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

April 1, 2017 – September 30, 2017

Cooperative Agreement
No. AID-BFS-IO-15-00001

October 2017

USAID FROM THE AMERICAN PEOPLE

IFDC

Table of Contents

List of Annexes

List of Tables

List of Figures

List of Acronyms

ABI	Agribusiness Indicators
AFAP	African Fertilizer and Agribusiness Partnership
AfDB	African Development Bank
AFU	Agricultural and Forestry University
AgMIP	Agricultural Model Intercomparison and Improvement Project
AGRF	African Green Revolution Forum
AGRA	Alliance for a Green Revolution in Africa
AGRI	Agribusiness Regulation and Institutions
AMITSA	Regional Agricultural Input Market Information and Transparency System
ARDB	Agronomic Research Database
ASDSIP	Agriculture Sector Development Strategy and Investment Plan
AU	African Union
AUC	African Union Commission
AUDPC	Area Under the Disease-Progress Curve
AWD	Alternate Wetting and Drying
B	Boron
BFS	Bureau for Food Security
BINA	Bangladesh Institute of Nuclear Agriculture
BMP	Best Management Practices
BPS	Bulk Procurement System
BRRI	Bangladesh Rice Research Institute
CA	Cooperative Agreement
CA	Cooperative Agreement
CAADP	Comprehensive Africa Agriculture Development Programme
CAN	Calcium Ammonium Nitrate
CF	Continuous Flooding
CIF	Cost, Insurance, and Freight
cm	centimeter
COMESA	Common Market for Eastern and Southern Africa
CSA	Climate-Smart Agriculture
CSM	Crop Simulation Models
Cu	Copper
DAP	Diammonium Phosphate
DFIS	Database for Fertilizer Information Services
DPP	Department of Policy and Planning
DREA	Department of Rural Economy and Agriculture
EAT	Enabling Agricultural Trade
EBA	Enabling Business in Agriculture
ECOWAS	Economic Community of West African States
EF_m	Emission Factors
FAO	Food and Agriculture Organization of the United Nations
FDP	Fertilizer Deep Placement
Fe	Iron
FMSP	Fertilizer Market Stabilization Program
FP	Farmer’s Practice

FQA	Fertilizer Quality Assessments
FSP	Fertilizer Subsidy Program
FTF	Feed the Future
FY	Fiscal Year
GA	Greater Accra
GDP	Gross Domestic Product
GHG	Green House Gas
GHS	Ghanaian cedi
GoG	Government of Ghana
GoT	Government of Tanzania
GoU	Government of Uganda
ha	hectare
IDF	import declaration form
IFA	International Fertilizer Association
IFDC	International Fertilizer Development Center
IFPRI	International Food Policy Research Institute
IPNI	International Plant Nutrition Institute
ISABU	*Institut des Sciences Agronomique du Burundi* (Burundi Institute of Agronomic Sciences)
ISFM	Integrated Soil Fertility Management
ISRIC	International Soils Resource Information Center
IT	Information Technology
K	Potassium
KBS	Kenya Bureau of Standards
KCl	Potassium Chloride
kg	kilogram
LC	Letter of Credit
LCA	Life Cycle Analysis
LIV	Local Improved Varieties
LRP	Locally Recommended Fertilizer
m	meter
M&E	Monitoring and Evaluation
MAFAP	Monitoring and Analyzing Food and Agriculture Policies
MAAIF	Ministry of Agriculture, Animal Industry and Fisheries
MALF	Ministry of Agriculture, Livestock and Fisheries
MD	Microdosing
ME&P	Markets, Economics and Policy
METASIP	Medium-Term Agriculture Sector Investment Plan
mg	milligrams
MINAG	Ministry of Agriculture
MISA	Management Information System for Agriculture
mm	millimeter
Mn	Manganese
MoF	Ministry of Finance
MoFA	Ministry of Food and Agriculture
MOP	Muriate of Potash
MOU	Memorandum of Understanding

mt	metric tons
N	Nitrogen
NAAIAP	National Accelerated Agricultural Inputs Access Program
NFP	National Fertilizer Policy
NIFA	National Institute of Food and Agriculture
NPK	Nitrogen, Phosphate, Potassium
NUE	Nitrogen Use Efficiency
OOC	Out of Compliance
P	Phosphorus
PEDSA	Strategic Plan for Agricultural Development
ppm	parts per million
PPS	Purchasing Power Support
PR	Phosphate Rock
PRDSS	Phosphate Rock Decision Support System
PU	Prilled Urea
PUDP	Prilled Urea Deep Placement
PVoC	Pre-Export Verification of Conformity
RAE	Relative Agronomic Effectiveness
RCBD	Randomized Complete Block Design
REC	Regional Economic Community
S	Sulfur
SFT	Soil Fertility Technology
SHS	Kenyan shilling
SMaRT	Soil Testing, Mapping, Recommendations Development, and Technology Transfer
SSA	Sub-Saharan Africa
SSTP	Scaling Seeds and Technologies Partnership in Africa
STV	Stress-Tolerant Varieties
TAFAI	The Africa Fertilizer Access Index
TAZARA	Tanzania-Zambia Railway Authority
TFRA	Tanzania Fertilizer Regulatory Authority
TL	Tolerance Limit
TN	Technical Networks
TSP	Triple Superphosphate
UB	Urea Briquette
UDP	Urea Deep Placement
USAID	U.S. Agency for International Development
USDA	U.S. Department of Agriculture
WAFP	West Africa Fertilizer Program
WAP	Weeks After Planting
Zn	Zinc

Progress Toward Cooperative Agreement Award Objectives

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

Under the awarded agreement and in collaboration with USAID, IFDC conducted a range of activities and interventions prioritized from each annual work plan for the agreed-upon workstreams. A summary description of the major activities is presented below.

Workstream 1: Developing and Validating Technologies, Approaches, and Practices

IFDC's Soil and Plant Nutrition Program is developing and validating technologies that address nutrient management issues and advance sustainable agricultural intensification. These technologies are important for building climate resilience at the smallholder level as well as for improving agricultural productivity and nutrition. During this reporting period, IFDC devoted time and resources to:

- Fertilizer technologies refined and adapted for increased nutrient use efficiency and climate resilience for upland and lowland crops, including crops grown in areas subject to stress (e.g., flooding, drought, salinity). This included:
    - Adaptive trials for saline, submergence and drought -prone areas in Asia.
    - Field research in submergence-prone areas in sub-Saharan Africa (SSA)
    - Nutrient management trials for maize production in SSA involving fertilizer deep placement (FDP) and improved maize varieties.
    - Nutrient management trials for vegetable production in SSA involving FDP.
    - Climate mitigation through improved carbon sequestration.
    - Quantification of carbon dioxide emissions from urea.
    - Literature review of CERES-Rice impact.
- Balanced soil-plant nutrition programs involving the use of secondary and micronutrients in balanced fertilization regimes to improve crop yield, nutrient use, and grain quality. This included:
    - Development of a conceptual framework (SMaRT) for delivering balanced fertilizers to smallholder farmers.
    - Soil fertility mapping to facilitate site- and crop-specific fertilizer recommendations.
    - Greenhouse experiments on activation of phosphate rock.
    - Quantifying the efficiency of sulfur fertilizers.
    - Greenhouse study to evaluate the effect of zinc on sorghum productivity and NPK use.

