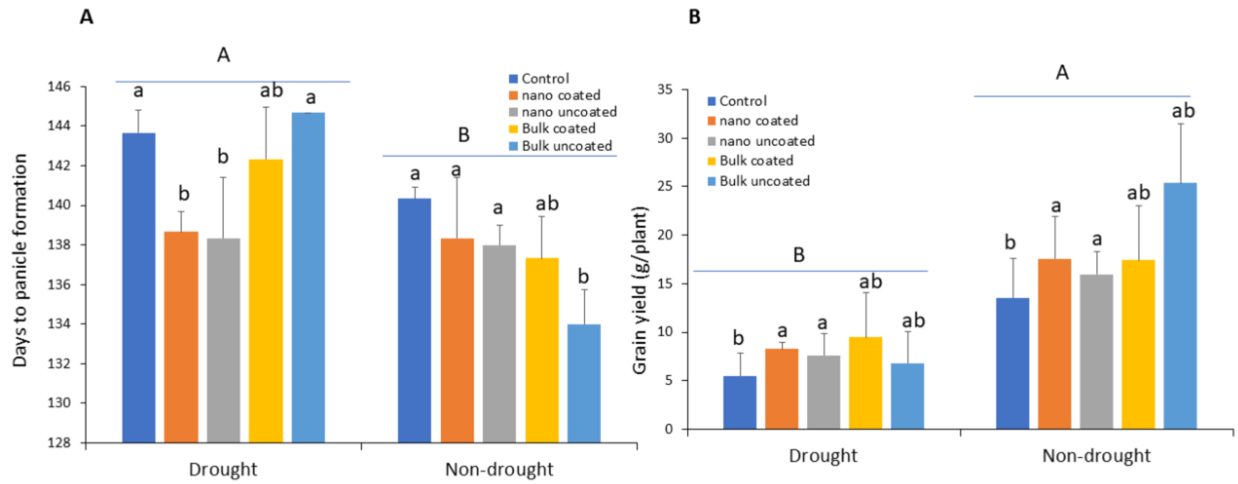
Time period: Winter-Spring 2018-2019

Funding (if cost-shared): USAID BFS-SFT and USDA NIFA grant on the applications and implications of nanotechnology in agriculture

Partners: CAES and UTEP

Details: Potted soil (sandy loam; pH 6.87; organic matter content of 0.92%; and a bioavailable [DTPA-extractable] Zn level of 0.1 mg/kg, indicating a Zn status well below the critical soil level of 0.5-1.0 mg/kg for most crops) in three replicates (8 liters volume) was amended with P (75 mg/kg). No K was added, as the soil contained enough K (1903 ppm). Wheat seeds were planted; two weeks later, Zn and N (100 mg/kg) were added by subsurface incorporation of the fertilizer materials into the pots with the plantlets. The N source was urea granules coated, or not, with zinc oxide (ZnO) nano (1%) or bulk (2%) particles (as the Zn sources). The 1 and 2% Zn amounted to roughly 2 and 4 mg Zn/kg soil, respectively. One week after Zn treatment, the plantlets were exposed, or not, to drought stress by maintaining the soil at 40% of field moisture capacity until harvest. Ten treatments were involved in three replications: control; nano ZnO (1%) coated urea; nano ZnO (1%) uncoated urea; bulk ZnO (2%) coated urea; and bulk ZnO (2%) uncoated urea. Coating Zn particles onto urea was achieved using vegetable oil at 1% of the urea weight. Each of these treatments was duplicated for the drought and non-drought conditions. During the course of growth, vegetative growth (tiller number, panicle number, and plant dry biomass) and reproductive (grain) yield were monitored.

Results: Upon maturity, plants were harvested, processed, and analyzed for their elemental contents. The analysis of the entire data is currently underway; however, preliminary results indicated that in the control plants, panicle initiation was delayed by drought by an average of 3 days. Under drought, nano ZnO strongly reduced the panicle formation time, regardless of whether it was coated on urea or not (Figure 19A). In contrast, bulk ZnO did not affect the panicle formation time under drought. Zn fertilization had a less significant effect on panicle initiation time under the non-drought condition, despite a trend toward reducing the time to panicle formation in all Zn treatments. Only uncoated bulk ZnO resulted in a significantly different panicle formation time compared to the control (Figure 19A). Compared to the control, grain yield was promoted by Zn fertilization under both drought stress and non-drought conditions (Figure 19B). However, as with panicle formation, this effect was significant only with the nano ZnO, regardless of coating. Overall, drought clearly had strong negative effects on both panicle initiation time and grain yield. However, we note that high variability among the treatment replicates might have influenced the significance of these results.



Note: Different large letters above horizontal lines indicate significant differences between drought and non-drought conditions. Different small letters on bars indicate significant differences among the treatments, separately for drought and non-drought conditions.

Figure 19. Effect of drought and Zn fertilization on panicle initiation (A) and grain yield (B) in wheat.

Nevertheless, the findings indicate that Zn as nanoparticles can accelerate wheat phenological development and reproductive yield under drought stress, similar to what was previously reported for sorghum. A broader implication of this study is that low Zn input from ZnO nanoparticles may suffice for enhancing crop productivity under drought stress. This clearly demonstrates one of the goals of nanotechnology, which is to reduce the rate of nutrient input into the biosphere. Although nano-scale micronutrient coating, such as Zn onto bulk fertilizers, may eliminate the problem of small and large nutrient particle segregation in bulk blends and facilitate one-time application regimes, it may not affect yields significantly compared to separate applications. That being said, it is plausible that improvements to the coating process may alter outcomes.

Output: A manuscript has been submitted to a journal for peer review.

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

IFDC and the University of Central Florida (UCF) are partnering in the development of nano-zinc coated urea fertilizer for efficient delivery of zinc micronutrients and improved N use efficiency. Urea is coated with ZnO nanoparticles synthesized with different capping agents to improve Zn release and uptake. A combination of urea, sodium salicylate (SAL), and n-acetyl cysteine (NAC) was used as the capping agent to improve Zn solubility and plant uptake. Several greenhouse tests were conducted.

On June 3, 2019, IFDC personnel visited UCF to discuss the partnership and learn about UCF’s research portfolio.

The following are research activities conducted through the partnership.

Research activity (i): Large-scale synthesis of dual-capped ZnO nanoparticles

Location: UCF, Orlando, Florida

Time period: FY2019

Partners: UCF

Details: Large amounts of NAC-SAL ZnO, NAC-Urea ZnO, and Urea-SAL ZnO nanoparticles were synthesized using a sol-gel method at room temperature. The nanoparticles' suspensions were centrifuged for 5 min at 10,000 rpm, and the precipitates were lyophilized to obtain dry nanoparticle powder. 100 g of each nanoparticle formulation was shipped to IFDC, along with 500 mL of the as-synthesized nanoparticle suspensions, so that IFDC could run further studies on the urea coating.

Research activity (ii): Particles characterization by HR-TEM

Location: UCF, Orlando, Florida

Time period: FY2019

Partners: UCF

Details: The hydrodynamic diameters of the NAC-SAL ZnO, NAC-Urea ZnO, and Urea-SAL ZnO nanoparticles in suspension were previously measured by Dynamic Scattering Light. The average diameters for the three formulations were around 100 nm, possibly due to particle aggregation (particle-particle and particle-capping agent interactions). To better characterize particle size, the lyophilized nano-powders were dispersed in de-ionized (DI) water to prepare High-Resolution Transmission Electron Microscopy (HR-TEM) samples. HR-TEM images of nanoparticles (Figure 20) show the gel-like network of inter-connecting ultra-small crystalline sol particle clusters. Individual particle diameter for all of the formulations was around 5 nm.

Output: A manuscript is being developed.

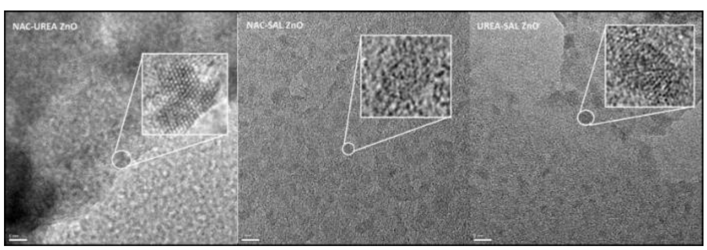


Figure 20. HR-TEM images of Urea-SAL ZnO, NAC-SAL ZnO, and NAC-Urea ZnO nanoparticles (scale bar = 5 nm).

Research activity (iii): Seed germination

Location: UCF, Orlando, Florida

Time period: FY2019

Partners: UCF

Details: A seed germination test was conducted to evaluate the effects of nanoparticles on seed germination and root elongation. To this end, 3 ppm solutions of NAC-Urea ZnO, NAC-SAL ZnO, Urea-SAL ZnO, Bulk ZnO, and Zn $(NO_3)_2.6H_2O$ were assessed on sterile filter paper placed into Petri dishes and loaded with 5 mL of each test solution. Seeds of Ferry-Morse beefsteak tomato cultivar were sterilized with 10% NaClO solution and rinsed with DI water before being soaked in the test solutions for 2 hours (20 mL each). Seeds were drained and transferred onto filter papers. Each Petri dish contained 10 seeds placed 1 cm apart in 6 replicates for each test solution. Petri dishes were wrapped in aluminum foil and kept in a growth chamber (no light/dark, 25°C, 80% humidity).

Results: Germination rate and root length were measured on the 7th and 10th days. On the 7th day, NAC-Urea ZnO-treated seeds had the highest germination success at 100%, and DI water had the lowest at 87%. On the 10th day, NAC-SAL ZnO and Zn $(NO_3)_2.6H_2O$ had 100% germination success rates. Figure 21 shows the results for root length on the 7th and 10th days. On day 10, NAC-SAL ZnO nanoparticles significantly improved root elongation compared to the DI water control.

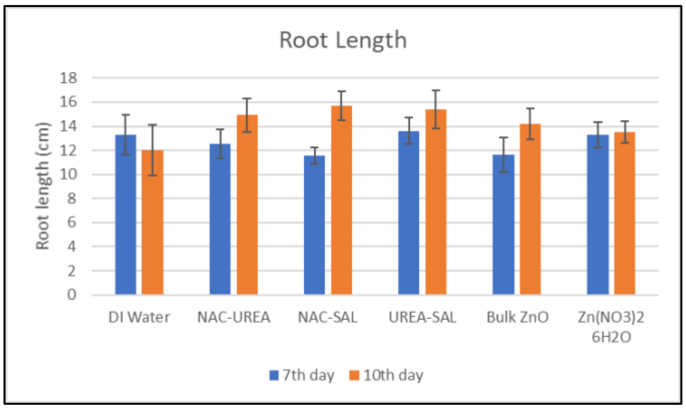


Figure 21. Root length of tomato seeds.

Research activity (iv): Greenhouse tomato experiment

Location: UCF, Orlando, Florida

Time period: FY2019

Partners: UCF

Details: A qualitative evaluation of tomato plants was conducted in which 30 seedlings that started from BHN 602 VFFF hybrid seeds (5 plants per treatment) were grown in 2 lbs of organic soil amended with 3% (w/w) urea fertilizer coated with NAC-SAL ZnO, NAC-Urea ZnO, or Urea-SAL ZnO nanoparticles. Bulk ZnO-coated urea fertilizer and urea fertilizer only were used as treatment controls, and soil only was used as the untreated control. Plants were evaluated for 12 weeks by measuring plant height, number of flowers, number of fruit sets, number of leaves, yield, and biomass.

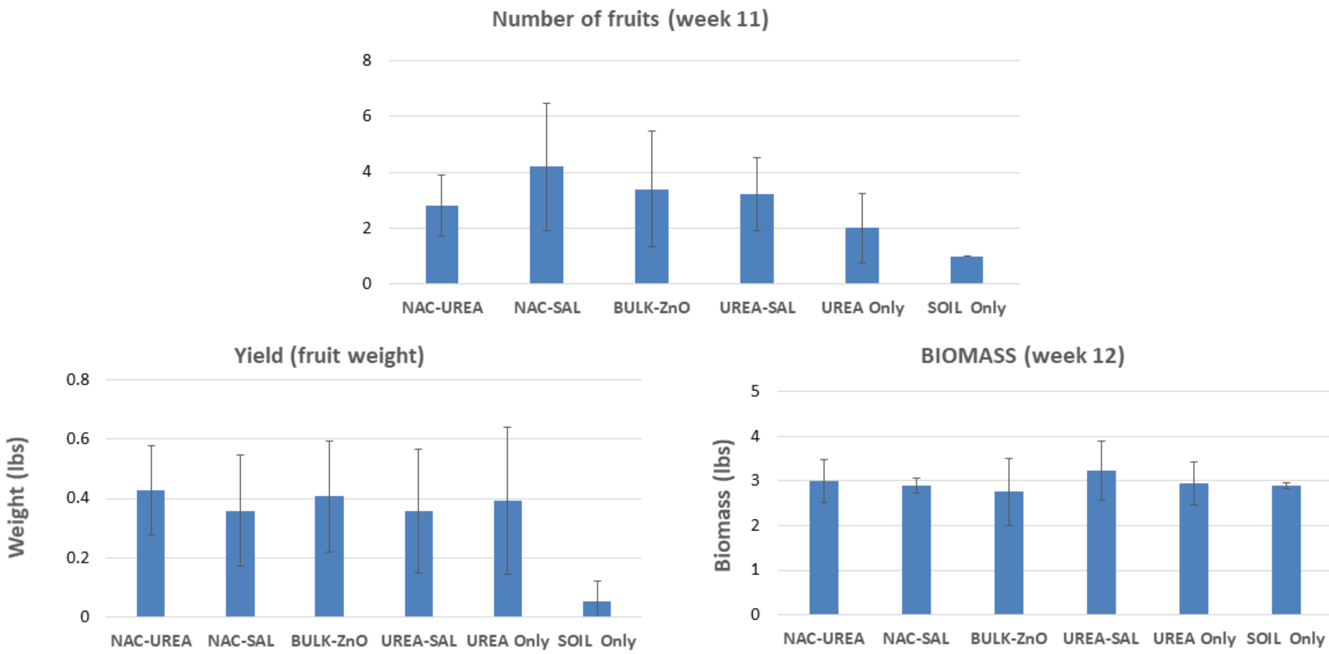


Figure 22. Effect of different Zn-coated urea on tomato performance: Number of fruits (week 11), yield (week 12), and biomass (week 12).

Results: Results on the number of fruits, yield, and biomass are presented in Figure 22, indicating that coating urea with ZnO nanoparticles can increase fruit yield, in terms of numbers, compared to urea alone. Coating urea with these products is ongoing at IFDC.

Next steps: Data will be verified by repeating the study.

1.3.1.2 Quantifying the Efficiency of S, Cu, and B on Crop Yield and Nutrient Uptake

Similar to the deficiency of Zn, widespread deficiencies of S, Cu, and B affect crop yields in our target countries. S and Cu deficiencies also affect human nutrition. Although B is the second most deficient micronutrient in crops (after Zn), it has no apparent role in human nutrition. Sulfur, a macronutrient, plays an important role in enhancing the methionine and cysteine (sulfur containing amino acids) content in legumes and has been shown to increase the nutritional quality of protein and to increase the proportion of legume protein that can be utilized by humans and non-ruminant livestock. Deficiencies of micronutrients, such as Zn and Cu, also increase the susceptibility of crops to infectious disease. The elemental sulfur (ES) evaluation trials in Northern Ghana to quantify S and N efficiency reported below was partially funded by Shell.

A. Residual Sulfur Trials

Research activity: Field trials to evaluate the agronomic effectiveness of a new S fertilizer product (Thiogro-urea, which is micronized ES + urea) under field conditions in northern Ghana

Location: Northern Ghana

Time period: FY2018-2019 and FY2019-2020

Partners: Shell

Funding (if cost-shared): BFS-SFT and private sector (Shell)

Details: Traditionally, sulfate (SO_4-S) is used as the main source of sulfur (S) for plant nutrition, since elemental sulfur (ES) has been reported as generally inert and incapable of supplying S for crop production. However, with advances in micro and nano-sized elemental S, and other technological advances, ES is no longer "inert or very slow-release S" that could not meet plants' S demand. Through greenhouse and field trials, Thiogro-urea (micronized ES + urea), a new S fertilizer product, was found to be an effective S source that reduced SO_4-S leaching loss. During FY 2018-19, 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), the Thiogro ES produced yields that were not significantly different from the ammonium sulfate fertilizer applied at 50 kg S/ha. Although applying the Thiogro ES at a rate of 75 kg S/ha consistently produced the greatest yields across all 12 locations, the differences in yield among the various rates of application were not statistically significant.

Results: Despite the increases in S uptake with a 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 (Table 6). The results of the soil analyses portend that a follow-up experiment is imperative to determine the residual effects of the Thiogro ES fertilizer in supplying S to subsequent crops.

Table 6. Residual soil S concentrations (mg/kg) of the experimental sites after maize harvest

Location	Latitude	Longitude	Thiogro ES 25 kg S/ha	Thiogro ES 50 kg S/ha	Thiogro ES 75 kg S/ha	Ammonium Sulfate 50 kg S/ha	S Check (0 S)	Farmer Practice (0 S)
Wakpang	8.6866 N	-1.2019 W	7.26	14.1	19.9	4.36	0.64	0.30
Bondando	10.2466 N	-1.0325 W	7.81	14.5	20.3	4.45	0.80	0.25
Tusani	9.7613 N	-1.9951 W	7.25	13.8	20.0	4.31	0.67	0.20
Kpandu	9.2932 N	-2.0973 W	6.83	13.7	19.5	4.27	0.64	0.23
Zambulugu	10.9904 N	-1.5707 W	7.83	14.3	20.4	4.50	0.63	0.24
Ariga	10.1332 N	-1.8412 W	6.84	13.6	19.4	4.19	0.52	0.64
Azumsapelga	10.6379 N	-1.8039 W	7.20	13.8	19.9	4.28	0.56	0.30
Bazua	10.1707 N	-1.6556 W	8.03	14.7	20.6	4.55	0.82	0.10
Nyimatie	9.9135 N	-2.7166 W	7.01	13.8	19.8	4.30	0.54	0.17
Nabulo	9.5074 N	-2.3737 W	6.90	14.6	20.3	4.36	0.82	0.10
Bulenga	9.9496 N	-2.6843 W	7.08	13.8	19.8	4.28	0.56	0.36
Zumara	10.4596 N	-2.1021 W	7.12	13.8	19.9	4.28	0.70	0.12

Numbers are mean values of 24 (6 sample/plot x 4 plots) replicates (values are presented in three significant figures).

During FY 2019-20, we established 12 trial plots to evaluate the effects of the residual S from the applied Thiogro ES fertilizer product.

Next steps: The trials are currently ongoing in the field and are expected to be harvested during November and December 2019. Then soil and plant tissue analyses will be conducted, and economic and statistical models will be used to determine an economically optimum Thiogro ES (S) application rate based on the expected profit from the Thiogro ES application. We will conduct a comparative experiment to evaluate the agronomic effectiveness of other S fertilizer products (such as Thiogro ESS and Special S) and to determine their economically optimum rates of application.