- Greenhouse study to evaluate the response of wheat to zinc and manganese micronutrient fertilization.
    - On-farm trials to evaluate the effect of micronutrient fertilizer blends in maize production in Mozambique.
    - Balanced crop nutrition research in Burundi.
- Fertilizer quality assessments for East and Southern African markets to support policy efforts to harmonize fertilizer regulations. During the reporting period, fertilizer quality assessments were conducted in Kenya and Uganda.
- Development of an IFDC institutional database.
- Compilation of lessons learned from the evaluation of soil test kits.
- Identification of critical soil fertility issues in SSA led by Kansas State University.

Workstream 2: Supporting Policy Reforms and Market Development

Under Workstream 2, IFDC's Markets, Economics and Policy Program conducted evidence-based policy analysis to support reform processes and other initiatives that are focused on accelerating agricultural growth through the use of improved technologies, particularly fertilizers and complementary inputs. This analytical approach enables IFDC to support the development of fertilizer markets and value chains that allow greater private sector participation and investment with appropriate public sector regulatory oversight. The following is a summary of activities during the reporting period:

- Documenting policy reform processes and fertilizer market development. Activities included:
    - Analysis of the fertilizer subsidy program in Ghana.
    - Strategies for sparking private sector agribusiness growth in Uganda.
    - Report of recommendations on fertilizer subsidy reforms and market development in Tanzania.
    - Participation in three technical networks supporting the African Union (AU) CAADP Malabo Implementation Strategy
    - Input subsidy review studies
- Impact assessment studies on the performance of policy changes and supporting programs and lessons learned for future policy reforms and implementation. The following activities were conducted:
    - Support to fertilizer quality assessments conducted under Workstream 1.
    - Assessment of agro-dealer programs in SSA.
- Economic studies to inform public and private decision-making and identify policy-relevant areas for intervention to streamline the flow of fertilizers at reduced prices for smallholder farmers. Activities included reporting on fertilizer cost build-up studies in Ghana and Kenya.
- Identification and development of a set of preliminary indicators to denote fertilizer access across SSA countries for The African Fertilizer Access Index (TAFAI).

Cross-Cutting Issues Including Learning Agendas and Knowledge Management

Under the awarded agreement, IFDC conducted a range of activities and interventions prioritized by the 2017 annual work plan. This section summarizes the various associated outreach activities and the means of dissemination of research outcomes and findings. These are listed and reported in Table 16 and in Annexes 1 and 2.

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

Under Workstream 1, IFDC's Soil and Plant Nutrition team develops, refines, and validates fertilizer and soil management technologies and practices that help smallholder farmers increase production while reducing the negative environmental impacts of agriculture on the natural resource base. During the reporting period, activities under Workstream 1 focused on validating these technologies, including evaluating the effectiveness of fertilizer deep placement, micronutrients for balanced fertilization, and activated phosphate rock, and improving the availability of nutrients from fertilizers. In addition, a systems approach framework for soil mapping and fertilizer recommendations was developed. The work on fertilizer quality assessments for Kenya and Uganda continued. An impact study on the global use of the CERES-Rice model was also conducted. Below is a summary of activities for this reporting period.

1.1 Technologies Refined and Adapted for Climate Resilience and Improved Nutrient Use Efficiency

Fertilizer management is a major challenge for rice cultivation in stress-prone environments subject to drought, submergence, salinity, and other conditions. Farmers in these areas have poor control over water and fertilizer application. For conventional split application of nitrogen, farmers are often unable (in the case of flooding) or unwilling (in the case of flooding and drought) to apply the follow-on splits. Fertilizer deep placement could be a better alternative since it could be done before or at planting, ensures applied fertilizers are least likely to be lost due to runoff and volatilization losses, and eliminates the need for additional applications, and ensuring higher yields. However, this higher upfront fertilizer cost could be unattractive to risk-averse farmers.

1.1.1 *Technologies and Best Management Practices Developed and Validated for Stress-Tolerant Rice Cultivars in Asia*

During the 2017 Boro season, four field trials were established under saline-prone areas in Bangladesh. Six treatment combinations of fertilizer practice and rice varieties (Table 1) were tested in each trial to compare the performance of urea briquette deep placement (UDP) with farmers' practice. The deep placement of prilled urea (Figure 1) was added to the trials to compare it with deep placement of urea briquettes. The deep placement of both urea briquettes and prilled urea was done by hand.

Table 1. Experimental Treatments Used for Saline Trials in Bangladesh during Boro 2017

Treatments		N Rates (kg/ha)
Variety	**Fertilizer**	**Saline Soils (*Boro* 2017)**
Local improved (V1)	Farmers' practice	155±10*
	PU deep placement	78
	UB deep placement	78
Stress resistant (V2)	Farmers' practice	155±10*
	PU deep placement	78
	UB deep placement	78

The treatments are combinations of fertilizer practices and rice varieties.
PU: prilled urea; UB: urea briquette.
*The same N rates were used for both varieties.

Fertilizer treatments had significant interaction with variety on grain yields. In general, deep placement (briquettes and prilled urea) produced significantly higher grain yields compared to farmers' practice in both varieties (Table 2). Farmers used almost double the amount of N compared to deep placement. While farmers use urea in multiple splits, the timing of application may not be synchronized with plant demand. Therefore, the farmers' practice of fertilizer application is very inefficient and probably not economic (based on lower yields and higher urea use).

Figure 1. Deep Placement of Granular Urea by Hand in a Saline-Prone Area (Satkhir District) in Bangladesh

Figure 2. UDP Performance Evaluation Trial under Rainfed Drought Condition at Ratanpur, Satkhira, Bangladesh. At this site, Prilled Urea Deep Placement Plots Have Poor Plant Performance (Yellowish and Stunted Growth) Compared to Other Plots

The effects of prilled urea deep placement (PUDP) were variable with site. During the Boro season (dry season), PUDP produced similar yield as UDP (Table 2), except at the Ratanpur site. In Ratanpur, the yield in PUDP plots was significantly lower than all other treatments. It should be noted that water should be drained completely for PUDP. Otherwise, applied urea dissolves in water immediately and comes to the soil surface, which occurred at the Ratanpur site. These results suggest that PUDP may give comparable yields to UDP, urea briquette deep placement, particularly during the dry season when plots can be drained for fertilizer application; deep placement, however, is very challenging and not possible without complete mechanization. These results confirm that for small landholders, the use of briquettes is viable compared to PUDP.

Scientific publication comparing results from Myanmar and Bangladesh will be prepared.

Table 2. Comparison of Plant Height, Number of Panicles, and Grain Yields with Farmers' Practice (FP), PUDP, and UDP (briquette) under Local Improved Varieties (LIV, BRRI Dhan 28) and Stress (Salinity)-Tolerant Varieties (STV, BINA Dhan 10) at Different Locations in Bangladesh

Fertilizer	Plant Height, cm			Panicles per m^2			Yield, kg/ha	
	LIV	STV	Average	LIV	STV	Average	LIV	STV
Debhatta, Satkhira								
FP	88a	98a		342	425	383b	4851b	6188b
PUDP	88a	97a		387	486	436a	5713a	6864a
UDP	89a	98a		383	470	426a	5629a	6818a
Gobindapur, Satkhira								
FP	92a	97a		318	405	362b	5713b	6432b
PUDP	88a	96a		380	455	417a	5798ab	6800a
UDP	90a	97a		366	420	393ab	5816a	6703a
Ratanpur, Satkhira								
FP	82	101	92a	251b	324b		4898b	6293b
PUDP	74	91	83b	188c	202c		3652c	4216c
UDP	87	100	94a	286a	351a		5475a	6649a
Satkhira Sadar, Satkhira								
FP	89a	103a		320	323	321b	5854a	6355b
PUDP	88a	96b		360	385	372a	5821a	6857a
UDP	90a	98b		360	388	374a	5854a	6805a

Within a column and location, means followed by the same letters are not significantly different at $P<0.05$.

During the wet season (*Aman* 2017), the above fertilizer treatments are being tested under both drought-prone and submergence-prone areas in Bangladesh with local popular and stress-tolerant varieties. Crop cuts will be done during November-December, and results will be reported in the next semi-annual report.

In addition to Bangladesh, the experiments are also being conducted in Nepal under drought conditions and in Myanmar under submergence conditions. In Nepal, experiments are conducted in partnership with the Agricultural and Forestry University (AFU). These experiments will determine the optimum method of N fertilizer placement in both local improved varieties (LIV) and stress-tolerant rice varieties. Moreover, a farmer survey has been conducted to determine the knowledge gap between farmers' fertilizer management practices and government recommendations.

Figure 3. Deep Placement of Granular Urea in Nepal

1.1.2 *Technologies and Best Management Practices Developed and Validated for Rice Production in Submergence-Prone Areas in Sub-Saharan Africa (SSA)*

This field research is being undertaken in partnership with AfricaRice and Savanna Agricultural Research Institute (SARI) to develop appropriate soil fertility management technology tailored for submergence-prone areas in the three northern regions of Ghana. Previous efforts to improve rice productivity in submergence-prone areas focused mainly on varietal improvement. However, identifying farmer-friendly nutrient management technologies for the submergence-tolerant genotypes could bring synergistic benefits in increasing rice productivity in these areas. The use of nitrogen (N) efficient urea briquettes with one-time application that continues to provide N for the plant's entire growth cycle could be an effective means of supplying N to submergence-tolerant rice cultivars to cope better under the vagaries of the flooded conditions.

Although rice is traditionally grown in flooded soils, most rice cultivars die within days of complete submergence, often resulting in total crop loss. These losses disproportionately affect rice farmers in rainfed and flood-affected areas where alternative livelihood and food security options are limited. Average rice yields in these unfavorable areas in northern Ghana, for example, are very low, averaging 1.5-2.2 tons per hectare (ha), compared to the average yield of irrigated ecosystem of 4-7 tons/ha. These frequently flooded areas could benefit considerably from the use of submergence-tolerant rice varieties and appropriate nutrient management practices. During FY17, adaptive trials were established in seven communities in northern Ghana to evaluate the effectiveness of urea deep placement (UDP) technology in improving rice productivity in submergence-prone areas using the submergence-tolerant rice varieties NERICA L-19 and NERICA L-49 as test varieties. In each trial, the effectiveness of UDP technology was compared with microdosing (MD) technology and the locally recommended fertilizer management practice (LRP).

The experiments were laid in a split plot design with an individual plot size of 10 meters (m) × 10 m. The first factor, submergence-tolerant rice varieties, was randomized on the main plots, while the second factor, the three fertilization technologies (UDP technology, MD technology, and LRP), was randomized on the subplots. For all treatments, basal NPK (15-15-15) fertilizer was applied at a recommended rate of 250 kilograms (kg)/ha (two 50-kg bags/acre) three days after transplanting. For the UDP-treated plots, one 1.8-gram sized urea briquette was placed in between every four rice plants (resulting in an application rate of 113 kg/ha) at a depth of 7-10 centimeters (cm) seven days after transplanting. For the MD treatment, granular urea was applied six weeks after transplanting, if applicable; otherwise, the application was delayed until the field had drained enough to allow for fertilizer application. For this treatment, the granular urea was measured with a "beer top" and applied in between every two plants (rate of ~96 kg/ha) by incorporating it into the root zone of the rice plant. Similarly, for the LRP treatment, granular urea was applied six weeks after transplanting, if applicable, by broadcasting 1.5 kg of granular urea per plot (rate of ~150 kg/ha) (this method of application was modified during the second season). Although the urea application rates differed with each technology, no attempt was made to equalize the N application rate, because the intent of the trial was to compare the different nutrient management technologies for rice production in submergence-prone areas.

Preliminary results across all seven locations showed that greatest rice yields (Figure 4A) and N uptake (Figure 4B) were observed from the UDP treatment, followed by the MD and the LRP treatments in that order, irrespective of rice variety used.