B. Omission Trials in Kenya

Research activity (i): Trial to test various fertilizer S sources

Location: Western Kenya

Time period: FY2019

Details: This trial was designed to test various fertilizer S sources, as follows:

1. Ammonium sulfate (AS)
2. Sulfate of potash (SOP)
3. NPS (sulfur supplied in this compound as both sulfate and elemental S)
4. No-sulfur control

Other nutrients were supplied at the following rates: 110 kg N, 45 kg P_2O_5, 30 kg K_2O, 0.5 kg Zn, and 0.3 kg B/ha. S from the various sources was supplied at 8.4 kg/ha.

Results: Yield means for the 3 S sources were 3.05, 3.09, 3.13, and 2.78 mt/ha for the AS, SOP, NPS, and no-S control, respectively. Though not significantly different at p≤0.05 from the S omission, the trend confirms equal efficacy of S sources.

Research activity (ii): Copper (Cu) source and magnesium (Mg) response trial

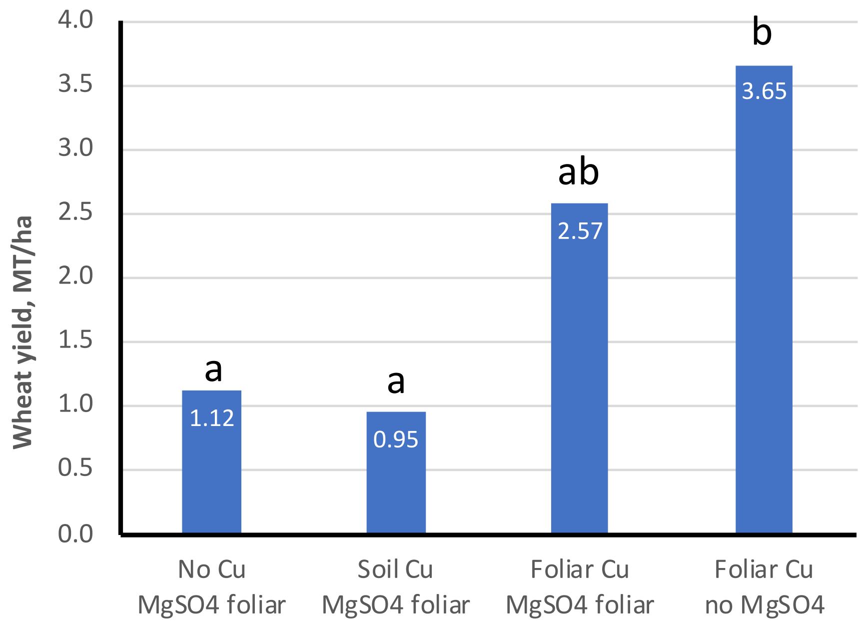
Location: Western Kenya

Time period: FY2018-2019

Details: Soil analyses in Narok indicated both Cu and Mg deficiencies. The purpose of this trial was to determine plants' response to a Cu source and Mg applied as foliar Mg sulfate. All of the treatments contained 93 kg N, 50 kg P_2O_5, 10 kg K_2O, 10 kg S, and 0.2 kg B/ha. The distinguishing treatments were as follows:

1. No Cu + foliar Mg sulfate (1 kg Mg/ha)
2. Soil Cu as cuprous oxide (0.4 kg Cu/ha) + foliar Mg sulfate (1 kg Mg/ha)
3. Foliar Cu as copper sulfate (0.25 kg Cu/ha) + foliar Mg sulfate (1 kg Mg/ha)
4. Foliar Cu as copper sulfate (0.25 kg Cu/ha) only

Results: An analysis of variance indicated a significant difference between treatments (p ≤0.015), with the Cu foliar without Mg giving significantly greater yields than both no Cu + Mg foliar and soil Cu + Mg foliar (Figure 23). There was not a significant difference between the two Cu foliar treatments with or without Mg, indicating that the foliar Mg treatment did not affect yields.



Treatments followed by the same letter were not significantly different at p ≤ 0.05.

Figure 23. Wheat response to Cu source and foliar magnesium sulfate.

Yield differences are attributed to the Cu foliar treatment, which increased yields by over 2.5 mt/ha compared to treatments where no foliar Cu was applied. Soil-applied Cu (applied as cuprous oxide at 0.3 kg Cu/ha) had no effect on yields. This was somewhat surprising, as wheat's response to various sources of soil Cu, including cupric oxide, has been reported in the literature. The foliar treatment (applied at 0.25 kg Cu/ha as a copper sulfate solution) also had a visible impact on wheat rust, which likely accounts for some of its response as a fungicide. Foliar-applied Cu has proven effective on a number of crops in IFDC trials where Cu deficiencies were indicated, including wheat, maize, beans, rice, and potato in Rwanda and Burundi.

Table 7. Soil analyses from the sites used in Kenya trials.

Farmer Name	GPS Coordinates		County	Crop	Trial	Total N	Organic C	C/N	CEC	pH	EC
	Latitude	Longitude			type	%	%	ratio	meq/100g		uS/cm
James Karbolo	-1.041035	36.142826	Narok	Wheat	Activated PR	0.25	4.32	17.3	29.6	6.6	132
Sally Rono	0.306857	35.380612	Uasin Gishu	Wheat	Activated PR	0.19	2.40	12.6	19.5	6.1	47.9
Regina Regina	-1.040558	36.155842	Narok	Wheat	Cu/Mg	0.25	3.74	14.9	27.5	6.8	80.7
David Motia	0.788120	34.708307	Bungoma	Maize	Multiple	0.11	1.05	9.57	6.98	5.3	23.3
Monicah Akinyi	-0.075385	34.658148	Kisumu	Maize	Multiple	0.13	2.76	21.2	39.9	6.7	53.7

Farmer Name	Crop	Trial Type	P	K	Ca	Mg	S	Na	Fe	Mn	B	Cu	Zn
			Mehlich-3 extractable, ppm										
James Karbolo	Wheat	Activated PR	11	893	4270	311	< 0.5	16	187	52	1.1	0.7	73.8
Sally Rono	Wheat	Activated PR	7	1120	1870	436	< 0.5	8	133	294	0.4	1.3	4.4
Regina Regina	Wheat	Cu/Mg	29	924	4080	278	< 0.5	17	192	36	0.8	0.9	67.2
David Motia	Maize	Multiple	7	44	610	97	6.6	5	77.9	77	0.1	1.8	0.6
Monicah Akinyi	Maize	Multiple	2	301	5420	947	2.1	85	82.5	148	0.6	2.0	1.1

Research activity (iii): S, Zn, and B omission trials

Location: Western Kenya

Time period: 2019

Results: Using the same nutrient rates, omission of S, Zn, and B reduced mean yields from 3.05 mt/ha to 2.76, 2.60, and 2.66 mt/ha, respectively. While contrasts showed that none of these reductions were significant at $p \leq 0.05$, they still indicate a consistent trend of yield reduction due to omission and are in line with deficiencies identified in the soil analysis. The trial was affected by drought, which likely affected the full expression of treatment differences.

Research activity (iv): Trials on secondary and micronutrients initiated or repeated in 2019

Location: Western Kenya

Time period: FY2019

Details: Rainfall was much more consistent in 2019. Several trials on secondary and micronutrients were conducted. The following trials were conducted on five maize sites in western Kenya:

1. Zinc sources trial: Compares powder-coated sources of zinc oxide, zinc sulfate, zinc oxysulfate, Smart Zn, and granular zinc sulfate. This trial also measures Zn response vs. a no-Zn control.
2. Boron rates and sources trial: Compares disodium octaborate tetrahydrate, borax heptahydrate, and calcium borate (all having different solubilities) at two rates (0.15 and 0.3 kg/ha). The objective is to optimize B delivery. This trial also measures B response vs. a no-B control.
3. Topdress trial: Evaluates the economic returns of various topdress N sources available in Africa: urea, CAN, Agrotain-coated urea, and Yara Amidas (urea-ammonium sulfate compound).
4. S sources trial: Evaluates efficacy and economic returns of available S sources: OCP's 19:38:0+7S, polysulfate (a K-Ca-Mg sulfate), ammonium sulfate, and Yara Amidas (40 N, 6 S). This trial also measures S response vs. a no-S control.
5. Lime-micronutrients interaction trial: Compared NPKS and NPKS Zn B, with and without lime, on acid soil sites (maize only).

For wheat, at three sites in western Kenya, a copper sources trial compared the effects of foliar Cu, Cu oxysulfate, cuprous oxide, copper sulfate, and Cu-EDTA.

Results: Harvest for these trials began in October and results will be reported in 2020.

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

1.3.2.1 Best-Bet Trials in the Savanna Areas of Ghana

Research activity: During FY 2018-19, nutrient omission trials were established based on soil fertility maps developed by IFDC for the Savanna areas of Ghana. These "best-bet" trials are being repeated during FY 2019-20.

Location: Savanna areas of Ghana

Time period: FY2018-2019 and FY2019-2020

Partners: Feed the Future Ghana Agriculture Technology Transfer (ATT) project, Soybean Innovation Lab (SIL), Ministry for Food and Agriculture (MOFA), and the University for Development Studies (UDS)

Details: Based on the soil fertility maps developed for the region, the nutrient omission trials were designed to have one treatment with a complete suite of potentially limiting essential plant nutrients ("Balanced" treatment). Each subsequent treatment omitted one essential limiting nutrient from the "balanced" treatment, and one treatment contained the blanket N-P-K fertilizer recommendation. Based on the literature review and results from a preliminary study, the fertilizer rates we utilized for the nutrient omission trials are presented in Table 8.

Table 8. Treatments and the corresponding fertilizer application rates.

Treatment #	Treatments Description	N*	P	K	S	Zn	B
		(kg/ha)					
1	Balanced (All nutrients)	115	40	35	30	5	1
2	Minus sulfur	115	40	35	0	5	1
3	Minus zinc	115	40	35	30	0	1
4	Minus boron	115	40	35	30	5	0
5	NPK only	115	40	35	0	0	0
6	Check (0 nutrient)	0	0	0	0	0	0

** N fertilizer is split-applied: one-half is basally applied, and one-half is applied 6 WAP.*

Results: Despite the importance of NPK-based fertilizers, results from the nutrient omission trials show that S, Zn, and B are often required to enhance crop productivity. For maize, grain yield was increased by at least 60% when these secondary and micronutrients were added compared to the recommended NPK fertilization. By adding only S and Zn (minus B treatment) to the blanket NPK, an average increase of ~49% in maize yields was observed. In addition, by adding Zn and B to the blanket NPK (minus S treatment), maize yields increased by an average of ~23%, and the addition of S and B (minus Zn treatment) to the NPK resulted in an average yield increase of ~29% compared to the NPK-only treatment.

In these trials, the quantities of secondary and micronutrients used were based on our best estimate from an improved recommendation from the soil analyses. The economics of the recommendation were not initially required. During FY 2019-20, 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 to result in increased productivity and profitability to the smallholder farmers. The nutrient omission trials were designed to have one treatment with identical fertilizer application rates as the "balanced" treatment, one with lower rates, and one with higher secondary and micronutrient addition rates to the NPK-based fertilizer recommendation (Table 8). Thus, at all locations, five treatments were compared:

1. Control (no fertilizer application)
2. Locally recommended fertilizer application
3. Best-Bet fertilizer application (using application rates in Table 8)
4. "Low" Best-Bet application (same NPK rates, but 50% of Zn, S, and B rates)
5. "High" Best-Bet application (same NPK rates, but 125% of Zn, S, and B rates)

The treatments were laid out in a randomized complete block design with a plot size of [10 m x 5 m (50 m^2)]. Twelve rows of maize were planted to a length of 5 m. Each treatment was replicated four times, and one treatment was randomly assigned to a plot within each block. The trials are currently growing in the field, and the first-year cropping is expected to be harvested during November and December. The follow-up is planned to be established in March 2020 to validate Year 1 results.

Next steps: We will conduct economic analyses to determine the economically optimum secondary and micronutrient application rates. Based on the economic analyses, we will develop an actual "best-bet" fertilizer formulation and application rates recommendation for the region.

1.3.2.2 Nutrient Omission Trials in Ghana (Year 2)

Research activity: Nutrient omission trials to validate results from Year 1 trials

Location: Savanna (Sudan and Guinea savanna) agroecological zones of Ghana

Time period: FY2018-2019 and FY2019-2020

Details: Soil fertility maps developed for the savanna agroecological zones of Ghana (northern Ghana) revealed the extent of the variability in soil nutrient levels and suggest severe nutrient deficiency in the regions' soils. Thus, to increase productivity in these soils, and to realize the full benefits of investments in fertilizers, farmers must supply the limiting essential plant nutrients to crops. During FY2018, we began using the SMaRT concept (Soil testing, Mapping, Recommendations development, and Technology transfer) to develop fertilizer recommendations for the entire agroecological zones.

We began with nutrient omission trials to quantify crops' response to S, Zn, and B relative to the blanket NPK recommendation. The trials also evaluated the synergetic effects of liming and balanced fertilization on the growth, development, and production of maize in acidic soils, since a vast portion of the land in the study area has acidic soil with a pH < 6.

Results: The results of the Year 1 trials show that, across the sites with the near-neutral soils, the average maize grain yields from the check (no fertilizer application) was ~1.4 mt/ha. Applying only NPK fertilizer, as done by most farmers in the area, increased maize grain yield to an average of ~4.5 mt/ha. By applying the complete suite of limiting nutrients, maize grain yield increased to an average of ~7.5 mt/ha.

Compared to the "balanced" fertilizer treatments, the omission of S (minus S treatment) reduced the maize grain yields by an average of ~34%, Zn omission resulted in an average of ~28% yield reduction, and B omission resulted in an average of ~14% yield reduction. Addition of the complete suite of limiting essential nutrients ("Balanced" treatment) resulted in an average of ~68% increase in maize yield compared to the blanket application of only NPK fertilizer sources. By adding only S and Zn (minus B treatment) to the blanket NPK, an average increase of ~49% in maize yields was observed. Also, by adding Zn and B to the blanket NPK (minus S treatment), maize yields increased by an average of ~23%. The addition of S and B (minus Zn treatment) to the NPK resulted in an average yield increase of ~29% compared to the NPK-only treatment. Maize grain yields from the strongly acidic soils were relatively low compared to yields from the near-neutral and the moderately acidic soils. Despite the low yield from the strongly acidic soils, fertilizer application significantly increased maize yield, but omission of essential nutrients (e.g., S) negatively affected maize yield.

Lime application significantly increased maize yield in the strongly acidic soils, regardless of the fertilizer treatment. Across the sites with the strongly acidic soils, applying only lime without any fertilizer led to an increase in maize yield by an average of ~64%. For the plots receiving only NPK fertilization, liming led to an increase in yield by an average of ~57%. For the treatment with the complete suite of limiting nutrients, lime application resulted in a maize grain yield increase of ~53%. For the moderately acidic soils, although liming and fertilization had significant interactive effects on the maize grain yields produced from the acidic soils, the magnitude of yield increases due to liming was not as great compared to the strongly acidic soils. Thus, the combined data from the Year 1 trials suggest that, regardless of the nutrient omitted, addition of the micro- and secondary nutrients to the soils with near-neutral pH significantly increased maize yield. In addition, for the strongly acidic soils, liming was critical in increasing maize productivity. However, these results were from a one-season experiment only and needed to be repeated to validate the results.

During FY2019, we established 60 nutrient omission trials across the entire savanna (Sudan and Guinea savanna) agroecological zones of Ghana to validate the results obtained during the Year 1 study. In all, soils at 20 sites fell within the near-neutral soil classification, 25 in the moderately acidic classification, and 15 in the strongly acidic classification.

Next steps: The follow-up (Year 2) trials are currently ongoing in the field and are expected to be harvested during November and December 2019. Plant tissue analyses will be used to determine nutrient uptake from selected plots. After Year 2 results are reported, we will conduct a stakeholder workshop to discuss the results and determine a way forward for fertilizer production/importation for farmers in the region. "Best-bet" trials will be conducted to develop an economically optimum fertilizer recommendation. A publication will be developed.

1.3.2.3 Expanding Spectral Analytical Techniques to Fertilizer Analysis

Research activity: Verification of the efficacy of spectral methods in quantifying nutrient values in fertilizer samples

Location: IFDC headquarters, Muscle Shoals, Alabama, United States

Time period: FY2019-2020

Partners: Private partners

Details: Since IFDC already has access to many fertilizer samples that have been analyzed using traditional wet chemistry methods, the efficacy of the spectral methods in quantifying the nutrient values in the same fertilizer samples can also be verified.

So far, great improvements have been made in the calibration modules as they relate to plant, soil, and fertilizer analysis. Several trials have been conducted to evaluate the different responses in the spectral analysis using liquid and solid materials compared to wet chemistry. The analysis using the liquid materials has proven to have greater efficacy due to the incompatibility on the matrixes in solid samples in the plant tissue, soil, and fertilizer.

The initial work on soil analysis has been done using a simple extraction matrix and looking for correlations in actual nutrient availability in the soil at a specific time.

Results: For the fertilizers, NPK analysis has shown an improvement with R_2 levels above 0.6. This is still in progress to see how we can improve the R_2. For P and K, a correlation above 0.95 was obtained from the initial research (Figure 24 and Figure 25).

This work was done in collaboration with private industry.

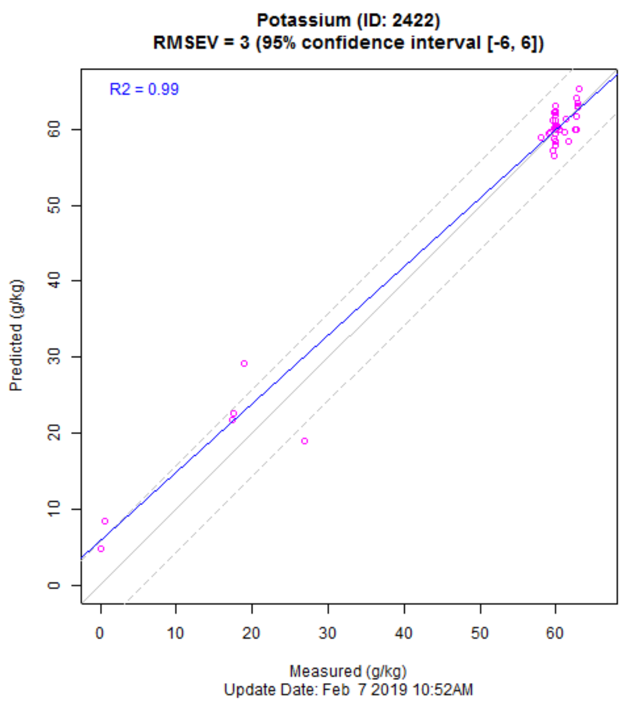


Figure 24. Correlation of potassium between predicted and measured.

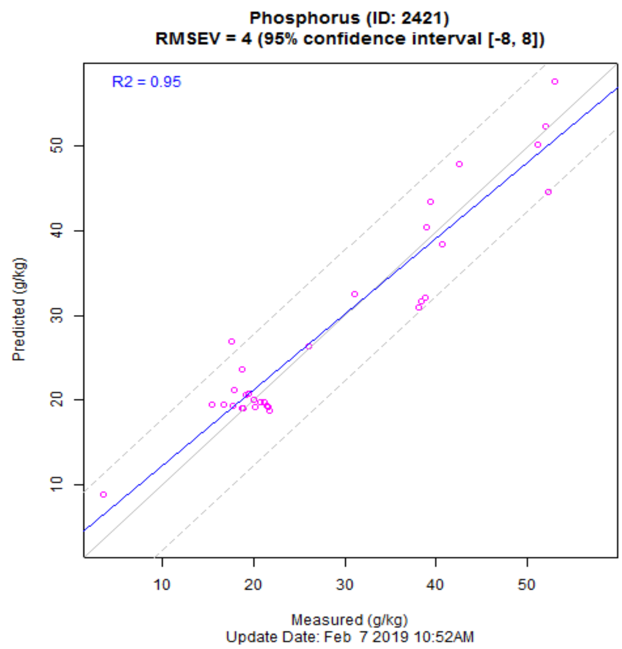


Figure 25. Correlation of phosphorus between predicted and measured.

Next steps: IFDC is now set up to start analyzing the fertilizer samples. The initial research will be done to create a good calibration curve for nitrogen fertilizers. The initial report is expected to be completed by the end of the next year.

1.3.2.4 Development of Balanced Rice Fertilizer in Mozambique

Research activity: Based on the results form soil analyses and expert knowledge (IFDC and Yara), on-farm omission trials were established in Buzi district to evaluate the rice yield response and economic returns of S, Zn, B, Cu, and lime products.

Location: Buzi, Mozambique

Time period: FY2019

Partners: Yara

Details: Improved fertilizer recommendations for rice intensification were developed and tested under farmers' field conditions. A total of 16 omission trials were established during the 2018/19 growing season, starting in November-December and ending in June-July. Four field days for land preparation, basal fertilizer application and sowing, and thinning and weeding were organized to promote good agriculture practices such as seed and fertilizer rates, fertilizer placement, and optimal plant density.

Unfortunately, on March 14-15, 2019, just before the panicle initiation, Cyclone Idai made landfall in Buzi district. Cyclone Idai brought devastating flooding from torrential rains. Rice fields remained flooded for more than a week and affected the trials.

Despite this setback, eight fields were able to be harvested. This is largely due to their location and the high resilience characteristics of the introduced rice varieties (higher number of tillers) combined with applied fertilizers that boosted the root systems. Table 9 shows the yield data from the omission trials.

Table 9. Yield data from omission trials

	Treatments								
	All with Briquettes	All -S	All -Zn	All -B	All	All -Cu	All -Lime	NPK Only	Control
Yield (mt/ha)	1.7	1.7	1.6	1.6	1.7	1.4	1.4	1.5	1.0

Figure 26. Discussing proper weeding during a field day in Buzi, Mozambique

1.3.2.5 Nutrient Omission Trials in Senegal

Research activity: Conduct nutrient omission and rate trials to quantify the effect of key nutrients, including secondary and micronutrients, on millet and peanut yields and economic returns in Senegal.

Location: Senegal

Time period: FY2019

Partners: NARES

Details: This activity has been cancelled because the NARS partners were not well prepared to start this activity for the past winter season. The nutrient omission trial activity should rather be part of the multi-year Dundël Suuf soil fertility mapping project funded by USAID in Senegal.

1.3.2.6 International Training Program on Bringing Balanced Crop Nutrition to Smallholder Farmers in Africa

The training was held May 27-31, 2019 in Accra, Ghana.

1.4 Sustainable Intensification Practices: Integrated Soil Fertility Management

Poor residue and fallow management and a focus on monocropping (rice, wheat, maize, cassava), combined with soil 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) are evident in the social, economic, and environmental impacts in South Asia, Southeast Asia, and sub-Saharan Africa. The activities described below combine ISFM and CA to develop climate-smart cropping systems for rice in Cambodia and Mozambique, and for maize in Ghana.

1.4.1 Nutrient Recycling

Use of organic fertilizers and amendments are essential component of ISFM. This activity explores opportunities to increase quantity and quality of organic fertilizers available improving soil fertility and soil health.

Research activity: Evaluation of a rapid test kit (Solvita) to evaluate nitrogen mineralization in tropical and subtropical soils

Location:

Time period: FY2019-2020

Partners: Auburn and Tuskegee universities

Details: A series of three studies are being performed to examine N mineralization over time. The Solvita test will be compared to traditional laboratory incubations and field N mineralization studies to assess the viability of these quick and simple tests for estimating N mineralization in highly weathered Ultisols and Oxisols.

Laboratory Incubation Studies: Twelve soils with varying physical characteristics and organic matter concentrations will be collected from Alabama and two international locations chosen by IFDC. These soils will be used to evaluate the Solvita test compared to a 30-week mineralization incubation study with standard chamber techniques. The incubation chamber method is a long-term standard method in which extractable nitrate-N and ammonium-N are measured before and after weekly incubation sampling intervals.

Field Studies: One field site has been selected to compare field N mineralization estimates with N mineralization estimated by the Solvita test. This is a long-term (>20 year) study at the E.V. Smith Research Center in Shorter, AL. This study contains four replications of two treatments (i.e., ryegrass cover and no ryegrass cover) in a cotton rotation. With only eight plots in the study, detailed N mineralization can be measured using the Solvita system, field measurement of extractable nitrate-N and ammonium-N, and standard anion/cation-exchange resins (which catch nitrate and ammonium N) using a buried bag technique. Such data will be collected biweekly for six months following termination of the cover crop. Cotton yield will be determined, and other crop response data (Normalized Difference Vegetation Index [NDVI] readings, plant height, or other indicators) will be collected. Nitrogen mineralization will be estimated via the Solvita method and a 30-week incubation study as described previously.

Additional on-farm field sites will be selected by IFDC cooperators. Similar to the first field study, detailed N mineralization will be measured using the Solvita system, field measurement of extractable nitrate-N and ammonium-N, and standard anion/cation-exchange resins (which catch nitrate and ammonium N) using a buried bag technique. Cash crop yield will be determined to compare areas with and without long-term cover crop incorporation or animal manure application, and other crop response data (NDVI readings, plant height, or other indicators) will be collected.

Results: We have collected soil from 12 locations in Alabama, and we still have a few more to go. These are currently being stored in a cold location, and preliminary background characterizations are underway.

Next steps: The soils listed in the table below will be used for the laboratory incubation studies, which start in November. The graduate student has been identified for this project. She does not graduate until this December, which explains the time delay for the start of this project.

Soils have been selected from:

Soil Number	Basic Characteristics/Cropping
1	North Alabama, long term history of no-till
2	North Alabama, long term history of no-till
3	Headland, AL. Sampled from the long-term peanut/cover crop rotation.
4	Auburn, AL. Sampled from the Old Rotation.
5	Shorter, AL. Sampled from the long-term wheat rotation, Field Crops Unit.
6	Shorter, AL. Sampled from a Pacolet sandy loam.
7	North Alabama (Tennessee Valley). Sampled from an Ultisol with high P fixing characteristic.
8	Auburn, AL. Sampled from the Cullars Rotation.
9	Sand Mountain Substation. Fallow soil sample from plots with a long history of pasture use.
10	West Alabama. Sample from the long-term grazing plots, Marion Junction.
11	Fairhope, AL. Sample from a loamy sand with a long history of pecan cropping.
12	Auburn, AL. Loamy sand from the Turfgrass Unit with a long history of grass production.

Thus, the first round of incubation work will be completed by May 2020 (30-week trials), with the E.V. Smith Field trial initiated in February of 2020 as well. The site at IFDC should also be identified by then.

Output: First work by the graduate student should be presented at the 2020 American Society of Agronomy meetings.

A link to a more detailed report is in Annex 3.

1.4.2 Developing a Highly Productive and Sustainable Conservation Agriculture Production System for Cambodia

Research activity: Assessing changes in soil organic C and N stocks and soil functions of sandy paddy fields under conventional tillage and conservation agriculture production systems

Location: Stung Chinit irrigation scheme (Santuk district, Kampong Thom province) in Cambodia and KSU

Time period: FY2019-2020

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

Details: The intensification of rice farming over the last 10 years in Cambodia has generated significant increases in rice productivity. However, it has also raised a number of questions related to economic profitability, food quality, and environmental sustainability.

This activity will take advantage of conventional till and no-till paired experiments conducted by KSU since 2011. Determination of total carbon (C) and fractionation of C will be done prior to the start of the proposed trials.

There are two main objectives of the study. The first is to quantify the soil organic C (SOC) and N storage using a diachronic approach based on a paired-plot comparison of paddy fields under conservation tillage (CT) and conservation agriculture (CA) at different years (2014 and 2018). The second is to assess the changes of three main soil functions (Biofunctool® approach: C transformation, soil structure, and nutrient cycling) between CT and CA.

Experimental Design. The experimental plots are designed to test the effect of tillage practices (no-till and conventional tillage), cropping pattern and intensity (crop cycles and cover cropping), and fertilizer levels on the changes in soil health in lowland rice production.

Table 10. Cropping systems pattern.

Soil Analysis		Paired-Plot	Cropping System	Rice Cycle	Fertilizer Rate	2011	2012	2013	2014	2015	2016	2017	2018
Sampled and soil parameters assessed in Dec. 2014 + backup RUA													
Dec. 2014	Dec. 2018	L1.1	CT	3 rice cycle	3	3 rice	3 rice	3 rice	2 rice	1 rice	1 rice	1 rice	1 rice
Dec. 2014	Dec. 2018	L1.2	CA	3 rice cycle	3	3 rice	3 rice	3 rice	2 rice	1 rice	1 rice	1 rice	1 rice
Dec. 2014	Dec. 2018	L4.1	CT	2 rice cycle: early wet + wet season rice	3	2 rice	2 rice	2 rice	2 rice	2 rice	1 rice	1 rice	1 rice
Dec. 2014	Dec. 2018	L4.2	CA	2 rice cycle: early wet + wet season rice	3	2 rice	2 rice	2 rice	2 rice	2 rice	1 rice	1 rice	1 rice
Dec. 2014	Dec. 2018	L5.1	CT	2 rice cycle: wet season rice + dry season	3	2 rice	2 rice	2 rice	2 rice	2 rice	1 rice	1 rice	1 rice
Dec. 2014	Dec. 2018	L5.2	CA	2 rice cycle: wet season rice + dry season	3	2 rice	2 rice	2 rice	2 rice	2 rice	1 rice	1 rice	1 rice
Dec. 2014	Dec. 2018	L6.1	CT	1 rice: wet season	3	1 rice	1 rice	1 rice	1 rice	1 rice	1 rice	1 rice	1 rice
Dec. 2014	Dec. 2018	L6.2	CA	1 rice: wet season	3	1 rice	1 rice	1 rice	1 rice	1 rice	1 rice	1 rice	1 rice
Sampled and backup at the soil lab at RUA													
Dec. 2014		U5.1	CT	1 rice: wet season	3	1 rice	1 rice	1 rice	1 rice	1 rice	1 rice	1 rice	1 rice
Dec. 2014		U5.2	CA	1 rice: wet season	3	1 rice	1 rice	1 rice	1 rice	1 rice	1 rice	1 rice	1 rice
Dec. 2014		U6.1	CT	1 rice: wet season	3	1 rice	1 rice	1 rice	1 rice	1 rice	1 rice	1 rice	1 rice
Dec. 2014		U6.2	CA	1 rice: wet season	3	1 rice	1 rice	1 rice	1 rice	1 rice	1 rice	1 rice	1 rice

Results:

Soil Sampling:

- 592 bulk soil samples collected from four soil depths (0-5, 5-10, 10-20, and 20-40 cm) were air-dried, sieved, and ground. These soil samples are being shipped to KSU, and the following chemical analysis will be conducted with SOC; total N, P, K; Ca; and Mg. SOC fractions (Hot-water extractable organic C and Permanganate oxidizable organic C) were analyzed at the RUA Soil Lab, and the results being summarized.
- 52 soil samples collected from one depth (0-10 cm) were analyzed using ‘The Biofunctool®’ approach, including soil respiration, available N, available P, POXC, pH, Lamina bait, litter index, water infiltration, and aggregate stability. All variables have been analyzed except the aggregate stability.

For the diachronic analysis, two soil sampling periods were used, December 2014 and December 2018 (0-5, 5-10, 10-20, and 20-40 cm depth). ‘The Biofunctool®’ approach was conducted on the soil samples collected in December 2018 at 0-10 cm depth.

The first set of soil analysis was conducted at the RUA Soil Lab by Mr. Sambo Pheap with support from bachelor students.

*Table 11. Permanganate oxidizable organic C, available N, pH, P0Bray ** and in-situ respiration for the cropping patterns in Table 10.*

Treatment	POXC (mg/kg soil)		Available N (mg/100g)		pH-H20 (1:2.5)		P-Bray II (ppm)		Situresp Abs (T0-T24)	
	mean	std dev	mean	std dev	mean	std dev	mean	std dev	mean	std dev
L 1.1	721,5	37,4	36,9	6,6	5,20	0,20	26,9	14,7	0,91	0,36
L 1.2	777,5	36,7	50,9	19,3	4,88	0,23	14,6	7,5	0,88	0,31
L 4.1	627,2	12,5	27,5	1,1	4,87	0,13	30,9	5,0	0,37	0,31
L 4.2	744,3	116,6	36,5	7,4	4,70	0,25	31,0	19,4	0,71	0,47
L 5.1	627,9	31,3	35,3	10,2	4,95	0,21	21,9	6,6	0,42	0,26
L 5.2	672,9	64,3	33,9	8,1	4,78	0,41	35,9	8,2	0,60	0,38
L 6.1	669,5	63,9	33,9	5,5	5,03	0,29	31,5	14,1	0,69	0,31
L 6.2	753,8	46,8	41,4	6,5	4,73	0,29	20,9	9,1	0,92	0,20
U 5.1	606,3	60,9	35,2	11,2	5,33	0,21	22,2	8,0	0,18	0,07
U 5.2	677,3	75,0	35,6	11,5	4,83	0,03	41,9	13,9	0,34	0,31
U 6.1	644,7	42,9	36,9	13,2	5,32	0,21	25,3	16,6	0,31	0,28
U 6.2	761,1	57,4	39,1	10,9	4,67	0,23	26,6	10,3	0,86	0,34
NV	751,9	88,4	44,2	9,9	4,74	0,19	17,7	23,7	0,74	0,26

Next steps:

Summarizing Data for Long-Term Predictions of Soil Health. The team will parameterize 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), or Decision Support System for Agrotechnology Transfer (DSSAT) models. The training and hiring of a team of graduate students and undergraduates who will do the modeling is being done in synergy with other projects.

A link to a more detailed report from KSU is in Annex 3.

1.4.3 Evaluation of the Role of Legumes in Rice-Based Farming Systems for Nutrition Improvement, Soil Health, and Income Generation

Research activity: Since most farmers in the target areas have no access to water for cultivation of vegetables as an off-season option, the cultivation of chickpea as an alternative crop to be grown in rotation with rice is being evaluated. This activity will complement the ongoing IFDC Food security through climate Adaptation and Resilience in Mozambique (FAR) Project.

Location: Buzi District, Mozambique

Time period: FY2019

Details: Chickpea is a new crop for farmers, requiring close collaboration with extension and research services. The chickpea growing season starts in April (onset of winter); however, cyclone Idai produced higher than average temperatures in the area in mid-March, and fields remained flooded until April-May. Therefore, it was impossible to establish the on-farm demonstration trials. The activity will be implemented in FY2020.

1.4.4 Evaluation of the Synergistic Effect of CA Practices in Combination with an Activated PR Amendment as a Component of ISFM in Northern Ghana

Research activity: Trials in northern Ghana to evaluate the synergistic effects of CA and ISFM practices along with activated PR as a P fertilizer source.

Location: Northern Ghana

Time period: FY2019-2020

Partners: Africa RISING Project

Details: The current agricultural intensification process encourages monocropping and conventional tillage practices on soils inherently low in organic matter content. This has resulted in reduced resilience and increased vulnerability to climatic variability and production risks among smallholder farmers in SSA. These negative effects of agricultural intensification could be mitigated with farming practices that encompass and encourage soil health, such as conservation agriculture (CA) and integrated soil fertility management (ISFM).

During FY2019-2020, in partnership with the Africa RISING project in Ghana, we established eight trials in northern Ghana to evaluate the synergistic effects of CA and ISFM practices along with activated PR as a P fertilizer source. The purpose of the trials was to develop resilient agricultural and nutrient management practices for improved yield with reduced risks under adverse soil and climatic conditions. We hypothesized that soil amended with activated PR as a nutrient source, combined with CA and ISFM, will improve rooting and drought tolerance while conditioning soil acidity, resulting in overall increases in productivity.

The trials were laid in a split plot design with the first factor, CA practices, randomized on the main plots and the second factor, rates of P fertilizer sources, randomized on the subplots. The size of each subplot was 10 m x 5 m; each main plot was 60 m x 5 m in size. The treatments comprised two farming practices and five P source x rate treatments. The farming practices were climate-resilient CA and non-CA farming practices. The P source x rate treatments were:

1. Activated PR at locally recommended P rate
2. Activated PR at 75% of locally recommended P rate
3. DAP at locally recommended P rate
4. DAP at 75% of locally recommended P rate
5. Togo phosphate rock at locally recommended P rate
6. Control (0 P)

Thus, for each site we had two main plots and six subplots with four replications for each treatment combination. At each location, a climate-resilient and drought-tolerant maize hybrid was used as the test crop.

Next steps: The trials are ongoing and are expected to be harvested in November and December. After trials are harvested to determine grain yield, plant tissue analyses will be conducted to determine nutrient uptake from selected plots. Following harvest, SOC and N storage will be quantified. Year 1 results will be reported.

The trials will be repeated in FY2020 to validate the results of Year 1. Based on the results of Year 1, demonstration plots will be established to educate farmers and build their capacities for climate-resilient maize production in vulnerable soils under vulnerable climate. We will use economic and statistical models to determine economically optimum activated PR rates for CA systems.

Output: A publication will be produced.

1.5 Improving the DSSAT Cropping System Model for Soil Sustainability Processes – Cross-Cutting with Workstream 2

Over the past few years, IFDC has lost expertise in database management and programming due to budget reductions. Due to the large amount and types of biophysical and socioeconomic data, IFDC is using the database platform developed for the global Agricultural Model Intercomparison and Improvement Project (AgMIP). The use and refinement of AgMIP's database for implementation by IFDC is being conducted in partnership with the University of Florida, the developer of the AgMIP database.

The partnership with the University of Florida is also being used to improve the existing soil dynamics model in the DSSAT Cropping System Model using the soils and agronomic data generated by IFDC over past years.