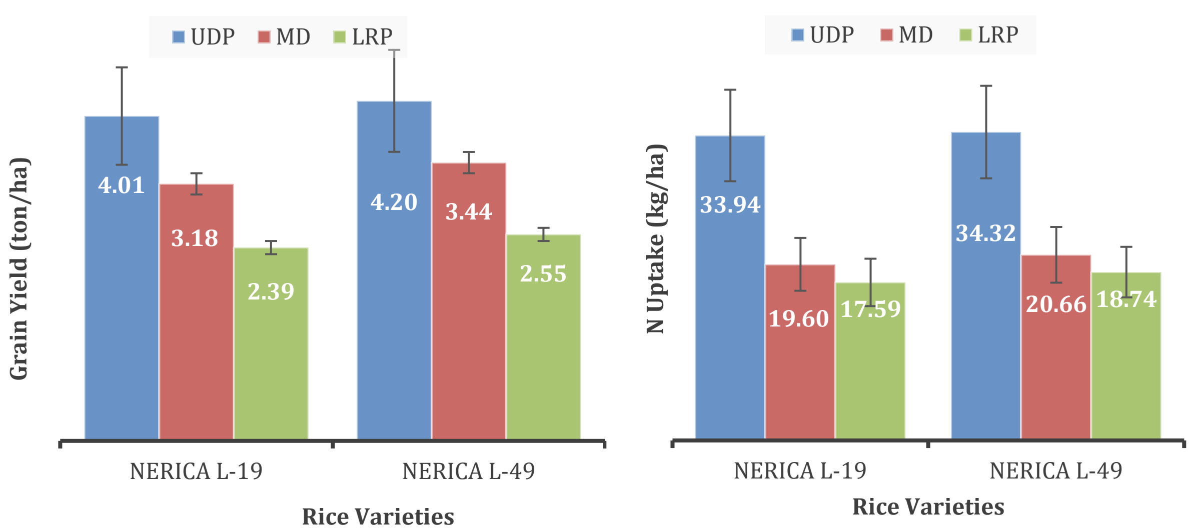

Figure 4. Average (A) grain yield and (B) N uptake of submergence-tolerant rice varieties grown at seven locations in the three northern regions of Ghana under urea deep placement (UDP), microdosing (MD), and locally recommended fertilizer practice (LRP) Treatments

Although the preliminary results suggest that UDP could be an appropriate soil fertility management technology for submergence-tolerant rice varieties for rice production in submergence-prone areas, these are results from only one season. Therefore, during the last quarter of FY17, the trials were repeated at nine locations to validate to results in order to draw conclusions and make recommendations. For this second season, the LRP treatment was modified whereby the granular urea was incorporated into the soil rather than surface-applied. Thus, for this treatment, a furrow was made in between two rows and a pre-determined quantity of granular urea (150 kg/ha) was placed in the furrows and covered with soil. The plants are growing in the field and expected to be harvested in November 2017.

Based on the results, a production guide will be developed to facilitate the upscaling of the appropriate nutrient management technology for rice production in submergence-prone areas and to enable partner organizations and projects, extension services departments of Ministries of Food and Agriculture, agriculture-based non-governmental organizations, and others to scale out the technology to submergence-prone areas across sub-Saharan Africa.

1.1.3 *Technologies and Best Management Practices Developed and Validated for Upland Maize Production for Smallholder Farmers in Sub-Saharan Africa (SSA)*

To improve nitrogen use efficiency, smallholder farmers have been trained to avoid the traditional practice of surface broadcast fertilizer application and instead to apply fertilizers at the subsurface, near the root zone of the maize plants. This practice requires farmers to measure the amount of fertilizer required for each plant and to apply that amount inside a hole dug near the plant. Farmers then cover the hole with soil after fertilizer application (Figure 5). Although this procedure has shown to be effective in increasing nutrient use efficiency and, consequently, maize yields, it is cumbersome and labor intensive. Farmers are therefore reluctant to adopt the practice. An innovative approach is to apply the quantity of fertilizer required by the plant in the form of fertilizer briquettes. This would eliminate the possibility of an imbalanced mix of fertilizers and the need for measuring the granular fertilizer before applying it to the plant. During the first quarter of FY17, adaptive trials were established to analyze urea briquette application for climate-resilient maize varieties. The maize will be harvested in November 2017.

Figure 5. Measuring the Fertilizer Dosage for a Maize Plant

Maize has high potential to address critical food security problems and could play a key role in any future strategy to reverse the declining trend in per capita food production in sub-Saharan Africa (SSA). However, the annual maize yield loss from drought is estimated at 30%, but localized losses might be much higher in marginal areas where annual rainfall is below 500 millimeters and soils are bare or shallow. A range of maize varieties (open-pollinated varieties and hybrids) purported to be early maturing and/or drought tolerant have been developed and are being introduced to farmers to minimize the impacts of erratic rainfall on smallholder farmers in SSA.

Previous studies suggest that the response of the maize varieties to urea briquette application differ, with the medium- and late-maturing varieties responding better in terms of increased yields than the early maturing variety, possibly due to the time of application of the urea briquette. Currently, with the emphasis on early maturing maize varieties and drought-tolerant hybrids to mitigate the effects of the impact of drought and erratic rainfall on maize production, adaptive trials were conducted during the first quarter of FY17. The trials were conducted to refine urea briquette application for these climate-resilient maize varieties. Fifteen sites were selected in the three northern regions of Ghana (six in Northern region, four in Upper East region, and five in Upper West region).

The experiments were laid in a randomized complete block design (RCBD) with an individual plot size of 10 meters (m) × 10 m. Treatments were three fertilizer application methods, namely (i) subsurface application of granular urea; (ii) subsurface application of urea briquettes; and (iii) microdosing fertilizer technology. Complete methodology and results will be presented in the next semi-annual report. The plants are growing in the field and expected to be harvested in November 2017. Based on the results, a production guide will be developed to facilitate the upscaling of the appropriate climate-smart nutrient management strategy for upland maize production for smallholder farmers.

1.1.4 Technologies and Best Management Practices Developed and Validated for Upland Vegetable Production for Smallholder Farmers in Sub-Saharan Africa (SSA)

This trial is being conducted to improve nutrient use efficiency in vegetable production, thereby reducing the cost of production and increasing farm profitability. In SSA, women are heavily involved in vegetable production; thus, the introduction of technologies that increase the productivity of vegetable production could increase household incomes, improve nutrition through crop diversification, and make the enterprise more attractive to women.

Declining soil fertility is becoming a major constraint for vegetable production in SSA. In spite of this constraint, there has been a sharp increase in the demand for and cultivation of vegetable crops for domestic markets in recent years. Such growth in the vegetable industry has placed significant pressure on natural resources, particularly since more than 80% of the population depend on the land for income and to fulfill their basic needs. Therefore, intensification, rather than extensification, of vegetable production is required, which calls for effective nutrient management. The low nutrient recovery in vegetable crop production and associated environmental problems have prompted researchers to re-examine nutrient management practices on vegetable crops in which reasonable yield and quality are expected from fertilizer application.