1.5.1 Modify and Refine the AgMIP Database

Research activity: Modify and refine the AgMIP database for IFDC's biophysical and socio-economic data

Location: IFDC headquarters and University of Florida (UF)

Time period: FY2019

Partners: AgMIP and UF

Details: In collaboration with AgMIP and UF, IFDC was able to initiate a centralized database project. This database is designed to be compatible with other database systems, such as CGIAR. To date, IFDC has been able to upload 468 experiments from Bangladesh, Myanmar, University of Tennessee, and Northern Ghana. This includes:

- Nutrient omission trials from Northern Ghana
- S trials with the University of Tennessee
- GHG emission trials from Bangladesh for N_2O simulation
- Greenhouse trials on effect of micronutrients on cereals.

More datasets from the field work are expected to be shared and posted in the database.

This database is in progress, and support from a programmer will be needed to construct a better fit system for IFDC's database.

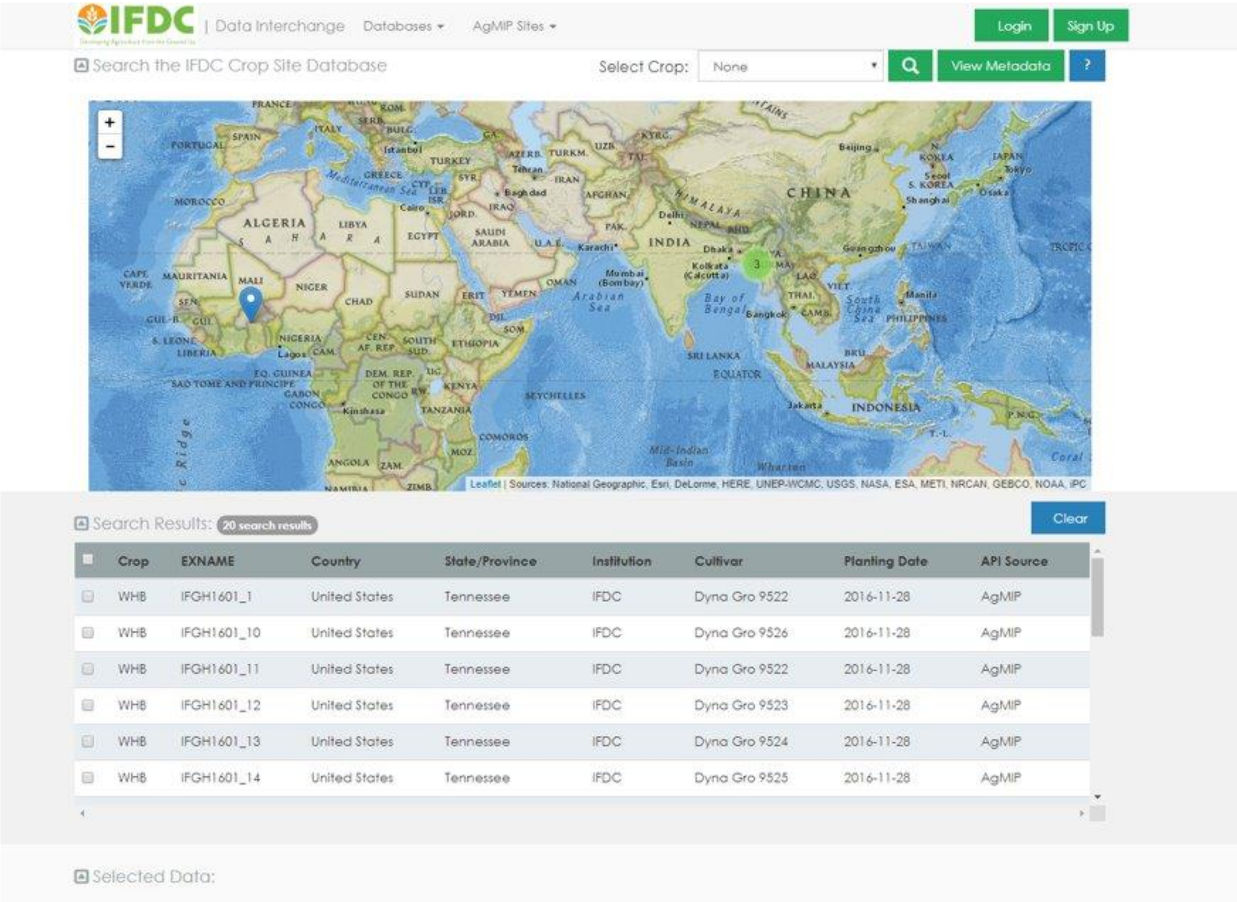


Figure 27. IFDC Crop Site Database

1.5.2 Improving the DSSAT Cropping System Model for Soil Sustainability Processes

Research activity: Improve the existing soil dynamics model in the DSSAT Cropping System Model (CSM) using IFDC soils and agronomic data

Location: Institute for Sustainable Food Systems, University of Florida (UF)

Time period: FY2019

Partners: UF

Details: The geospatial addition to the DSSAT software, GSSAT, originally developed by IFDC, is being refined and evaluated using spatial soil data from Ghana and Burkina Faso. 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. A brief update on each activity in this project can be found in Table 12.

Table 12. Status of DSSAT Improvement Deliverables

Activity	Deliverable	Status
A. Model Improvements		
Soil C Balance Component	Soil C balance fully tested and prepared for release	Complete
N_2O Emissions Model	N_2O emissions model tested with additional datasets	Partially complete. Bangladesh dataset from Yam Gaihre uploaded to database.
Generic Fertilizer	Generic fertilizer module fully implemented in DSSAT-CSM, including lookup table for fertilizer properties to be read by the model	Fertilizer characteristics table has been defined. Algorithms have been added for urease and nitrification inhibitors.
Improvements to Rice Plant Growth and Development Model	Assistance provided to IFDC for identification and implementation of priority improvements to rice plant growth and development model	Ongoing
	A version of DSSAT-CSM with at least one of the priority rice model improvement implemented	Ongoing
Methane Emissions Module	MERES model updated for linkage to DSSAT-CSM v4.7	Complete
	Preliminary linkage of MERES model to DSSAT-CSM v4.7	Partially Complete
Potassium Stress Conceptual Model Development	Assistance provided to IFDC for development of conceptual model for potassium plant stress	No New Progress
Soil P movement model implementation	Assistance provided to IFDC for implementation of existing soil N movement routines for movement of soluble soil phosphorus	No New Progress
Soil K diffusion conceptual model development	Assistance provided to IFDC for development of conceptual model for soil potassium diffusion.	No New Progress
Soil NH_4 diffusion conceptual model development	Assistance provided to IFDC for development of conceptual model for soil ammonium diffusion	No New Progress
B. Data Acquisition for Modeling		
Data for model testing: LTAR data with N_2O emissions and soil C and N dynamics	IFDC datasets appropriate for testing methane emissions model identified and converted into DSSAT format	N_2O data from Bangladesh rice experiment have been obtained from Yam and converted to AgMIP format.

Activity	Deliverable	Status
IFDC datasets for slow release fertilizers and inhibitors	At least one IFDC dataset which includes slow or controlled release fertilizers, and/or use of inhibitors, in DSSAT format for use in testing the generic fertilizer module	No New Progress
C. Improvements to the GSSAT Spatial Modeling Platform		
Complete input data reading and file generation, link with the latest DSSAT version, and generate recommendation maps merging input and simulated data	GSSAT with completed input data reading and file generation	Complete (Year 1)
Expand applications to other countries, explore buy-in opportunities, conduct training program	Resources to expand GSSAT applications to other countries identified and contacts made with other organizations	Complete
Test GSSAT with additional data	GSSAT tested with additional data, which may include data from SECC, CIA Tool, Gates Foundation, Feed the Future, others	No New Progress
D. Development of IFDC Database for Biophysical and Socioeconomic Modeling		
Install database at IFDC, including authentication system for user access	AgMIP Crop Site Database installed at IFDC	Complete (Year 1)
	Functional user authentication system for IFDC Crop Site Database	Complete (Year 1)
Develop searchable metadata definitions to harmonize with CGIAR data system	Searchable metadata to allow harmonization with CGIAR data system identified	Complete (Year 1)
Develop database interface to allow users to access the database	Database web-based user interface implemented	Complete
Develop an administrative interface for user and data controls	Database web-based administrative interface implemented	Complete
Expose IFDC data through GARDIAN and/or NAL portals	Procedures to expose data through CGIAR GARDIAN and/or NAL are defined	No New Progress
Ongoing support for IFDC database and data archive	Assistance provided for all IFDC database maintenance and operation, not to exceed 2 weeks effort	8.1 Weeks Effort Provided to Date

Activity	Deliverable	Status
E. IFDC Software Support		
Provide support for IFDC Java desktop application which communicates with our database to show crop/project information	Support provided for IFDC Java desktop application, not to exceed 2 weeks effort	8 hours support provided on PRDSS tool

Additional information on each of the activities in progress can be found in a report provided in Annex 3.

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

Under Workstream 2, IFDC conducts evidence-based research to support input policy reform initiatives. More specifically, IFDC focuses on fertilizer policies for market development, with emphasis on accelerating agricultural growth using improved crop management technologies, especially fertilizers and complementary inputs. The three broad categories under this workstream include documenting fertilizer/input market policy reform processes and engagement with partners to influence policy reforms, conducting impact assessments, and carrying out economic studies.

Together with Workstream 1 and other field-based IFDC operations, these studies will add to IFDC's knowledge management system, contributing to databases that provide useful information to draw lessons learned and identify gaps for further action or research. The progress made during the first semi-annual period of FY2019 under Workstream 2 is summarized below and in Annex 1.

2.1 Document Policy Reforms and Market Development

Workstream 2 activities on policy processes support efforts that provide the necessary impetus to catalyze reforms to existing policies. The aim is to create an environment that encourages private sector investments that will result in increased access to input markets by smallholder farm households. With BFS support, IFDC is partnering with organizations and stakeholders at various levels in countries that show high potential for policy change to: (a) support the reform processes utilizing evidence-based approaches and (b) build the capacity of stakeholders toward effective implementation of reforms.

In FY2019, IFDC engaged in the following set of sub-activities with associated deliverables.

- Influencing fertilizer policy reform processes at the country level; this was the case in Kenya, with fertilizer dialogue among stakeholders and creation of a fertilizer platform spurred by the Kenya Fertilizer Round Table (KeFERT).
- Engagement in capacity building on input policy reforms.
- Documentation of evidence-based policy reforms in selected regions/countries (ECOWAS).

2.1.1 Influencing Kenya Fertilizer Policy Reform Processes through the KeFERT Fertilizer Platform

Kenya's Ministry of Agriculture, Livestock, Fisheries and Irrigation (MoALF&I), in collaboration with IFDC and various public and private partners, organized the KeFERT meeting to bring together fertilizer stakeholders in the country and region. The meeting was held October 16-17, 2018, to spur coordinated efforts toward unblocking constraints that limit smallholder farmers' access to and use of fertilizers and soil amendments.

A detailed agenda for the proceedings and the presentations can be found at www.ifdc.org/KeFERT. The presentations can be downloaded at https://ifdc.org/presentations-given-at-the-2018-kenya-fertilizer-round-table/.

Improving Policies and Performance Through Stakeholder-Led Platforms

IFDC has facilitated the development of inclusive fertilizer sector platforms in various countries in SSA where stakeholders can gather for informed, evidence-based discussions and action related to soil and fertilizer sector development priorities and improving the policy and regulatory enabling environment. A recent example is IFDC's national-level work in Kenya.

In October 2018, IFDC worked with Kenya's Ministry of Agriculture, Livestock, Fisheries and Irrigation and fertilizer sector partners to organize an initial Kenya Fertilizer Roundtable (KeFERT), aimed at better coordinating efforts to expand smallholder access and use of fertilizers. Public and private stakeholders subsequently agreed to form the Kenya Fertilizer Platform and work together to develop a roadmap for fertilizer sector development and address priority issues identified by KeFERT. Issues include regulatory standards, fertilizer quality, counterfeit products, and logistics and transport bottlenecks.

KeFERT resulted in the formation of the Kenya Fertilizer Platform (July 2019), a public-private mechanism composed of key stakeholders involved in fertilizer access, quality, and use. The purpose of the Fertilizer Platform is to resolve issues and enable dialogue, coordination, and information exchange. The platform will facilitate action on key fertilizer issues through public-private task forces on an ongoing basis. A key outcome of the platform is to create a more competitive fertilizer sector that results in increased accessibility, affordability, and availability of fertilizers to smallholder farmers.

Progress: The Kenya Fertilizer Platform was launched on July 9, 2019, and the event was presided by the Ministry of Agriculture Principal Secretary. The event was well attended, with over 70 participants of the key stakeholders from the private sector, public sector, and development partners, among others. The Kenya Fertilizer Platform proposed structure of KeFERT is composed of a Steering Committee and a Secretariat. The platform will begin as an informally at the initial stages, with the option for formalization/registration of its legal standing in future. Currently, IFDC has assumed the role of the interim Secretariat for the Kenya Fertilizer Platform.

The Kenya Fertilizer Platform will facilitate resolution of the current and emerging issues associated with integrated soil fertility management; initiate policy dialogue in which all stakeholders participate toward review or formulation of appropriate policies for efficiency and effectiveness of the fertilizer supply chain; and establish a feedback mechanism through which information can be promptly shared between the public and private sector for efficiency in the farm inputs subsector.

Based on the key priority areas identified during the KeFERT event in October 2018, a stakeholders meeting was held September 18, 2019, on "Technical Discussion on Fertilizer Standards." This brought together over 20 participants, who exchanged views on the best way to formulate Kenya fertilizer standards. Benchmarking Kenya fertilizer standards against the international and regional standards was emphasized. The discussion was guided by presentations from the Kenya Bureau of Standards (KEBS) and the African Fertilizer and Agribusiness Partnership (AFAP) on the KEBS Process for Fertilizer Standard Setting and Technical Presentation on Fertilizer Standards, respectively.

The meeting provided an invaluable opportunity for the government to hear from and interact with a cross-section of stakeholders from across the value chain and learn about and begin to address key points of concern with regards to the current fertilizer standards in Kenya, their correct interpretation and application, and how standards will be set and communicated going forward. The primary aspect to the success of the platform is it provided the participants with an opportunity to learn and be updated on topics of relevance vis-à-vis fertilizer standards in Kenya.

2.1.2 Capacity-Building Activities: Policy Reforms

USAID BFS Agriculture Core Course: Policy, Governance, and Standards – Agriculture Input Policy

At the request of BFS policy advisors in Washington, D.C., and in partnership with the Rutgers University FTF Policy Research Consortium, a presentation was given on the importance and impact of agricultural input policies during the USAID BFS-sponsored agriculture core course for inter- and intra-agency staff involved in U.S. Government international development activities. The training covered the importance of agro-input policies for seeds, fertilizers, pesticides, and agricultural machinery. It also discussed the key impacts of input policy reforms on the respective sectors for better food security and improved incomes and welfare among smallholder farmers in specific countries. The training session content was prepared in collaboration with the BFS policy team and the Rutgers consortium.

At the request and advice of the BFS policy advisor, a poster was developed outlining *Seed Sector Reforms in Zambia* and their impact on private sector participation, seed exports, and increased adoption of high-yielding and high-quality seeds in the country. The poster was submitted and further presented at the training session for mission staff on advanced topics in agricultural policy on December 12, 2018.

2.1.3 Documenting Global and SSA Fertilizer Market Trends and Outlook

IFDC is a member of the Fertilizer Expert Outlook Group, a World Bank initiative that has been carried out by the Food and Agriculture Organization (FAO) of the United Nations for the past 20 years, with participation from the private global industry and IFDC. During 2018, IFDC personnel collected/updated, validated, and analyzed data for projections on fertilizer consumption and demand, with a focus on SSA. The outputs of the annual Fertilizer Outlook Expert Group meeting are joint projections of fertilizer supply, demand, and supply-demand balances to be published in joint World Fertilizer Trends and Outlook (WFTO) report, issued annually by FAO. Projections were presented, discussed, and further validated with the Fertilizer Outlook Expert Group, and in some cases, the projections were replaced based on group consensus.

Progress: During this work plan period, no further progress has been made toward continuing this activity, since no meetings were convened during the FY2019 by FAO to further advance this initiative.

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

This is an ongoing activity initiated in 2015, when IFDC joined the Partnership for Enabling Market Environments for Fertilizer in Africa (PEMEFA), a Michigan State University (MSU)-led "consortium" of five organizations 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), the New Markets Lab (NML), and IFDC.

IFDC-led activities under PEMEFA were laid out in the Alliance for African Partnership (AAP) workplan 2017-18 as "Activity 1.2 – *Study concept on the Impacts of 2012 ECOWAS Fertilizer Regulatory Framework on Fertilizer Trade and Use in the Region.*" Since the ECOWAS regulatory framework is yet to be fully adopted and enforced in the West African region, this activity was reformulated in November 2018 as *"Implications of the 2012 ECOWAS Fertilizer Regulatory Framework on Fertilizer Quality and the Development of a Private Sector-led Supply Chain"* to focus on the major issues of quality control and private sector investments in the regional fertilizer market. Two major deliverables, due at the end of the AAP grant, were produced and submitted in a timely manner on December 31, 2018:

- A policy brief on "ECOWAS Fertilizer Regulatory Framework: Implications for the Development of Private Sector-Led Supply of Quality Fertilizers in West Africa" by Bocar Diagana, Emmanuel Alognikou, Porfirio Fuentes, Joaquin Sanabria and Latha Nagarajan. https://www.canr.msu.edu/resources/ecowas-fertilizer-regulatory-framework-implications-for-the-development-of-private-sector-led-supply-of-quality-fertilizers-in-west-africa

In addition to these, IFDC also contributed to the following:

- Five-year PEMEFA technical proposal: Some of the proposed research activities under the concept note mentioned above were selected and integrated into a proposal developed by PEMEFA to seek additional funding beyond the AAP grant. One of the targeted sources is the Bill & Melinda Gates Foundation. For this reason, the PEMEFA group held preliminary discussions to identify key potential themes in line with the Gates Foundation's current agenda.
- Finally, upon request from *Fertilizer Focus*, a leading magazine in the fertilizer industry, an article titled "Beyond Subsidies: How Else Can African Governments Support Private Sector Investment in Fertilizer Value Chains?" was submitted by PEMEFA for publication in a forthcoming edition of the magazine. This was also presented at the West Africa Fertilizer Forum held in Lomé, Togo, during April 24-26, 2019.

Note: The AAP grant has been closed, and PEMEFA is searching for new funding to continue collaboration between the partner institutions.

2.1.5 Policy Briefs on Fertilizer Policies and Market Development

The overall purpose of these briefs is to contribute to influencing policy reforms through active engagement with stakeholders, such as research institutions, private and public sectors, and in-country missions, through wider dissemination forums. IFDC's experiences engaging in fertilizer and input policy reform processes, particularly interventions or policies that have had significant impact on poverty and food security, are being captured and documented as short policy briefs, either through the IFDC team or in engagement with partners in Africa, Asia, and Latin America, for wider dissemination.

Progress: As a part of this activity, a country-level policy brief with a focus on Bangladesh has been documented during the FY2019. The brief discussed the "Role of Private Sector in Fertilizer Market Development for Macro and Micronutrients in Bangladesh" (see link in Annex 3).

2.2 Impact Assessment Studies

To support policy reforms for the development of input markets and value chains, IFDC is implementing the following sub-activities in Kenya and Rwanda, and the outputs produced are summarized below.

- Streamlining Kenya's input subsidy program toward delivering e-vouchers:
  - Technical report on "Proposed Kenya National E-Incentive Inputs Program (KeNEIIP) Management," a technical report prepared and presented to the Ministry of Agriculture of Kenya in April 2019.
- Assessing the effectiveness and impact of agro-dealer development/input supplier networks toward improved access to and use of technologies among farmers and the effects of market interventions in Rwanda.
  - Surveys prepared and administered across different sampling groups – data analysis in progress.

These two activities are being implemented through extensive consultations and surveys with relevant stakeholders in Kenya and Rwanda and in partnership with donor organizations, such as AGRA and the Ministry of Agriculture, policy research institutions at the national level (Tegemeo Institute of Agricultural Policy and Development), the Kenya Agricultural and Livestock Research Organization (KALRO), and CSOs.

2.2.1 Assessment of Kenya Fertilizer Subsidy Program

The Government of Kenya requested that IFDC and other policy think-tanks in Kenya assess the government's existing subsidy program in order to help them better target farmers for improved crop and soil productivity. The assistance will also provide valuable information for policy formulation and supportive interventions for streamlining the existing subsidy program.

Significant progress has been made during the FY2019 reporting period in two ways:

2.2.1.1 Technical Assistance Toward Designing Existing Input Vouchers in Kenya

As a part of Kenya's efforts to streamline and reform the existing input subsidy program, and at the request of the Principal Secretary of the Ministry of Agriculture, IFDC provided short-term technical assistance to study and recommend a modified input subsidy approach design.[1] The modified design would help ensure and improve the accountability of program implementation, thus improving the efficiency of the program through enhanced private sector participation as well as the quality of the services offered, including balanced fertilization practices based on soil recommendations and improved access to the benefits offered to last-mile customers.

- The short-term technical assessment was conducted during March 14-28, 2019, followed by a debriefing to the Cabinet Minister, along with recommendations and a suggested way forward. Key stakeholders from across the public and private sectors were included during the assessment. The final assessment report on "Proposed Kenya National E-Incentive Inputs Program (KeNEIIP) Management" was submitted and presented to the Ministry for further adoption and implementation, along with key steps and a required timeline in April 2019 (see link in Annex 3).

  There is broad consensus and support for reform from the Ministry to introduce a smart subsidy and to have this target a range of crops and inputs. The recommendations from IFDC in this regard were agreed to in principle, especially on the efforts required for the Ministry and stakeholders to roll out an e-wallet that would act as an incentive to purchase a range of inputs to stimulate profitable farming for smallholders.

- In response to the technical report, the Ministry further adopted and forwarded a set of recommendations for streamlining the existing subsidy reforms based on the recommendations of IFDC's Proposed KeNEIIP Management report. The Ministry also produced a detailed a report, including all the recommendations of IFDC's technical assessment on "A Proposal of the Adhoc Committee on Implementation of Agricultural Inputs E-Subsidy Management System in Kenya" in May 2019, which was submitted to the Principal Secretary of Agriculture in Kenya for adoption.

- The Principal Secretary of Agriculture, Kenya, has further approached several development partners (World Bank, International Fund for Agricultural Development [IFAD], European Union [EU], FAO) since May 2019 with the technical support from IFDC in proposing a way forward for the shift to e-subsidy. A few recommendations from the development partners that need to be addressed prior to the e-subsidy shift included:
  - Development of farmer registration criteria.
  - Development of agro-dealer identification and registration criteria.
  - Development of clear guidelines of the counties' role and involvement in the program.
  - System development for private sector participation.
  - Creation of the program funding mechanisms.
  - Identification of the commercial banks to be involved and the mode of operation.
  - Establishment of the program management unit.
  - Development of a clear agreement between Safaricom, as the E-Incentive technology provider, and the Government of Kenya on ownership of the program.

Progress: Several consultations (in July, September, and November 2019) were held since IFDC's technical assessment report on e-vouchers among different stakeholders to generate consensus on shifting to a nationwide e-voucher program beginning with the 2020 cropping season. The IFDC team participated effectively, along with Ministry officials, toward supporting e-subsidy programs.

[1] A report was produced based on the technical assistance.

The Ministry of Agriculture, in coordination with the Principal Secretary's office, is currently weighing different options on establishing a few key steps and guidelines in meeting the development partner's recommendations for an effective implementation.

2.2.1.2 Detailed Economic Study on the Impact of the Fertilizer Voucher Program

At the end of the FY2018 workplan period, as per the request of the Ministry, IFDC, together with Tegemeo (the premier agricultural research institute in Kenya), developed an impact assessment of the Kenya Fertilizer Voucher Program. The Terms of Reference (ToRs) have been reviewed by the Ministry, and discussions for obtaining additional funds to cover the impact assessment are ongoing. The impact assessment is seen as a key priority for all stakeholders. AGRA held a donor coordination meeting on this topic in mid-March to which IFDC, FAO, EU, IFAD, World Bank, USAID, AFAP, and others were invited. There is broad consensus that the Ministry should be supported in its reform process. AGRA and IFAD/EU are interested in funding the impact assessment, but they would like to see it broadened to include all inputs (seeds, mechanization, etc.).

Progress: This study could not be undertaken as planned, as the consultations with IFAD/EU and AGRA in April and August to finalize the ToR and necessary funding mechanisms for the assessment did not take place as expected.

2.2.2 Effectiveness of Agro-Dealer Development Programs Toward Sustainable Input Supply and Technology Transfer for the Last Mile in Rwanda

This research activity was launched to assess the effectiveness of agro-dealer development programs in documenting the impact of the donor's investment in such initiatives (e.g., are they narrowing the "last-mile gap" between farmers and input access) and the sustainability of such input networks in the developing country context. During FY2019, this activity was initiated in partnership with the Agribusiness-Focused Partnership Organization (AGRIFOP), a local Rwandan CSO involved in the capacity building of agro-dealer programs in Rwanda.

The major aim of this assessment is to identify strategies/mechanisms that ensure farmer accessibility to agro-inputs and, thus, increase the demand for major agro-inputs in a more sustainable manner. The assessment will answer questions related to:

- What is the extent to which the agro-dealer development and technology transfer programs have increased the demand for agro-inputs across Rwanda?
- Have these programs improved the efficiency in delivery of agro-inputs and reduced transaction costs and in dissemination of technology and knowledge among the farming households?
- Have the agro dealer development initiatives resulted in sustainable agro-dealers and agro-dealer enterprises, i.e., factors influencing the sustainability of initiatives?
- Have the agro-dealer networks reduced the distances traveled by farmer to buy agricultural inputs?
- Document success stories on the effectiveness of agro-dealer development programs and technology transfer mechanisms and on sustainable farming systems through improved adoption of technologies.

All of the objectives outlined above would capture the differences in terms of benefits and enterprise development among gender and youth. This would be an effort to understand how effective these programs are in providing inclusive economic opportunities.

To measure the effectiveness of agro-dealer development programs on technology transfer, we plan to assess through indicators or information related to the following areas:

- Detailed analysis of the agro-input enterprises to determine the efficiency in input delivery, including:
  - Impact of a credit facility on the supply of agro-inputs to agro-dealers, in the absence of donor-backed credit guarantee mechanisms.
  - Role and relevance of district- and national-level trade associations/cooperative unions.
  - Role of input policies and regulations in the effective supply of inputs.
  - Sustainability of agribusiness enterprises at dealer level.

- Farm-level discussions to elicit:
  - Increased productivity levels (yields) at the farm level.
  - Accessibility/availability: Increased access to farm inputs (reduced distance to access the inputs shop.
  - Affordability of the inputs (transaction cost reduction) at farm level.

Lessons learned from such an evaluation will answer the question *"How can farmers' access to and use of agro-inputs be improved on a large-scale, at an affordable cost, in a more sustainable way?"*. Further, they would inform policy and scaling up of interventions that would create demand for such agro-inputs through innovative partnerships among different stakeholders in the agro-input value chain. In this context, the purpose of this exercise is to assess the impact of agro-dealer development and technology transfer programs on farm productivity levels and, in turn, demand for the use of agro-inputs through programs such as Common Market for Eastern and Southern Africa's (COMESA's) Regional Agricultural Inputs Program (COMRAP), Rwanda Agro-Dealer Development (RADD) I and II, and Private Sector-Driven Agriculture Growth (PSDAG).

The major outcome of this study will be to determine the extent of demand for agro-inputs in general and the extent of technology adoption and knowledge gained by participants. Hence, the survey design will include both participants and non-participants of the program whenever possible and compare with the existing baseline information to understand the impact currently.

Progress: The following progress has been made toward implementing this activity since April 2019.

In June 2019, progress was made toward finalizing all of the technical aspects of the proposed assessment program, including the study locations, number of dealers to be surveyed across different provinces, survey procedures, and hypothesis to be tested.

- A field trip was also undertaken to finalize all the details in consultation with the stakeholders, including AGRIFOP, AGRA-Rwanda, and other USAID-funded program partners who are engaged in input delivery programs in Rwanda.

- A meeting was held with the USAID mission in Rwanda (Mr. Jean Damascene) to obtain the concurrence to further carry out this research work and seek guidance.

Sampling plan for agro-dealers: The sampling and data collection process involves two stages – one at the agro-dealer level to capture enterprise development and its impact on "demand for agro-inputs and improved access to agro-inputs" and the second at the level of farm households, who were the major beneficiaries of the technology transfer programs.

Baseline survey comparisons: Before the start of RADD I, a baseline survey was conducted in 2009/10 to identify the existing potential for further enterprise development among agro-dealers or input suppliers and the demand for such inputs among farmers (by the National University of Rwanda). For this exercise, we would attempt to follow-up with agro dealers who participated during the baseline surveys in 2009/10 to determine the impact of agro-dealer development programs on their business efforts.

- *Agro-dealers who did not participate in any of capacity building development programs* – This includes agro-dealers who are still operating but were never trained and a few that participated in input subsidy programs.
- *Agro-dealers who participated in different agro-dealer development programs* to strengthen their capacities and financial linkages. For instance, the agro-dealer development programs in operation were COMRAP, RADD I, and RADD II. Thus, our sample would include agro-dealers trained by COMRAP, RADD I and II, and PSDAG.
- Further, the representative sample of agro-dealers that includes *trained agro-dealers who are accredited and participate in input subsidy programs* will be compared with trained agro-dealers who did not go through accreditation.
- The evaluation also would document and capture the *agro-dealers who participated in agro-dealer development initiatives but were not able to continue (drop-offs)* business operations for various reasons.
- *Focus group discussions with farming communities (10 locations across 4 provinces)* Farm-level inquiries will focus on measuring the impact on "productivity or yields" and "other inputs use" due to the adoption of improved technology practices. Here, we propose to conduct series of focus group discussions among farming households that are served by input suppliers in their respective locations. The focus group discussions will be conducted at locations based on distance gradient.

Table 13. Sampling schema for the surveys.

Province	Districts	Agro-Dealers with Training		Agro-Dealers with No Training		Agro-Dealers Trained but Dropped Off	Total
		Accredited	No Accredited	With Subsidies	No Subsidy		
East	2	15	5	3	2	5	30
West	3	20	10	6	4	5	45
North	3	20	10	6	4	5	45
South	2	15	5	3	2	5	30
Total	10	70	30	18	12	20	150

- During the months of August-September 2019, baselines were fixed, and the pilot surveys were held among agro-dealers (30) to test the questionnaire.

- Detailed surveys (four sets of questionnaires) were prepared and piloted to capture information across the above described sampling schema. The final surveys are planned for the months of November through January.

The data analysis and reporting will be completed during the FY2020 reporting period, and a dissemination event across stakeholders is also planned.

2.3 Economic and Market Studies

IFDC's FY2019 work in this sub-activity involved the following key areas with the progress on expected outputs:

- Supporting policy efforts to harmonize fertilizer quality regulations built around evidence-based scientific analysis.
  - Consolidated reports on the fertilizer quality assessments (FQA) carried out in SSA and Asia were produced and the individual country-level report on Zambia was completed.
- Documenting data on fertilizer cost buildups and market margins across different countries in SSA.
  - A consolidated report on the cost buildup studies conducted in West Africa was produced.
- Initiating The African Fertilizer Access Index for Kenya (TAFAI-Ke).
  - The draft paper is being completed and will be reported during the FY2020 reporting period after peer-review process.
- Micro-economic research studies related to fertilizer technology use, markets, value chains, and environmental implications in partnership with land-grant universities.
  - Two dissertations have been completed using the data from Bangladesh.
- Enhancing monitoring and evaluation (M&E) capacities of soil fertility research projects.
  - In progress; one student enrolled in the University of Georgia Ph.D. program on evaluation methods.
  - Agronomic and economic efficiency indicators of fertilizer technologies in Asia (Bangladesh and Myanmar) are being documented using the plot-level data on UDP vs. non-UDP plots in farmers' fields using a cross-sectional panel data during 2009-2019.
- Documenting gender data on access to and use of fertilizers across IFDC projects, with a specific focus on Bangladesh.
  - The draft paper has been completed and is under peer review for validity. It is expected to be included during the FY2020 reporting period.
- Initiating activities to improve fertilizer use, access, and market development in Honduras and Guatemala.
  - The activity could not be initiated due to a hold on Northern Triangle countries by USAID. However, the concept note has been prepared and suitable partners have been identified for further implementation once approved.

2.3.1 Fertilizer Quality Assessments: Support Policy Efforts to Harmonize Fertilizer Regulations (with Workstream 1)

Nutrient shortages, granule degradation, and heavy metal contamination are common quality problems in fertilizer markets of developing countries. IFDC undertook quality assessments in 12 sub-Saharan African countries (2010-2018) and Myanmar in Southeast Asia (2017) to quantify the problems and identify their sources. Except for Zambia, results of the FQAs were reported in previous semi-annual reports. The Zambia FQA findings are reported below. In addition, IFDC synthesized lessons learned from all the FQAs.

2.3.1.1 FQAs in Zambia

Research activity: Fertilizer quality assessment in Zambia

Location: Zambia

Time period: Chemical analysis of fertilizer samples was completed in June 2018. The report was developed in FY2019.

Partners: Zambia Agricultural Research Institute (ZARI) and the Zambia Ministry of Agriculture and Livestock (ZMAL)

Details: With funding provided by USAID, IFDC conducted a series of fertilizer quality assessments in Eastern and Southern Africa. The assessment was conducted in Zambia because of the country's increasing trend in fertilizer consumption, large land areas with the potential for agricultural production, and the government's existing programs to reduce poverty and food insecurity. In addition, Zambia does not have a National Fertilizer Quality Regulatory System. Findings from this study can be used as a baseline to build a National Fertilizer Quality Regulatory System that can be harmonized with a regional regulatory system for member states of COMESA.

First, the IFDC fertilizer quality assessment team trained a group of 23 officials from government agencies that handle agricultural research, standardization, and environmental preservation. Then, a random approach was used to select a sample of fertilizer dealers and collect fertilizer samples for chemical analyses. Data on fertilizer markets, dealers, physical properties of the products, and storage conditions were also collected from the sample of dealers. After conducting chemical analyses on fertilizer samples in the labs, the estimated nutrient content and cadmium (Cd) content of the fertilizers were incorporated into the dataset for analysis.

Results: Out-of-compliance (OOC) shortages of macro and secondary nutrients in the most traded fertilizers (urea, 10-20-10+6S [Compound D]; calcium ammonium nitrate [CAN] 27%, 11-22-16+4S; and ammonium nitrate) occurred with high frequencies and severities. These shortages will likely cause nutrient deficiencies in crops. Considering that there was no evidence of adulteration in the samples from these fertilizers and that the degradation of physical properties was minimal, the expected origin of the nutrient shortages OOC is in product manufacturing.

The combined analysis of granulated compound and straight fertilizers of intermediate to low market trade also showed frequent and severe P_2O_5 and K_2O OOC shortages. Again, there was no evidence of adulteration and only mild degradation of physical properties, which suggests that the nutrient shortages originated in product manufacturing.

The combined analysis of the 23 bulk blends identified in Zambia showed frequent but low severity of total N shortages OOC, no shortages of P_2O_5 OOC, and highly frequent and severe K_2O

shortages OOC. It is apparent that segregation attributed to the use of crystalline, instead of granular, KCl. This explains the K_2O shortages in the bulk blends. Nutrient shortages in Zambian bulk blends are mild compared to nutrient shortages in bulk blends manufactured in other regions of Africa. All samples analyzed for Cd showed values well under the international tolerance limit, but it is recommended to continue to monitor fertilizers' Cd content and the origin of the phosphate rock used in fertilizer manufacture.

Nineteen percent of the 50-kg bags weighed had OOC shortages of at least -0.5 kg, and 10% of the bags had weight shortages of at least 1 kg. Additional investigation is needed to identify where and how this fraud is committed.

Inspections conducted before imported fertilizers enter Zambia should become stricter. It is important to establish a system that ensures pre-export verification of conformity (PVoC). This should be followed by confirmatory inspections at the points of entrance to Zambia. As Zambia's fertilizer consumption grows, a regulatory framework specific to fertilizers needs to be developed. An agency within the Ministry of Agriculture should be provided with the funds, trained personnel, laboratories, and other physical resources to conduct quality inspections along the value chain, analysis of samples, and administration of the regulation's legal aspects.

Interaction and good relationships between the government and private sector are essential to establish an environment of good fertilizer quality in the markets. Regulatory system implementation by government officials should be accompanied by self-regulation by the private sector.

Output: A report on the FQA in Zambia was developed and is linked in Annex 3.

Effect of Fertilizer Physical Properties on Nutrient Content

It is common that farmers, fertilizer dealers, and fertilizer quality officials are unaware of the effect of fertilizer physical properties on fertilizer nutritional characteristics. Most believe that as long as the actual nutrient content in the bags matches the nutrient content declared on the bag labels, the product quality is adequate.

The interrelationship between a fertilizer's physical and chemical properties is explained by IFDC through trainings for government quality inspectors, in FQA reports, and during FQA workshops delivered to government and private stakeholders.

Granule segregation in blends and granule degradation in compounds and blends produce uneven distribution of nutrients inside fertilizer bags. When a fertilizer with either of these problems is applied in the field, the nutrients will be also segregated. This will cause sections of the field to have high concentrations of some nutrients and low concentrations of others. Non-uniform distribution of nutrients reduces yields and nutritional crop values. Caking and high moisture content can also affect nutrient distribution inside the bags and crop fields.