One nutrient management strategy that has gained worldwide interest and acceptability is fertilizer deep placement (FDP) technology. FDP technology in irrigated and lowland rice production has been widely recognized as an effective nutrient management practice. Application of fertilizer briquettes has also proved to be profitable in different upland crops, such as tomato, cabbage, cauliflower, potato, maize, and banana in many parts of the world, including Bangladesh, Mali, and Burkina Faso. Results to date have shown that 10-20% of urea could be saved by using FDP technology with simultaneous yield increases relative to the conventional fertilizer application practices for upland crops. Work on cabbage in Bangladesh suggests that the placement of NPK briquettes at a depth of 10 cm in the soil maintained a high level of NH_4-N during the active absorption period by the cabbage crop. Yield increases resulting from the FDP technology have been reported in Burkina Faso on tomato (26% increase), cucumber (22%), and yard long bean (9%), compared to conventional fertilizer application practices. Further, it is reported that the NH_3 volatilization loss resulting from surface application of prilled urea is very high, and farmers lose large amounts of money as a result of N fertilizer inefficiencies. To control this loss, deep placement of fertilizer may be a good option to minimize production costs as well as to increase yields.

During the FY16 cropping season, the effectiveness of NPK briquettes in increasing yields and fertilizer use efficiency was evaluated on chili peppers and eggplant in the Kumbungu district of Northern Ghana. Preliminary results showed that there was a two-fold yield increase in pepper and an 80% increase in eggplant yields, with better quality fruits from the NPK briquette plots, relative to the conventional farmer practice of prilled urea broadcast application. During the first quarter of FY17, nine sites were selected in the three northern regions of Ghana (three in each region) to evaluate the effect of FDP technology on yield and nutrient use efficiency to validate the preliminary results on a number of vegetable crops (okra, pepper, eggplant, tomato, and onion). The study also evaluates the synergetic effects of FDP technology and organic material on the growth, development, and production of the vegetables. The vegetables will be harvested in November-December 2017.

The experiments were laid in a split plot design with an individual plot size of 10 meters (m) × 10 m. The first factor, soil organic matter treatment, was applied on the main plots, while the second factor, four fertilization treatments were randomized on the subplots. The NPK briquette (prilled urea for N, diammonium phosphate [DAP] for N and P, and muriate of potash [MOP] for K), urea briquette, and straight fertilizer (prilled urea, TSP, and MOP) were used to provide different nutrient combinations. The treatments were selected on the basis of fertilizer recommendation by the local extension services department. The full methodology and results will be presented on completion of the trial in the next semi-annual report. Also based on the results, a production guide will be developed to facilitate the upscaling of the appropriate nutrient management technology for vegetable production to enable partner organizations and projects, extension services departments of Ministries of Food and Agriculture, agriculture-based non-governmental organizations, and others to scale out the technology to other areas across SSA.

1.1.5 *Quantify Climate Mitigation Role of Enhanced Efficiency Fertilizers and Practices: Improved Carbon Sequestration*

A 15-25% yield increase generally occurs with UDP compared to broadcast urea (split-applied). It is anticipated that root biomass accumulation in deep-placed urea would be at least 10% more relative to their broadcast counterparts. The deep placement of urea has been shown to reduce/eliminate the diffusion of NH_4-N into floodwater and, hence, substantially reduce NH_3 volatilization loss. As shown in the next section, deep placement also slows the diffusion of CO_2 formed during hydrolysis of urea into the floodwater and the atmosphere. This expectation leads to the second hypothesis that UDP increases soil organic matter build-up through the utilization of CO_2 (C sequestration) by algae, rice, and weeds and, thus, reduces carbon footprint of urea.

A total of 540 soil samples (180 topsoil and 360 subsoil) were collected from rice fields in Bangladesh that have been under UDP practice from three to 20 years and from rice fields where only broadcast application of prilled urea was used. The fields included the former project sites of the Improved Livelihoods for Sidr-Affected Rice Farmers (ILSAFARM) and Accelerating Agriculture Productivity Improvement (AAPI). All 540 samples were analyzed for: organic carbon, total N, and soil pH.

Significant differences in soil organic carbon (SOC) were observed between fields that were under rice-rice cropping versus dry season (Boro) rice-fallow (Figure 6). In the latter, during the fallow season the field was completely submerged with no water control for rice cultivation. This resulted in slower decomposition of organic matter and, thus, higher SOC compared to the rice-rice system. Overall, the deep placement of urea resulted in significant increase in SOC (Figure 7), particularly in the rice-rice cropping (Figure 8). The increase in SOC with UDP compared to broadcast urea application differed with location, with locations that have been under UDP practice for 15-20 years generally having greater increase in SOC. The effect of N management was observed up to 25 cm depth (rooting depth).

Managing SOC is complex because of soil, hydrology, temperature, cropping system, and management effects and their interactions. On the positive side, improved fertilizer management, such as deep placement, resulted in significant increase in SOC in intensified rice-rice cropping without any negative effect on rice yield. With the evidence gathered on deep placement technology to date, it can be classified as climate-smart agricultural technology that promotes sustainable increase in productivity, allows adaptation measures (stress-environment examples), and mitigates emissions (N losses, C sequestration, and CO_2 emission).