The ECOWAS fertilizer quality regulatory system, supported by IFDC since its creation, was one of the first systems to regulate fertilizer physical properties. National or regional regulatory systems in East and Southern Africa and Southeast Asia should do the same.

2.3.1.2 Synthesis of Lessons Learned from FQAs in SSA and Myanmar

Research activity: Summary of lessons learned from FQAs

Location: Nine West African countries, two East African countries, and Myanmar

Time period: FY2019

Details: In developing countries, low fertilizer use by smallholder farmers and poor fertilizer quality constrain food security, limit prosperity, and prevent remediation of soil nutrient depletion. Studies conducted in the fertilizer markets of nine West African countries, two East African countries, and Myanmar identified quality issues that vary among regions. The study comprised dealers' random selection, fertilizer sampling for chemical and physical analyses, and data gathering for fertilizer management conditions and value chain characteristics.

Results: Bulk blends, which make up most of the fertilizer trade in West Africa, showed serious nutrient shortages and physical problems associated with the use of inappropriate blending technology. Kenya and Uganda had severe nutrient shortages in fertilizer for foliar application and nutrient shortages in imported granulated products. Kenya's fertilizer quality problems are explained by limited regulation implementation, and Uganda's are explained by the lack of a regulatory system. The most serious problem in Myanmar was imported fertilizers contaminated with heavy metals. Quality problems in Myanmar result from a weak legal framework and limited regulation enforcement. Data do not support the concept that adulteration is a major source of quality problems in any of the countries that were studied; however, it is apparent that several quality problems are misinterpreted as adulteration. Bag weight shortages were found in all of the countries. Fertilizer quality assessments are used as the baseline to build or improve national or regional regulatory systems to protect farmers from poor quality fertilizers while promoting a culture of good quality fertilizers in developing countries.

Output: Fertilizer quality policy briefs were prepared and are available as links in Annex 3.

2.3.2 Fertilizer Cost Buildup Studies and Marketing Margin Analysis

Literature on agro-input markets in SSA shows that low fertilizer consumption is partly due to high transaction costs of supply, which limits its access, especially to resource-poor farmers. Though there is information available on the physical and other structural constraints that contribute to high transaction costs along the fertilizer supply chain, little is known about the current cost structure of supplying fertilizers in SSA. Considering that similar studies have been implemented in the past, tracking changes in the supply cost structure over time will help trace the impact of policy reforms affecting the fertilizer sector and provide lessons learned for other countries to adopt. The objectives of this activity are to: (a) assess the cost of supplying fertilizer from procurement and importation to distribution to farmers in selected SSA countries; (b) identify issues and constraints that are contributing to higher transaction costs; and (c) envision recommendations that could lead to additional policy changes and the implementation of programs and investments. With BFS funding, since 2015, four country-level studies have been documented under this sub-activity in Kenya, Tanzania, Mali, and Ghana.

Progress: This activity was completed during the semi-annual reporting period covering October 2018-March 2019. A discussion paper based on data, information, and completed reports from Mali and Ghana, "Changes in Cost of Supplying Fertilizer in West Africa: A Historical

Perspective," was finalized in January 2019 and was submitted during the semi-annual reporting period covering October 2018-March 2019.

2.3.3 The African Fertilizer Access Index

The proposed African Fertilizer Access Index for Kenya (TAFAI-Ke) will be a consolidated measure of various factors (policy, market, research, and development) that influence and are responsible for creating an enabling environment at the country level. Along with the initiation of the fertilizer sector platform in Kenya in October 2018, this will be an important contribution for the decisionmakers as well as other stakeholders. For this purpose, we collected the following set of indicators for each major group: research and development, industry competitiveness, policy and regulations, and services for the fertilizer sector in Kenya comparing the status over the last decade (2009/10 vs. 2018/19). Besides discussion with stakeholders in the value chain through KeFERT, additional information was also utilized through the existing efforts by AfricaFertilizer.org platform and World Bank measures on Enabling Business for Agriculture (EBA) and policy indicators collected through AFAP/AGRA-related work. The set of indicators on which information was collected are listed in Table 14.

Progress: The data and information have been analyzed, and a consolidated report comparing the indicators and progress over the decade in Kenya is being collated. The final report will be included in the FY2020 reporting period after peer review.

Table 14. TAFAI Indicators for Kenya (2009-10 vs 2018-19)

TAFAI Group	TAFAI Indicators for Kenya
Research and Development	Number of active blending/granulation plants Availability of recent soil maps Availability of recent fertilizer recommendations for food crops Percentage of food crops receiving balanced nutrition
Industry Competitiveness	Number of registered fertilizer companies Requirements to import and distribute fertilizers Market share of top four companies Market share of public/subsidized fertilizers Tariffs on fertilizer (import, export) and taxes on trade
Policy and Regulations	Requirements for registration of new fertilizers Status of fertilizer policy framework Quality of regulatory system Truth in labeling Use of smart subsidies
Services	Availability of extension services for smallholder farmers Existence and efficiency of national fertilizer / agro input dealers associations Concentration of rural agro-dealer network Availability of fertilizers in small packages (less than 50 kg) Retail-to-FOB price ratio for fertilizers used for food crops

2.3.4 *Economic and Environmental Implications of Fertilizer Technologies Using Life Cycle Analysis Approach*

Results from the ongoing GHG mitigation research in Bangladesh have shown that nitrous oxide (N_2O) and nitric oxide (NO) life cycle inventory emissions from fertilizers can be controlled, via application strategy, to levels associated with unfertilized plots. Thus, the quantification and reduction of GHG emissions associated with management practices in rice fields in Bangladesh may provide opportunities for farmers and policymakers to gain carbon credits. This work complements the agronomic work carried out on the quantification of GHG emissions by the life cycle analysis approach in the quantification of energy equivalents (and thus, carbon credits and associated monetary terms) consumed across different types of fertilization in a paddy-rice system in Bangladesh.

The proposed work in Workstreams 1 and 2 is being carried out by a graduate student from Rutgers University, to fulfill dissertation requirements, with data support from a field-level project in Bangladesh. For this purpose, the Rutgers University graduate student visited IFDC Headquarters in Muscle Shoals during February 20-22, 2019, and worked toward accessing the necessary scientific data for further analysis. During the trip, the student also set up the parameters needed for estimating the GHG emissions from UDP application versus the regular application process under different agronomic and irrigation regimes. The life cycle analysis using the data comparing broadcast vs. urea deep placement method in farmers' fields showed a distinctive advantage of both environmental and economic advantages using UDP in Bangladesh. Environmental benefits of adopting UDP include decreasing level of nitrification-denitrification, reducing greenhouse gas emission (reducing 50% CO_2 emission compared to prilled urea in *Aman* rice and 55% in *Boro* rice), and minimizing N in runoff water. Economic benefits associated with UDP include saving the amount of N fertilizer at 33%, reducing weeding cost, and increasing paddy yield (about 500 kg/ha more compared to prilled urea).

Progress: The thesis activity was completed in September 2019 and is linked in Annex 3.

2.3.5 *Economic Estimation of Fertilization Methods for Rice Paddy in Bangladesh – A Production Function Analysis*

This study evaluated the impacts of fertilizer deep placement technology, introduced by IFDC, in the designated FTF districts in Southwestern Bangladesh. The objective of this research was to examine the effects of adopting FDP technology on farmer yields, fertilizer productivity, and revenues, and the differences in fertilizer input (kg/ha) between broadcasting and FDP application. This study uses data from a survey of 2,000 farmers from 10 districts in Southwest Bangladesh collected in 2015 and 2016. All farmers surveyed used either deep placement and/or broadcast prilled urea; thus, all farmers used fertilizer during production.

The surveyed population is divided into two treatment groups: (a) fully adopted FDP and (b) mixed users using both fertilizer practices. Their yields, revenues, fertilizer productivity, and average fertilizer inputs were analyzed through ordinary least squares (OLS) fixed effects regressions.

The results show a significant positive relationship between FDP use and yields, total revenues, net revenues, and fertilizer productivity. There is a significant negative relationship between FDP technology and average fertilizer input. The farmers that fully adopted FDP had higher yields, revenues, and fertilizer productivity and less fertilizer input than the mixed and broadcast users. In addition, the adoption behavior of surveyed households in the 2015 treatment group was compared to the behavior of those in the 2016 group. Our study shows that deep-placement technology can be a climate-smart practice in helping farmers mitigate greenhouse gas emissions and slow climate change; however, it continues to face adoption barriers for farmers in Bangladesh.

Using the data from the uptake of UDP by farmer households in Bangladesh through the USAID-funded Accelerating Agriculture Productivity Improvement (AAPI) project, an economic analysis was conducted by a graduate student from Rutgers University to assess the agricultural productivity and climate-smart solutions for using the UDP method in Southwestern Bangladesh

Progress: This activity was completed during semi-annual reporting period covering October 2018-March 2019; the graduate student defended the dissertation toward his M.S. in January 2019. The dissertation research was guided by Rutgers University professors and an economist from IFDC. The following is a summary of the research undertaken by the graduate student. The dissertation is linked in Annex 3.

A research paper based on the dissertation is also in progress to submit for a presentation in an international conference during FY2020.

2.3.6 Enhancing the M&E Capacities of Soil Fertility Research Projects in IFDC

(Linked to activities in Workstreams 1 and 2 and overall IFDC activities)

Two kinds of activities have been undertaken during FY2019 and resulted in associated outputs.

a. Building the long-term capacity and internal capacities of monitoring, evaluation, and learning systems as a part of an effective learning process.

   An IFDC M&E specialist from Togo was identified, secured admission for the Ph.D. program at the University of Georgia, and started the academic sessions in January 2019 to specialize in qualitative research and evaluation methodologies and gain comprehensive knowledge on various tools and techniques to be applied in field situations.

   Progress: Currently, the student is exploring various topics for the dissertation research and will be engaged in evaluating specific soil fertility-related technologies that complement the BFS-SFT project goals.

b. As a part of the monitoring, evaluation, learning, and sharing (MELS) initiative, data on soil- and fertilizer-related outcomes, i.e., indicators from various IFDC projects , are being generated for a presentation for annual reporting purposes.

   Significant progress has also been made toward defining and collecting information on specific outcomes regarding fertilizer use and yields, nutrient use efficiency, and capacity building for women, and other significant indicators, including soil fertility technologies and good agricultural practices adopted by the farmers due to IFDC interventions over the last two decades in Asia and a few countries in sub-Saharan Africa.

   Progress: As a part of this exercise, the data on farmer field demonstrations from FTF/USAID-funded projects on fertilizer deep placement technologies – the AAPI (2010-2016) project in Bangladesh and FSI+ (20114-2019) project in Myanmar – comparing the agronomic and economic efficiency[2] of UDP/FDP use vs. traditional fertilization practices in farmers' fields (at the plot level) and across seasons (three seasons in Bangladesh and two in Myanmar) were analyzed for further interpretation and validity and will be presented as a short policy brief during FY2020.

2.3.7 Women's Access to and Use of Fertilizers in Field Crops and Vegetables

For various reasons, women 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. According to the FAO, closing the gender gap could increase agricultural output in the developing world by 2.5-4% and reduce the number of undernourished people by 12-17%.

To date, IFDC has not consolidated its thinking or evidence concerning the links between gender and fertilizer use. We do, however, have several projects with gender elements and some with rudimentary gender strategies. The purpose of this assignment is to take stock of the IFDC experiences concerning the integration of gender into its programs and the differential impacts of its programs on male and female farmers, especially regarding access to and use of fertilizers. The outcome of such an effort would offer best practices for IFDC and others for incorporating technologies that are "gender neutral," to those that are "gender aware," and eventually "gender transformative."

Progress: As part of this initiative, data from Bangladesh on documenting the experiences of the women farmer participants of the Accelerating Vegetable Productivity Improvement (AVPI)[3] project in Bangladesh from 2013 to 2019 were compiled and analyzed for this purpose to understand the change in use of fertilizer management practices by women farmers.

A draft report has been prepared, documenting the benefits of expanding the use of FDP technologies in vegetables by women farmers and assessing the knowledge gained by women in rural households on various fertilizer and crop management technologies and markets. The draft research paper is under peer review and will be submitted during FY2020.

2.3.8 Improving Fertilizer Use, Access, and Market Development: Case of the Coffee Sector and Other Food Security Crops in Honduras and Guatemala

The proposed activities for Honduras include an assessment of the fertilizer market in the context of the FTF Global Food Security Strategy-Honduras Country Plan (GFSS-HCP) zones of influence (ZOI). The focus is on smallholder and coffee producers, which comprise 90% of the coffee farming population and face production issues and food insecurity between coffee-harvesting seasons. A scope of work was developed for two activities during FY2019 for implementation; the activities include (a) assessment of the fertilizer/agro-input and -output markets in Honduras and

[2] Agronomic efficiency = grain yield/N applied and economic efficiency in terms of value cost ratios about N use for the same data points comparing UDP/FDP vs. non-UDP/FDP plots at farmer fields.
[3] This project was funded by the Walmart Foundation (Phase 1 and 2) and operated in the FTF districts of Bangladesh from 2012-13 to 2018-19.

(b) experimentation and scaling out of soil fertility management technologies with public-private partnership, viz., Honduras Outreach Inc. and DISAGRO (Guatemala).

***Progress*:** The activities could not be implemented as planned during FY2019, as funding and approval for Northern Triangle countries have been withheld until further notice from USAID.

2.3.9 Determining Factors Affecting Fertilizer Supply and Demand Among Supply Chain Stakeholders and Farmers in West Africa

Previous IFDC research and assessment findings have resulted in the hypothesis that fertilizer use among smallholder farmers in SSA has been negligible to nonexistent. This raises the question: Why are smallholder farmers not using or not increasing their use of fertilizer despite it being subsidized in many cases? Private sector players at importation seem willing to bring all the fertilizer needed into a country; however, farmers are not always willing to adopt and use fertilizer in food crops or even in cash crops. In an attempt to respond to the above, and considering that most studies are focused on the supply side of the market while neglecting the demand side, this proposed activity will implement research to determine what factors, other than cost or price of fertilizer at retail, are constraining the demand (use and/or consumption) of fertilizer by smallholder farmers who comprise the majority of the farming population in SSA and are typically the main targeted recipients of the fertilizer subsidy programs.

Since the work proposed here would complement the ongoing USAID-funded EnGRAIS project in West Africa, further consultations are in progress with IFDC's regional economist and colleagues implementing the EnGRAIS project to select a suitable FTF country in the region for conducting this research effectively. Results from this BFS-SFT economic study will further help the ongoing FTF project in formulating effective strategies toward increasing the availability and use of fertilizers that are appropriate and affordable for smallholder farmers in the proposed country and in the region.

Progress: A suitable FTF country (Niger or Senegal) for conducting the study will be selected near the end of FY2019 and will be included in the next workplan.

3. Workstream 3 – Sustainable Opportunities to Improve Livelihoods with Soils (SOILS) Consortium

In May 2019, IFDC, in collaboration with the Feed the Future Innovation Lab for Collaborative Research on Sustainable Intensification (SIIL) at Kansas State University, initiated the Sustainable Opportunities for Increasing Livelihoods with Soils (SOILS) Consortium. The primary goal of the SOILS Consortium is to improve soil fertility in the most vulnerable regions of sub-Saharan Africa.

The consortium is bringing together national and international partners to develop and implement soil health and fertility-enhancing innovations. Academic and research partners include Michigan State University, University of Colorado, Auburn University, and U.S. Department of Agriculture (USDA) Agricultural Research Service (ARS). Through innovative research, coordination, capacity building, networking, data sharing, and communication approaches, the SOILS Consortium will provide sustainable solutions to build resilient households with access to nutritious food.

3.1 Key Accomplishments

3.1.1 Organizational Structure Establishment and Planning:

Purpose: Develop the organizational structure and management plan for the SOILS Consortium.

Outputs:

- The SOILS Leadership Team was formed (i.e., Jerry Glover, John Peters, Upendra Singh, and Vara Prasad).
- Core Partners were selected (i.e., Auburn: Dr. Beth Guertal and Dr. Joey Shaw; Michigan State University: Dr. Sieg Snapp and Dr. Nicole Mason; University of Colorado – Boulder: Dr. Jeff Herrick; USDA-ARS: Dr. Jason Neff; University of Nebraska: Dr. Charlie Wortmann and Dr. Patricio Grassini).
- Advisory Members were selected (i.e., Africa Research in Sustainable Intensification for the Next Generation [Africa RISING]: Bernard Vanlauwe and Fred Kizito).
- Program Manager was identified and confirmed by the Leadership Team (i.e., Zach Stewart).
- The Management Plan and Organizational Structure were drafted and confirmed by the SOILS Leadership Team. The document outlines the roles and responsibilities of each member and institution.
- The Terms of Reference has been developed and confirmed by the Leadership Team for a Post-Doctoral Fellow to support the research needs of the Consortium. The search process has begun, but the position has not been filled.
- A SOILS promotional flyer has been developed.

3.1.2 Core-Partner Meeting: American Society of Agronomy (ASA) and Crop Science Society of America (CSSA) Annual Meeting: Baltimore, Maryland, November 5, 2018

Purpose: To bring the Core Partners together to share the structure and vision of the SOILS Consortium, identify and share Core Partner strengths, and share findings from the foundational Sub-Saharan Africa (SSA) Soil Fertility Prioritization Studies.

Outputs: Core Partners gathered at the ASA/CSSA meeting and shared their strengths relevant to the SOILS Consortium. Following the meeting, Core Partners summarized their activities in bios, which were compiled and shared with all Core Partners to familiarize the team with one another's work. Core Partner strengths were compiled to guide the co-development of the Core Partner Concept Notes. The Core Partners provided input to the goals and structure of the SOILS Consortium, and the Management Plan was revised accordingly. The SSA Soil Fertility Prioritization Survey and Summit Results were presented to highlight the need for the SOILS Consortium as driven by a consensus-based facilitated process.

3.1.3 Soft-Launch and Core Partner Strategic Planning Meeting: Soil Science Society of America (SSSA) Annual Meeting: San Diego, California, January 9, 2019

Purpose: To develop a strategic plan, draft activities for the SOILS Consortium to achieve in the near-term and long-tern, publicly share the foundational studies leading to the SOILS Consortium, and share the goals of the SOILS Consortium with the soil science research community.

Outputs: Through a facilitated process using the strengths, weaknesses, opportunities, and threats (SWOT) approach, the Core Partners developed a strategic plan for the SOILS Consortium's near-term and long-term activities. This has been a guiding document leading to the planned activities for the current year. IFDC and SIIL shared the goals of the SOILS Consortium and the SSA Soil Fertility Prioritization Survey and Summit results with the soil science research community to highlight the need for the SOILS Consortium; the soil science community gave their feedback. Approximately 45 SSSA members attended.

Obstacles: Due to a federal government "shutdown" during the planned event, USAID and federal employees were not allowed to participate in the public ceremony nor the facilitated planning meeting. The outputs of the facilitated planning meeting were documented and shared with members that were not able to attend to gain their input. A subsequent launch was conducted in Washington, D.C., with USAID.

3.1.4 USAID Formal Launch in Washington, D.C., March 15, 2019

Purpose: To formally launch the SOILS Consortium, showing USAID and IFDC's leadership, and to solidify activities for the first year of the consortium.

Figure 28. Robert Bertram (standing) addresses the SOILS team during the SOILS Consortium launch.

Outputs: The formal launch was held at USAID headquarters, with Rob Bertram and Albin Hubscher formally announcing the launch of the SOILS Consortium. A public press release was developed and published following the event. The USAID meeting garnered the support of USAID and IFDC leadership. A SOILS team meeting was held after the launch to plan specific activities for the coming year, building from the previous soil studies, strengths of the Core Partners identified at the ASA meeting, and the strategic plan developed during the SSSA meeting. The SOILS team identified three core activities for near-term activities: (a) release a call for concept notes (CNs) to bring together the research activities of the Core Partners for Year 1 activities; (b) organize a summit in Niger to partner with the Millennium Challenge Corporation (MCC) and The World Bank on a Presidential Level Initiative to Improve Soil Fertility; and (c) organize an Ethiopian Summit to bring together leading soil fertility institutions and people to reinforce the Ethiopian government's effort on scaling soil fertility recommendations.

3.1.5 Core Partner Concept Note Release

Purpose: To aid in co-designing Core Partner activities that bring together the strengths of the Core Partners to scale regionally applicable soil fertility recommendations.

Outputs: The CN has been developed and shared with the Core Partners for a competitive and co-developed initiative that has clear outcomes and is achievable in under one year. The CN was released to the Core Partners on March 19, 2019, and the CNs were received for review and co-development on April 15. Following submission, the SOILS Leadership Team and Core Partners co-designed Year 1 activities, integrating the CNs and the outcomes of the Niger Summit. Due to the recent momentum and country-led support in Niger, the CN will be Niger-focused with regional applicability. This work will be foundational for future long-term soil fertility improving activities of the SOILS Consortium. Core Partner Concept Notes were approved, and budgets were released for MSU, University of Colorado (CU), and Land-Potential Knowledge System (LandPKS) Initial Activities.

3.1.6 Full Proposal Development for Niger and Ethiopia

Purpose: Leveraging the work that is underway with the initial activities, full proposals for Niger and Ethiopia have been drafted. These proposals are designed to work towards accomplishing the recommendations from the country-specific Summits. These full proposals aim to be unified across partners, aligned with country priorities, and coordinated for a common goal of improving soil fertility. The full proposals also aim to be a platform for multiple donors to come together on a unified soil fertility enhancing goal. The full Niger proposal has been drafted and received by the leadership team and key partners for reviews and input. It is now ready to be reviewed by partnering donors, including MCC, World Bank, and the USAID Mission in Niger. This meeting has been set for November 18-22 in Niamey. The full Ethiopia proposal has also been drafted, led by ICRISAT and IFDC, and has received reviews and input from the leadership team. The SOILS team identified areas of this full proposal that can be delivered with initial SOILS funds through a short-term investment, which will help show the value to other donors. The next steps have been planned for wider review and input from the Ethiopia partners and review by partnering donors. This meeting has not been set but is targeted for January 2020.

3.2 Near-Term Events and Progress

3.2.1 Niger Soil Fertility Summit (May 2-3, 2019)

Purpose: There is a Presidential-level initiative calling for improved soil fertility in Niger. MCC, The World Bank, and USAID are keen to develop and support activities that lead to improved soil fertility in Niger. However, lead institutions are not coordinated, integrated, or aligned. The SOILS Consortium has brought together leading soil health activities across major production zones in SSA, and through synergies with these key partners, has co-developed unified regional strategies to improve soil health and fertility. Through a facilitated process with these soil fertility leaders, we have: (a) identified what needs to be done (i.e., agronomically and regulatory), (b) mapped ongoing activities, (c) identified partners, and (d) developed an agenda as a way forward.

Outputs: The summit occurred at the Grand Hotel in Niamey and brought together lead soil fertility institutions and participants working in Niger and the region. MCC, The World Bank, and SOILS Consortium co-branded the summit

Figure 29. Participants of the Niger Soil Fertility Summit

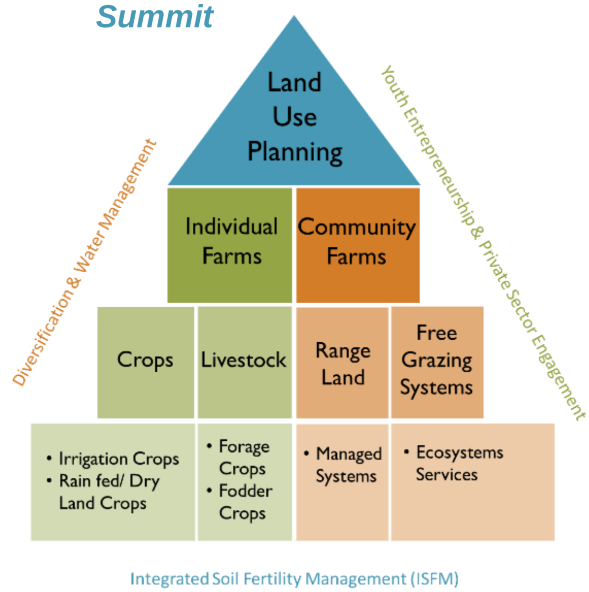


Figure 30. SOILS Consortium Collaborative Research and Policy Activities Framework for Niger

as a joint initiative. Ministerial-level government officials opened the event and their support has been maintained with constant communication following the event. A post-summit report highlighting the recommendations was written and shared with all participants (see supplemental documents). A one-page flier (French and English) was also developed for Niger government officials (See supplemental documents).

3.2.2 Ethiopia Joint Soil Fertility Summit (May 23-24, 2019)

Purpose: There are numerous soil fertility investments, limited in scale and time, occurring in Ethiopia. Each soil fertility initiative uses different methods, does not share data, and has no coordination for sharing and scaling their results. Current recommendations are only appropriate for a specific region, and recommendations are often differing. A national, site-specific fertilizer recommendation must be created to consolidate multiple studies across regions/topography and crops. The Ethiopian Government is committed to investing in scaling fertilizer recommendations, but there is little coordination and alignment among soil fertility activities, especially among donors. The SOILS Consortium is working to bring lead Ethiopian soil fertility institutions together to develop a framework for developing and scaling suitable soil fertility recommendations as aligned with the Ethiopian Government's vision.

Outputs: The summit occurred on the International Livestock Research Institute (ILRI) campus and brought together leading soil fertility institutions and participants working in Ethiopia. A professional facilitator led the summit to help organize recommendations. In preparation for this event, planning meetings with the ICRISAT/Ethiopian Institute of Agricultural Research (EIAR) team and the IFDC team were conducted to develop an agenda for the summit. These are two leading institutions where conflicting fertilizer recommendations have emerged. Previous national fertilizer frameworks were also incorporated to provide guidance for the summit and to ensure continuity and responsiveness to previous frameworks. The agenda was co-developed following these calls and built from previous soil fertility frameworks. The Ethiopian Minister of Agriculture delivered the opening remarks and highlighted the alignment with their initiatives. A post summit report highlighting the recommendations was written and shared with all participants (see supplemental documents).

Figure 31. Participants of the Joint Soil Fertility Summit in Ethiopia

Annex 1. Workstream Summary Tables (FY 2019)

Activity		Country	Description	Partnership	Outputs
1.1	**Technologies Developed, Refined, and Adapted for Improving Nitrogen Use Efficiency**				
1.1.1	Development and Evaluation of Enhanced Efficiency N Fertilizers	USA	1.1.1.1 Developing Enhanced Efficiency N Fertilizers A. Developing Hydrophobic and Controlled-Release Fertilizer B. Improving N Use Efficiency and Delivery of Secondary and Micronutrients	University of Florida (UF); Private Industry	A. A study was produced and is listed in Annex 3.
		Bangladesh; Myanmar;	1.1.1.2 Field Evaluation of Modified Urea-S Products A. Urea-Sulfur Evaluation in Bangladesh, Myanmar, and Nepal	CIMMYT NSAF Project;	In Progress; abstract on Nitrogen management paper accepted for international conference presentation
		Mali; Burkina Faso	1.1.1.3 Adapting Balanced FDP (NP and NPK Briquettes) to Intensive Rice Cropping Systems (SRI) in West Africa (Mali and Burkina Faso)	IER; INERA	Trials to complete next season – in progress
1.1.2	Scaling Fertilizer Deep Placement Technology	USA; Myanmar; Kenya	1.1.2.1 Mechanized Applicators A. Combined Mechanical UDP Applicator and Rice Transplanter B. Direct-Seeded Mechanized Applicator C. Modification to Manual Plunge-Type Applicator	Mississippi State University; National Agro Industries; FSI+, Myanmar	In progress
		Kenya/Uganda	1.1.2.2 High-Capacity Briquette Machine	Private sector	Prototype being built and will be available for testing by mid 2020

Activity		Country	Description	Partnership	Outputs
1.1.3	Climate Resilience and Mitigating GHG Emissions	Bangladesh; Myanmar; Nepal; Ghana	1.1.3.1 Resilience Trials in Stress Prone Environments	BRRI, BAU	Four journal articles published; one manuscript under peer-review-Annex 3.
		USA	1.1.3.2 Quantification of GHG Emissions of Various N Sources under Greenhouse Conditions		Three manuscripts submitted for journal publication. One journal article published-Annex 3.
1.2	**Activated Phosphate Rock**				
1.2.1	Complete and Analyze Ongoing Field Trials	Ghana	1.2.1.1 Activated Phosphate Rock Trials in Ghana		Year 2 results to be reported; stakeholder workshop; Publication.
		Kenya	1.2.1.2 Activated PR Trials in Kenya		In progress
1.2.2	Activated PR Demonstrations	Ghana	On-farm demonstrations to show the agronomic effectiveness of activated PR to farmers, agro-input dealers, agricultural extension officers, and key stakeholders		In progress

	Activity	Country	Description	Partnership	Outputs
1.3	**Balanced Crop Nutrition (Cross-Cutting with Workstream 2.3)**				
1.3.1	Efficient Incorporation of Micronutrients into NPK Fertilizers and Evaluation of Multi-Nutrient Fertilizers	USA	1.3.1.1 Laboratory, Greenhouse, and Field Evaluations of Various Rates, Sources, and Methods of Zn Delivery A. Greenhouse Trial Evaluating the Effects of Zn on Sorghum Yield and Nutrient Use Under Drought Conditions B. Low ZnO Nanoparticles Exposure Promotes Wheat Development and Grain Yield Under Drought Stress C. Nano-Zinc Coated Urea Fertilizer for Efficient Delivery of Zinc Micronutrients	CAES; UTEP; USDA NIFA; UCF	A. One study was published Annex 3.
		Ghana; Kenya	1.3.1.2 Quantifying the Efficiency of S, C, and B on Crop Yield and Nutrient Uptake A. Residual Sulfur Trials B. Omission Trials in Kenya	Shell	In Progress
1.3.2	Facilitate Site- and Crop-Specific Fertilizer Recommendations for Increased Economic and Environmental Benefits from Fertilizer Use	Ghana	1.3.2.1 Best-Bet Trials in the Savanna Areas of Ghana	ATT project, Soybean Innovation Lab, MOFA, and UDS	Completed and analysis in progress
		Ghana	1.3.2.2 Nutrient Omission Trials in Ghana (Year 2)		Stakeholder Workshop; “Best-bet” Trials; Publication
		USA	1.3.2.3 Expanding Spectral Analytical Techniques to Fertilizer Analysis	Private partners	Report
		Ghana	1.3.2.4 International Training Program on Bringing Balance Crop Nutrition to Smallholder Farmers in Africa	IFDC-Training division; private sector	The training was held May 27-31, 2019 in Accra, Ghana
1.4	**Sustainable Intensification Practices: Integrated Soil Fertility Management**				
1.4.1	Nutrient Recycling	Global	Evaluation of a rapid test to evaluate nitrogen mineralization in tropical and subtropical soils	Auburn University, Tuskegee University	In progress

Activity		Country	Description	Partnership	Outputs
1.4.2	Quantifying the Impacts of Rice-Legume Cover Crop-Based Cropping Systems Under CA with FDP in Cambodia	Cambodia; KSU		RUA:CE SAIN, GDA, DALRM, CASC, CIRAD, KSU SIIL	In progress
1.4.3	Evaluation of the Synergistic Effect of CA Practices in Combination with an Activated PR Amendment as a Component of ISFM in Northern Ghana	Ghana	Trials in northern Ghana to evaluate the synergistic effects of CA and ISFM practices along with activated PR as a P fertilizer source.	Africa RISING	In Progress
1.5	**Improving the DSSAT Cropping System Model for Soil Sustainability Processes – Cross-Cutting with Workstream 2**				
1.5.1	Improving the DSSAT Cropping System Model for Soil Sustainability Processes	United States	IFDC will be implementing the AgMIP database and improving DSSAT Cropping System Model to help in making timely and reliable recommendations on fertilizers, sowing dates, and other management inputs	University of Florida	In progress
1.5.2	Modify and Refine AgMIP Database	USA	Modify and refine the AgMIP database for IFDC's biophysical and socio-economic data	AgMIP; University of Florida	In progress

Activity		Country	Description	Partnership	Outputs
2.1	**Documenting Policy Reforms and Market Development**				
2.1.1	Support for Kenya Fertilizer Roundtable (KeFERT)	Kenya	KeFERT resulted in the formation of the Kenya Fertilizer Platform, a public-private mechanism composed of key stakeholders involved in fertilizer access, quality, and use.	Kenya's MoALF&I, private sector	Stakeholder consultations; meetings
2.1.2	Capacity-Building Activities: Policy Reforms	Global	A presentation was given on the importance and impact of agricultural input policies during the USAID BFS-sponsored agriculture core course for staff from inter- and intra-agencies involved in U.S. Government. A poster was also created.	BFS/Rutgers Consortium	Poster on Seed Policy Reforms in Zambia
2.1.3	Documenting Global and SSA Fertilizer Market Trends and Outlook	Global/SSA	Data from meetings with the IFEW group is being revised for publication in the IFEW joint World Fertilizer Trends and Outlook report.	IFA/FAO, World Bank	No progress during the workplan period
2.1.4	Partnership for Enabling Market Environments for Fertilizer in Africa	SSA	Efforts are being made to continue to support the PEMEFA. The AAP grant has been closed, and the PEMEFA is searching for new funding to continue collaboration between the partner institutions.	MSU-led Alliance for African Partnerships (AAP) consortium (MSU-IFDC-New Market Lab-AFAP)	1 policy brief 1 journal article Final report
2.1.5	Policy Briefs on Fertilizer Policies and Market Development	SSA/Asia/ Latin America and the Caribbean	The overall purpose of these briefs is to contribute to influencing policy reforms through active engagement with stakeholders, such as research institutions, private and public sectors, and in-country missions, through wider dissemination forums.		1 Policy Brief on Bangladesh – Role of private sector in fertilizer market development
2.2	**Impact Assessment Studies**				
2.2.1	Kenya Fertilizer Subsidy Program	Kenya	The Government of Kenya requested that IFDC and other policy think-tanks in Kenya assess the government's existing subsidy program to help them better target farmers for improved crop and soil productivity through E-Vouchers (technical assistance on streamlining Kenyan input subsidy program)	Ministry of Agriculture, KALRO, Tegemeo, CSO	1 technical report Several consultations with Ministry of Agriculture, Kenya

Activity		Country	Description	Partnership	Outputs
2.2.2	Effectiveness of Agro-Dealer Development Programs Toward Sustainable Input Supply and Technology Transfer in SSA	Rwanda	Field-level impact assessments of RADD will continue, and a report will be produced.	AGRIFOP/AGRA	Surveys and analysis in progress
2.3	**Economic and Market Studies**				
2.3.1	Fertilizer Quality Assessments: Support Policy Efforts to Harmonize Fertilizer Regulations (with Workstream 1)	Zambia, Kenya, Uganda	Fertilizer quality analyses will be produced to help draw economic and policy-level implications for the agriculture sectors in these countries.	EnGRAIS, West Africa Fertilizer Program	2 reports prepared
2.3.2	Fertilizer Cost Buildup Studies and Marketing Margin Analysis	Ghana, Mali, Kenya, Tanzania	Reports will be produced to encourage improvements within the fertilizer/agriculture market.		1 consolidated report
2.3.3	The African Fertilizer Access Index	Kenya	Efforts are being put forth to establish the Africa Fertilizer Access Index (TAFAI-Ke), and a draft report on said progress is underway.	AfricaFertilizer.org-IFDC	1 report in progress
2.3.4	Economic and Environmental Implications of Fertilizer Technologies Using Life Cycle Analysis Approach	Bangladesh	A graduate student from Rutgers University is conducting research to analyze GHG emissions to help farmers and policymakers gain carbon credits.	Rutgers University	1 dissertation completed

Activity	Country	Description	Partnership	Outputs
2.3.5 Economic Estimation of Fertilization Methods for Rice Paddy in Bangladesh – A Production Function Analysis	Bangladesh	A summary of a Rutgers University graduate student's research to assess the agricultural productivity and climate smart solutions for using the UDP method in southwestern Bangladesh.	IFDC-Dhaka field office, Rutgers University	1 dissertation completed
2.3.6 Enhancing M&E Capacities of Soil Fertility Research Systems in IFDC	Global	An IFDC M&E specialist from Togo is working with the University of Georgia to obtain his Ph.D. and ultimately help build on IFDC's monitoring, evaluation, learning, and sharing (MELS) systems.	University of Georgia	In progress
2.3.7 Women's Access to and Use of Fertilizers in Field Crops and Vegetables	Global/ Bangladesh	Efforts are being made to offer best practices for IFDC and others that incorporate technologies that are "gender neutral", to those that are "gender aware", and eventually "gender transformative."	IFDC – Bangladesh office IFDC – HQ (MELS)	Report in progress
2.3.8 Improving Fertilizer Use, Access, and Market Development: Case of the Coffee Sector and Other Food Security Crops in Honduras and Guatemala	Honduras, Guatemala	Collaborations are being established to aid the agricultural sectors in Honduras and Guatemala.	Honduras Outreach Inc., DISAGRO	On Hold
2.3.9 Determining Factors Affecting Fertilizer Supply and Demand Among Supply Chain Stakeholders and Farmers in West Africa	West Africa	Efforts are being made to determine why fertilizer is not being used by smallholder farmers in West Africa, despite its availability on the market.	EnGRAIS	Postponed to FY 20

Activity	Country	Description	Partnership	Outputs
3 Sustainable Opportunities to Improve Livelihoods with SOILS Consortium				
3.1 Key Accomplishments				
	Global	3.1.1 Organizational Structure Establishment and Planning	IFDC; KSU; Core Partners (i.e., Auburn; Michigan State University; University of Colorado-Boulder; USDA-ARS; University of Nebraska); Africa RISING	The Soils Leadership Team was established; Core Partners selected; Advisory Members selected; Program Manager identified; Terms of Reference or Post-Doctoral Fellow Developed; SOILS promotional flier developed
	USA	3.1.2 Core Partner Meeting: American Society of Agronomy (ASA) and Crop Science Society of America (CSSA) Annual Meeting	Core Partners	Core Partner Concept Notes; Management Plan revised' SSA Soil Fertility Prioritization and Summit Results presented
	USA	3.1.3 Soft-Launch and Core Partner Strategic Planning Meeting: Soil Science Society of America (SSSA) Annual Meeting	IFDC; USAID; SIIL; Core Partners	Strategic Plan developed
	USA	3.1.4 USAID Formal Launch	USAID; KSU; IFDC; Core Partners	Formal launch of the SOILS Consortium; Team meeting held
		3.1.5 Core Partner Concept Note Release	Core Partners	CN were released; Year one activities were established
		3.1.6 Full Proposal Development for Niger and Ethiopia	MCC; World Bank; USAID Mission Niger; ICRISAT; IFDC	Proposals have been drafted and will be approved to accomplish recommendations from the country specific summits

Activity	Country	Description	Partnership	Outputs
3.2 Near-Term Events and Progress				
	Niger	3.2.1 Niger Soil Fertility Summit	Core Partners; MCC; World Bank	Post summit report; one-page flier for Niger government officials
	Ethiopia	3.2.2 Ethiopia Joint Soil Fertility Summit	ICRISAT/EIAR; Core Partners	Post summit report

Annex 2. List of Publications and Presentations for FY2019

Journal Publications during the FY 2019 (Peer-reviewed)

1. Adisa, I.O., Pullagurala, V.L.R., Peralta-Videa, J.R., Dimkpa, C.O., Elmer, W.H., Gardea-Torresdey, J.L., White, J.C. 2019. Recent Advances in Nano-Enabled Fertilizers and Pesticides: A Critical Review of Mechanisms of Action. *Environ. Sci.: Nano* 6:2002-2030.