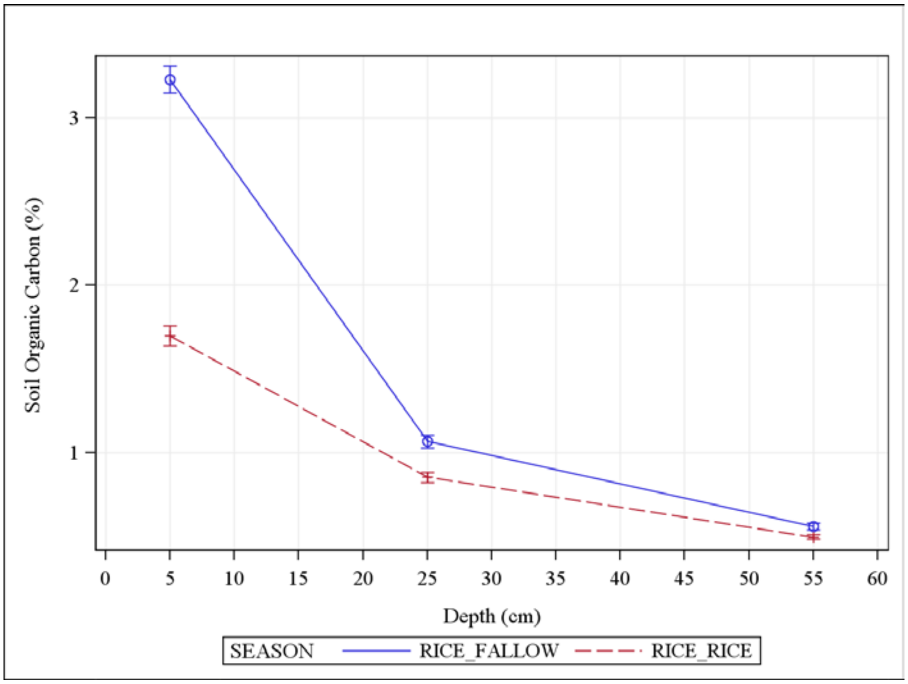

Figure 6. Effect of Cropping System on Soil Organic Carbon with Soil Depth

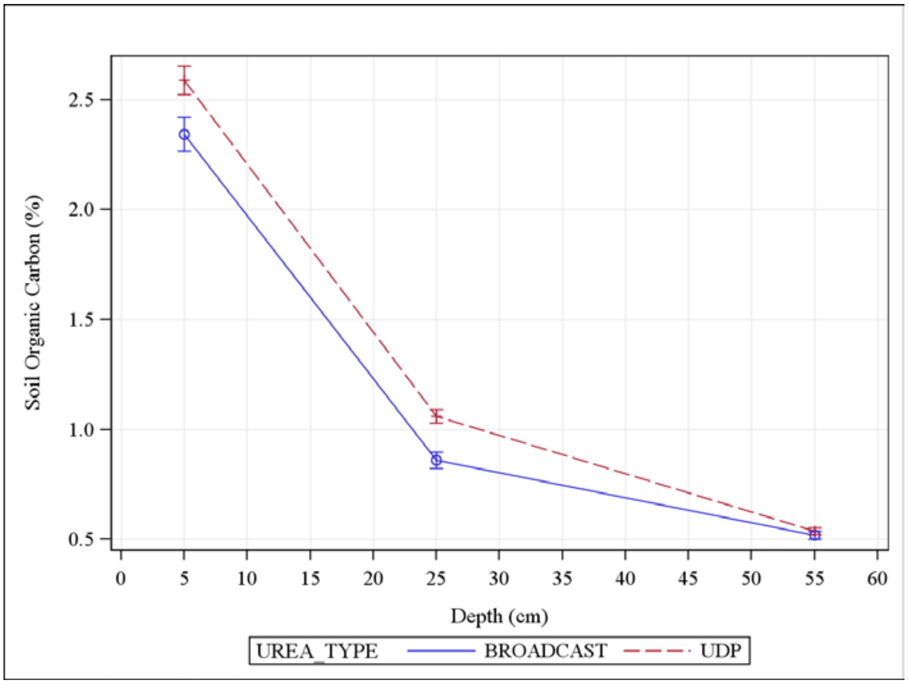

Figure 7. Effect of UDP versus Broadcast Application on Soil Organic Carbon for All Locations and Seasons

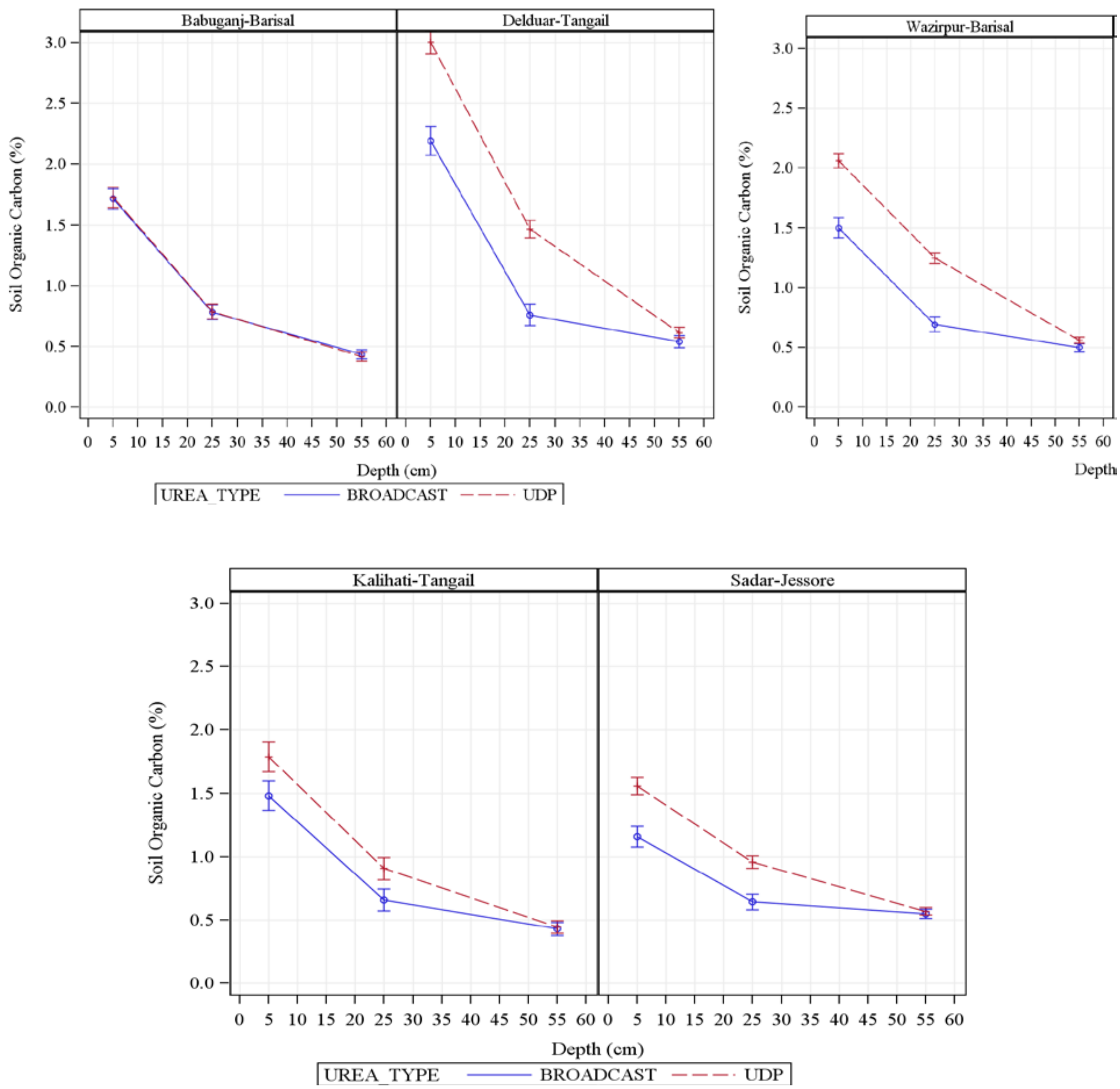

Figure 8. Effect of UDP versus Broadcast Application on Soil Organic Carbon for Five Locations during the Rice-Rice Cropping

1.1.6 *Quantify Climate Mitigation Role of Enhanced Efficiency Fertilizers and Practices: The Potential Benefits of Carbon Dioxide from Urea*

Carbon (C) is an essential element for crop growth with carbon dioxide (CO_2) in the atmosphere as the C source for photosynthesis. Enrichment of CO_2 concentration increases photosynthesis, leading to potential plant growth and yield. However, CO_2 is also responsible for 82% of greenhouse gases (GHGs). Hydrolysis of urea results in CO_2 emission. Globally, 192 million tons of urea is consumed in agriculture annually, resulting in 140 million tons of CO_2 emission as a byproduct of urea hydrolysis. This could translate to CO_2-enricment and improved crop growth or conversely to negative impact on the environment as a GHG. With the purpose to mitigate GHG emissions, increase the use efficiency of urea (reduced NH_3 volatilization loss), and benefit crop growth with CO_2-enrichment, the current research on the quantification and control of urea hydrolysis in soil was undertaken. The quantification of the CO_2 from urea hydrolysis from different urea sources under different environmental conditions will allow us to identify the potential benefits of CO_2 emissions in terms of plant uptake and consequently decreasing the negative impacts of GHG.

The carbon footprint for urea fertilizers is due to both production and use. In production, the carbon footprint component is associated with the use of natural gas as substrate and energy source for ammonia synthesis in the Haber-Bosch process that generates 3.6 kg CO_2 eq per kg N. When urea is applied to the soil, 0.73 kg CO_2 is released as a byproduct of hydrolysis for every 1 kg urea. Globally, the 192 million tons of urea used in agriculture in 2014 contributed to 326.4 million tons CO_2 eq (192 x 1.7 kg of CO_2 eq/kg of urea) from production and 140 million tons CO_2 (192 x 0.73 kg of CO_2/kg of urea) from urea hydrolysis along with N_2O and NO emissions from nitrification and denitrification, as mentioned previously.

This research explored different urea products that could control urea hydrolysis and/or CO_2 diffusion, thereby increasing the utilization of CO_2 for improved crop growth and reduced GHG emissions. CO_2 emissions from urea, UDP, urea with urease inhibitor (Agrotain), and ammonium nitrate (check) were compared under upland and flooded conditions. Based on the knowledge of different behaviors on urea hydrolysis in different soils, three different soils were used to test in different soil variations such as pH level and organic matter. Different moisture content was also tested to see how it influenced the CO_2 emission from the soil. LI-COR CO_2 analyzer connected to a data logger in to a custom-made CO_2 close chamber volatilization set up was programmed to record CO_2 emissions for four minutes from each pot per hour.

These studies will help assess different N fertilizer products and application methods regarding: (1) different emission rates of CO_2; (2) mitigation of GHG emissions; (3) improvements in nutrient use efficiency; and (4) the exploration of alternatives in advanced agriculture to capture and store carbon emissions. For now, the results (Figure 9 and Table 3) show a good indication that CO_2 emissions from the different urea fertilizer treatments differ, and there are opportunities to reduce the CO_2 emission rate and increase the potential of CO_2 sequestration/fixation by soil and plants.

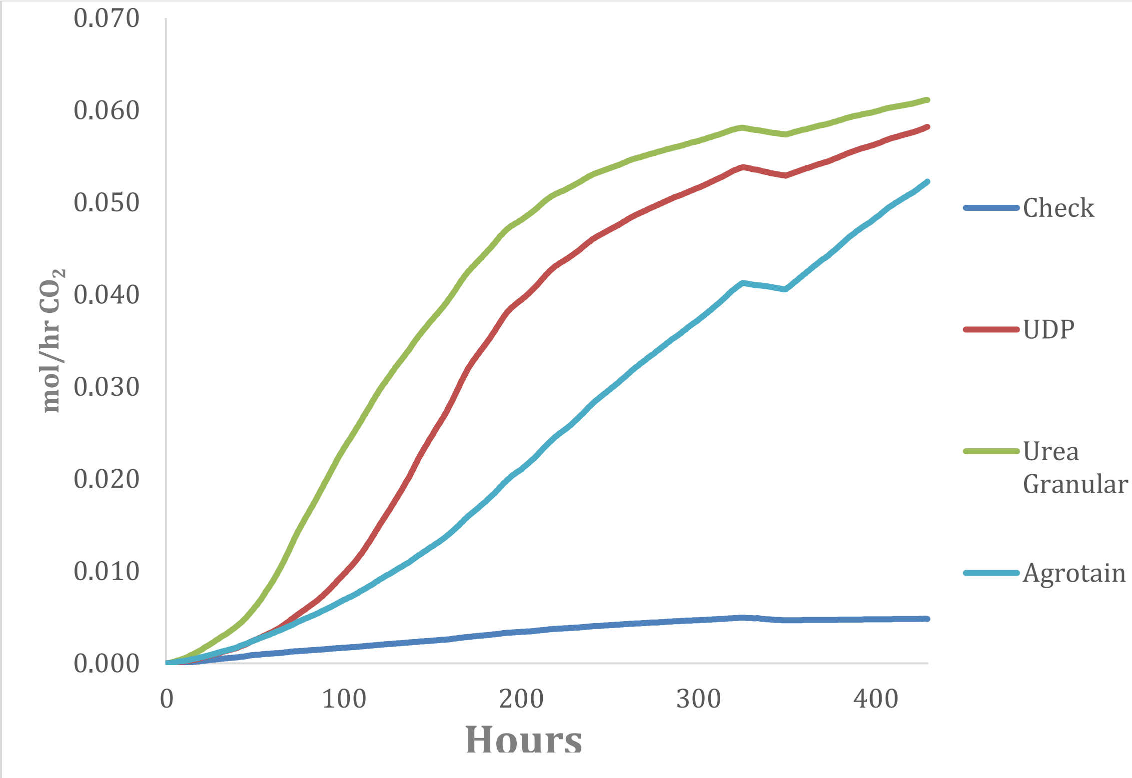

Figure 9. CO_2 release at 50% Field Moisture Capacity on Greenville Soil

Table 3. CO_2 Recovery (%) on Different Soils at Different FMC

Soil	Treatment	50%	75%	Flooded
Greenville	UDP	80.08%	72.81%	-0.99%
	Urea Granular	84.45%	71.10%	11.27%
	Agrotain	71.18%	51.98%	16.02%
Brownfield	UDP	76.88%	86.96%	12.26%
	Urea Granular	89.80%	96.75%	28.46%
	Agrotain	81.52%	89.42%	26.78%
Hiwassee	UDP	137.68%	81.07%	
	Urea Granular	141.99%	114.97%	
	Agrotain	119.52%	98.32%	

1.1.7 *Decision Support Tools Developed and Validated for Rice: CERES-Rice Model*

Rice is the most important cereal crop, and it is grown in a wide range of agro-environments – from temperate to tropical regions. It is also highly vulnerable to climatic variability and has a very low nutrient use efficiency. Crop simulation models are an attractive option for understanding and predicting the effect of the multitude of factors and processes that affect rice growth. A literature review was undertaken to quantify the scope of use and the impact of the CERES-Rice model in research, teaching, extension, and policy development.