2. Adu-Gyamfi, R., Agyin-Birikorang, S., Tindjina, I., Ahmed, S.M., Twumasi, A.D., Avornyo, V.K., Singh, U. 2019. One-Time Fertilizer Briquettes Application for Maize Production in Savanna Agroecologies of Ghana. *Agron. J.* 111:1-12. doi:10.2134/agronj2019.04.0292

3. Adu-Gyamfi, R., Agyin-Birikorang, S., Tindjina, I., Manu, Y., Singh, U. 2019. Minimizing Nutrient Leaching from Maize Production Systems in Northern Ghana with One-Time Application of Multi-Nutrient Fertilizer Briquettes. *Sci. Total Environ*. doi: https://doi.org/10.1016/j.scitotenv.2019.133667

4. Agyin-Birikorang, S., Tindjina, I., Adu-Gyamfi, R., Dauda, H.W., Fuseini, A.A., Singh, U. 2019. Agronomic Effectiveness of the Urea Deep Placement Technology for Upland Maize Production in Northern Ghana. *Nutr. Cycl. Agroecosyst*. (accepted)

5. Agyin-Birikorang, S., Winings, J.H., Yin, X., Singh, U., Sanabria, J. 2018. Field Evaluation of Agronomic Effectiveness of Multi-Nutrient Fertilizer Briquettes for Upland Crop Production. *Nutr. Cycl. Agroecosyst*. 110:395-406.

6. Agyin-Birikorang, S., Tindjina, I., Fuseini, A.R., Dauda, H., Issahaku, R., Singh, U. 2019. Application Timing of Urea Supergranules for Climate-Resilient Maize Cultivars Grown in Northern Ghana. *J. Plant. Nutr.*

7. Bindraban, P.S., Dimkpa, C., Angle, S., Rabbinge, R. 2018. Unlocking the Multiple Public Good Services from Balanced Fertilizers. *Food Secur*. 10:273-285. doi: https://doi.org/10.1007/s12571-018-0769-4

8. Bindraban, P., Mose, L., Hillen, M., Ruiperez Gonzalez, M., Voogt, M., Leenaars, J., Langeveld, K., Heerink N. 2018. Smart Fertilization and Water Management – Kenya-Netherlands Aid-and-Trade Opportunities. IFDC Report 2018/1. International Fertilizer Research Center, Muscle Shoals, Alabama, USA 102 pp.; 10 tables; 27 figs.; 115 ref.

9. Comer, B.A., Fuentes, P., Dimkpa, C.O., Liu, Y-H., Fernandez, C., Arora, P., Realff, M., Singh, U, Hatzell, M.C., Medford, A.J. 2019. Prospects and Challenges for Solar Fertilizers. *Joule* 3:1578-1605.

10. Conijn, J.G., Bindraban, P.S., Schröder, J.J., Jongschaap, R. 2018. Can Our Food System Meet Food Demand Within Planetary Boundaries? *Agric. Ecosyst. Environ*. 251:244-256. doi: https://doi.org/10.1016/j.agee.2017.06.001

11. Dimkpa, C., Bindraban, P. 2018. Nanofertilizers: New Products for the Industry*? J. Agric. Food Chem.* 66 (26): 6462-6473.

12. Dimkpa, C.O., Singh, U., Bindraban, P.S., Elmer, W.H., Gardea-Torresdey, J.L., White, J.C. 2019. Zinc Oxide Nanoparticles Alleviate Drought-Induced Alterations in Sorghum Performance, Nutrient Acquisition, and Grain Fortification. *Sci. Total Environ*. 688:926-934.

13. Dimkpa, C.O., Singh, U., Bindraban, P.S., Adisa, I.O., Elmer, W.H., Gardea-Torresdey, J.L., White, J.C. 2019. Addition-Omission of Zinc, Copper, and Boron Nano and Bulk Particles Demonstrate Element and Size-Specific Response of Soybean to Micronutrients Exposure. *Sci. Total Environ*. 665:606-616.

14. Fugice, J., Dimkpa, C., Johnson, L. 2018. Slow and Steady: The Effects of Different Coatings on Nitrogen Release in Soil. *Fertil. Focus*, 12-13.

15. Gaihre, Y.K., Bible, W.D., Singh, U., Sanabria, J. 2019. Quantifying Nitric Oxide Emissions under Rice-Wheat Cropping Systems. *Environ. Poll*., 250:856-862.

16. Nagarajan, L., Naseem, A., Pray, C. 2019. Contribution of Policy Change on Maize Varietal Development and Yields in Kenya. *Journal of Agribusiness in Developing and Emerging Economies*, 9(1):4-21.

17. Pray, C., Nagarajan, L., Naseem, A. 2018. The Role of Multinational Corporations in the Supply of Agricultural Production Technology to China & India. *World Food Policy* 4(2):19-30.

18. Sanabria, J., Wendt, J. 2019. Statistical Analysis of Non-Replicated Experiments in Farmer's Fields: A Case of Balanced Fertilization Trials for Bean in Burundi. *Agron. J*. 111(3).

19. Sharma, S., Borah, P., Meena, M.K., Bindraban, P., Pandey, R. 2018. Evaluation of Genotypic Variation for Growth of Rice Seedlings under Optimized Hydroponics Medium. *Indian J. Genet. and Plant Breed*. 78(3):292-301.

20. Stewart, Z.P., Pierzynski, G.M., Middendorf, B. J., Prasad, P.V. 2019. Approaches to Improve Soil Fertility in Sub-Saharan Africa. *J. Exp. Bot.*

21. Wassman, R., Sander, B.O., Yadav, S., Bouman, B., Singleton, G., Stuart, A., Hellin, J., Johnson, D., Hughes, J., Butterbach-Bahl, K., Kiese, R., Kraus, D., Janz, B., Linquist, B., Gaihre, Y.K., Chirinda, N., Wollenberg, E. 2019. New Records of Very High Nitrous Oxide Fluxes from Rice Cannot Be Generalized for Water Management and Climate Impacts. Quantifying Nitric Oxide Emissions under Rice-Wheat Cropping Systems. *Environ. Pollut*. 250:856-862.

22. Wendt, J. 2019. Utilization of Micronutrients in Africa. *Fertilizer Focus*.

Presentations

1. Agyin-Birikorang, S. Overview of Technological Advances in U.S. Agriculture. Presentation at the ‘‘USA Training and Study Tour on Technology Advances in Agricultural Production, Water and Nutrient Management’’ organized by the International Fertilizer Development Center (IFDC), Muscle Shoals, Alabama, August 2019.

2. Agyin-Birikorang, S., Nuhu, S.A., Fuseini, A.R.A., Dauda, H.W., Fugice Jr., J., Bible, W., Sylvester, C., Singh, U. Does Blanket Fertilizer Recommendations Still Work? A Case Study of Maize Production in Northern Ghana. Presented at the Annual International Meeting of the Soil Science Society of America. San Diego, CA, January 2019.

3. Bindraban, P. Phosphorus in Plant and Human Nutrition. Plenary Keynote at International Conference for Research on Phosphates and Derivatives. Mohammed VI Polytechnic University, OCP Group, Ben Guerir, Morocco, November 12–13, 2018.

4. Bindraban, P. Micronutrients for Sustainable Food Production. Keynote Argus Europe Fertilizer, Athens, Greece. October 24–26, 2018.

5. Dimkpa, C.O. Conditions for Enhancing Scale-Up and Commercialization of Bio-nanofertilizers. 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, New Delhi, India. September 2019.

6. Dimkpa, C.O. Application of Nanotechnology in the Fertilizer Industry. Presentation at the USA Training and Study Tour on Technology Advances, organized by the International Fertilizer Development Center (IFDC), Muscle Shoals, Alabama, August 2019.

7. Dimkpa, C.O. Role of Micronutrients in Crop Production in a Changing Climate. Presented at the Annual Meeting of the Agronomy Society of America. Baltimore, November 2018.

8. Dimkpa, C.O. Micronutrient Fertilizers as a One-Stop Shop for Improving Crop Production: From Conventional to Nanoscale. Presented at the Materials Innovation for Sustainable Agriculture Symposium, University of Central Florida, Orlando. October 2018.

9. Gaihre, Y. 2019. Nepal’s Experience with Balanced Application of Plant Nutrients and Policy Challenges. Presented at the Regional Dialogue, Innovations for Advancing Farmer’s Use of Balanced Nutrient Application in South Asia, Kathmandu, September 9, 2019.

10. Gaihre, Y.K., Singh, U., Aung, M., Baral, B.R., Hasnain, M. 2018. Climate Smart Fertilizer Management in Rice Cultivation under Stress Prone Areas for Food Security and Mitigating Greenhouse Gas Emissions. Paper presented at 5th International Rice Congress, October 15-17, 2018, Singapore.

11. Gao, Y., Wallach, D., Liu, B., Dingkuhn, M., Boote, K.J., Singh, U., Asseng, S. Kahveci, T., He, J. Zhang, R., Confalonieri, R, Hoogenboom, G. 2019. Comparison of Three Calibration Methods for Modeling Rice Phenology. Agricultural and Forest Meteorology.

12. Sanabria, J., Alognikou, E., Glass, K., Silvester, C., Bible, W. 2018. Fertilizer Quality Problems in Markets of Developing Countries: An Obstacle for Economic Growth and Food Security. Presented at the 2018 ASA Annual Meeting, Baltimore, November 2018.

13. Senthilkumar, K., Sillo, F.S., Dieng, I., Rodenburg, J., Saito, K., Vandamme, E., Dimkpa, C., Wendt, J., Bindraban, P.S. 2018. Effects of Micronutrient on Productivity and Profitability of Rice under Three Growing Environments in Tanzania. International Rice Congress 2018, October 2018. Singapore. Submitted.

14. Sharma, S., Meena, M.K., Bindraban, P., Pandey, R. 2018. Foliar Application of Bacteriosiderophore Improves Yield and Bioavailability of Iron in Soybean and Wheat. Abstract (IPC_2018_ABS_Q6139) submitted to the 4th International Plant Physiology Congress, Lucknow, India. December 2-5, 2018.

15. Singh, U., Fugice J. 2018. Recent Application of CERES-Rice Model in the Field of Climate Change. Paper presented at 5th International Rice Congress, Singapore. October 15-17, 2018.

16. Singh, U., Porter, C, Gaihre, Y, Fugice, J. 2018. Do Existing Crop Models Simulate Soil Processes Adequately for Soil Health and Climate Change Mitigation Applications? Paper presented at 5th International Rice Congress, Singapore. October 15-17, 2018

17. Singh, U, Ahsan, M., Glass, K., Fugice, J., Gaihre, Y. 2018. Quantify Climate Mitigation Role of Enhanced Efficiency Fertilizers and Practices. Presented at the American Society of Agronomy Annual Meeting, ASA in Baltimore, MD, November 2018.

18. Singh, U. 2018. Strategic Production and Use of Phosphorus for a Greener Planet. Presented at Phosphate Days Conference, Ben Guerir, Morocco, November 12-14, 2018

19. Singh, U. 2019. SOILS Consortium: IFDC's Vision. Presented at the Launch of Soils Consortium, Soil Science Society of America Annual Meeting, San Diego, CA, 9 January 2019.

20. Singh, U, Fugice, J., Agyin-Birikorang, S. 2019. Complete Fertilizers for Soil and Crop Systems. Presented at the Latin America Fertilizer Conference, Mexico City, Mexico. January 28-30, 2019.

21. Singh, U. 2019. Overview of Slow-, Controlled-Release and Stabilized Fertilizers. Presented at the at the 2019 IFDC/IFA International Training on the Production of Slow-, Controlled-Released, and Stabilized Fertilizers organized by the International Fertilizer Development Center (IFDC), In Partnership with International Fertilizer Association (IFA), Frankfurt, Germany. June 24-26, 2019.

22. Singh, U. 2019. Urea Deep Placement: Climate Smart Agriculture Technology. Presented at the at the 2019 IFDC/IFA International Training on the Production of Slow-, Controlled-Released, and Stabilized Fertilizers, organized by the International Fertilizer Development Center (IFDC), In Partnership with International Fertilizer Association (IFA) Frankfurt, Germany, June 24-26, 2019.

23. Singh, U. 2019. Climate Smart Agriculture and Effective Nutrient Management. Presented at the at the USA Training and Study Tour on Technology Advances in Agricultural Production, Water and Nutrient Management, organized by the International Fertilizer Development Center (IFDC), Muscle Shoals, Alabama, August 2019.

24. 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, New Delhi, India. September 2019.

Conferences

1. Phosphorus in Plant and Human Nutrition. Plenary Keynote at International Conference for Research on Phosphates and Derivatives. Mohammed VI Polytechnic University, OCP Group, Ben Guerir, Morocco, Nov. 12–13, 2018.

2. Micronutrients for Sustainable Food Production. Keynote Argus Europe Fertilizer, Athens, Greece. Oct. 24–26, 2018.

3. Soft-Launch and Core Partner Strategic Planning Meeting: Soil Science Society of America (SSSA) Annual Meeting: San Diego, CA. January 9, 2019.

4. USAID Formal Launch in Washington, D.C. March 15, 2019.

5. Niger Soil Fertility Summit: Niamey, Niger. May 2-3, 2019.

6. Ethiopia Joint Soil Fertility Summit. May 23-24, 2019.

Trainings

1. International Training and Study Tour on Technology Advances in Agricultural Production, Water and Nutrient Management Alabama, Arkansas, Illinois, Missouri, Tennessee, and Washington, DC. August 2019

2. Study Tour by Secretary of Agriculture and Department of Agric and Extension Ministry, Government of Nepal visit to IFDC-Head Quarters Facilities and Pilot Plant, Muscle Shoals, AL, USA, March 24-29, 2019.

Annex 3. List of Reports and Presentations Referenced in Annual Report

Agricultural Productivity and Climate-Smart Solutions in Southwestern Bangladesh - Master's Thesis (Selen Altiok)

Agronomic Effectiveness of the Urea Deep Placement Technology for Upland Maize Production

Agronomic Effectiveness of the Urea Deep Placement (UDP) Technology for Upland Maize Production in the Northern Regions of Ghana

Application Timing of Urea Supergranules for Climate Resilient Maize Cultivars Grown in Northern Ghana

Changes in Cost of Supplying Fertilizer in West Africa

Climate Smart Fertilizer Management in Rice Cultivation Under Stress Prone Areas - Presentation

Comparison of Three Calibration Methods for Modeling Rice Phenology

ECOWAS Fertilizer Regulatory Framework Implications for the Development of Private Sector Led Supply of Quality Fertilizers in West Africa

Exploring Farmers' Knowledge Gap on Fertilizer Management Practices in a Rice-Based Cropping System in Nepal

Fertilizer Quality Assessments in Benin, Burkina Faso and Liberia

Fertilizer Quality Assessment in Markets of Zambia

Fertilizer Quality Problems in Developing Countries: An Obstacle for Food Security and Economic Growth

Fertilizer Quality Problems in Developing Countries: An Obstacle for Food Security and Economic Growth-Presentation

IFDC Fertilizer Quality Assessments in Africa and Myanmar - IFA

Minimizing Nutrient Leaching from Maize Production Systems in Northern Ghana with One-Time Application of Multi-Nutrient Fertilizer Briquettes

Mitigating N2O and NO Emissions from Direct-Seeded Rice and Nitrification Inhibitor and Urea Deep Placement

Mitigating Nitrous Oxide Emissions from Rice-Wheat Cropping Systems with Nitrogen Fertilizer and Irrigation Management

Nepal's Experience with Balanced Application of Plant Nutrients and Policy Challenges-Presentation

New Records of Very High Nitrous Oxide Fluxes from Rice Cannot Be Generalized for Water Management and Climate Impacts

Nutrient Leaching from One-Time Application of Briquetted Multi-Nutrient Fertilizer

One-Time Application of Multi-Nutrient Fertilizer Briquettes for Maize (Zea mays L.) Production

One-Time Fertilizer Briquettes Application for Maize Production in Savanna Agroecologies of Ghana

Proposed KeNEIIP Management

Quantifying Nitric Oxide Emissions Under Rice-Wheat Cropping Systems

Resilient Rice Fertilization Strategy for Submergence-Prone Savanna Agro-ecological Zones in Northern Ghana

Role of the Private Sector in Fertilizer Market Development for Macro and Micronutrients in Bangladesh

Statistical Analysis of Non-Replicated Experiments in Farmers' Fields. A Case of Balanced Fertilization Trials for Bean in Burundi

Urea Deep Placement and Life Cycle Assessment in Bangladesh - Master's Thesis (MingZhe Yu)

Full Reports and SOILS Reports

Automated Mechanical UDP Applicator Combined with a Rice Transplanter - Full Report by Mississippi State University

Evaluation of a Rapid Test to Evaluate Nitrogen Mineralization in Tropical and Subtropical Soils-Full Report from Auburn University

Quantifying the Impacts of Rice-Legume Cover Crop-Based Cropping Systems Under CA with FDP in Cambodia-Full Report by KSU

SOILS Consortium Launch Seminar

Niger SOILS Summit Summary Report

Ethiopia SOILS Summit Report

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