Since its development in the early 1990s at IFDC through USAID funds, the CERES-Rice model has been applied to a wide range of focus areas, including crop management and climate change. One of the main aims of this model is to ultimately (indirectly) help farmers by identifying major yield-limiting factors and thus prioritizing and developing research areas to improve cropping systems. The nearly 300 studies performed in 15 countries utilizing the model have and will continue to increase our understanding of and decision making in crop management (e.g., planting window, variety selection, planting density, irrigation options, and nutrient rates), our assistance in agricultural policy development, and our comprehension of and preparation for climate change impacts. To ensure CERES-Rice correctly simulates the effect of high temperature, drought, and CO_2 change, a collaborative partnership between IFDC, the University of Florida, and the global Agricultural Model Intercomparison and Improvement Project (AgMIP) rice team has been developed.

Yield Gap/Trend Analyses

Since the early 1990s, the CERES-Rice model has been used to estimate yield potential and yield gaps and simulate yield trends. These analyses have been used to identify, from site-specific to national levels, constraints causing yield gaps and develop management strategies for closing them, such as adopting appropriate water and nitrogen management strategies. While models such as CERES-Rice simulate crop growth and development on a daily time step for a single growing season, research efforts have been made to analyze yield trends over longer timespans and across growing seasons to help address carryover issues such as water, soil organic matter, and nutrient limitations.

Currently, crop modeling systems such as CERES-Rice represent the only research approach capable of considering the multitude of complex processes and interactions involved in crop production and cropping systems and will therefore continue to play a vital role in analyzing and developing potential pathways toward improving crop yields.

Improving Crop Management

Increasing yields requires not only the identification of potential constraints but developing solutions that address such constraints. CERES-Rice enables researchers to strategically, in real time, identify and implement crop management practices such as irrigation and nitrogen management. The model has been used to evaluate management practices, allowing researchers to identify the effects of transplanting dates, planting geometry and nitrogen and water management.

These studies potentially enable researchers and policy makers to identify best management strategies to improve crop yields and minimize agricultural contributions to climate change, such as inappropriate water management and practices that increase nitrogen losses to groundwater and the atmosphere. In addition, some research on pest and disease management has been accomplished by pairing CERES-Rice with other models to evaluate yield impacts from these.

Climate Change

Far and wide, the bulk of the literature resulting from research performed using CERES-Rice focuses on the effects of climate change on rice production systems, including especially impacts on both irrigated and rain-fed rice yields and water use requirements in Asia.

These studies generated not only predictions regarding how climate change will impact yields and resource use but also, and more importantly, management techniques to enable producers to adapt to these changes and inform policymakers to plan and implement climate-mitigating strategies for the present and future.

Models have enabled researchers to reliably predict yield responses to climate change. With CERES-Rice specifically, researchers have used the model to quantify climate change and CO_2 enrichment impacts on phenology, growth, yield, evapotranspiration, disease development, and irrigation requirement of rice in multiple locations in more than nine countries across varying latitudes, giving a fuller glimpse of how future climate scenarios will affect crop production. These studies have yielded insights into how growth duration, planting date, fertilizer application, irrigation methods and varieties relate to climate change. The studies have provided for the ability to predict the effects of various expected scenarios and develop cropping strategies to cope with the changes.

The different applications of the CERES-Rice model is summarized in Table 4, and the role and impact of modeling will expand with increasing vulnerability to climatic variabilities and uncertainties. Through university partnerships and working with the AgMIP rice team, efforts are underway to evaluate the CERES-Rice model for a wide range of temperatures, CO_2 levels, and N rates from studies that have been conducted in the past. Results will be presented in the next semi-annual report.

Table 4. Summary of Applications of CERES-Rice

Application Type	Countries
Yield gap/trend analyses	Australia, India, Nepal, The Netherlands, Nigeria, Philippines, Thailand, USA, Vietnam
Strategic decisionmaking and planning	Bangladesh, China, India, Philippines
Tactical management strategies	Australia, Bangladesh, India, Nepal, Pakistan, Philippines, Thailand
Climate change studies	Bangladesh, China, Ghana, India, Indonesia, Japan, Nepal, Pakistan, Philippines, Thailand, USA
Prediction of greenhouse gas emission	China, India, Indonesia
Pest and disease management	Australia, Philippines, Thailand, USA, Vietnam
Aiding government policy	India, Indonesia, Taiwan

1.2 Balanced Plant Nutrition Through Improved Fertilizer Product Recommendations

The efforts described below are components of the deliverables for activities under Workstream 1, involving: the development of conceptual framework for balanced fertilizer delivery; development of soil fertility maps to facilitate site- and crop-specific fertilizer recommendations; promoting use of local phosphate rock activated with water soluble P fertilizer; improving efficiency of S fertilizer; and the use of secondary- and micro-nutrients in balanced fertilization regimes to improve crop yield, nutrient use, and grain quality. Secondary and micronutrients can influence crop yield responses in the presence or absence of macronutrients (NPK) globally. This is especially important for sub-Saharan Africa (SSA), which is affected by low soil fertility due to the low use of fertilizers in crop production. However, compared to yields, less is known regarding the effect of secondary- and micronutrients on macronutrient (NPK) use and grain nutritional quality.

1.2.1 *Development of Conceptual Framework for Balanced Fertilizer Delivery*

IFDC developed a conceptual framework for delivering balanced fertilizers to smallholder farmers. The SMaRT concept stands for Soil testing, Mapping, Recommendations Development, and Technology Transfer. While donors are increasingly investing in balanced crop nutrition and many national and international organizations are devoting research and development resources to the effort, the diverse approaches in identifying and quantifying deficiencies are often uncoordinated and do not take into account the market realities of manufacturing and delivering improved fertilizers to farmers. SMaRT was developed to improve understanding of the multiple steps involved in getting better fertilizers to farmers and to encourage coordination of the multiple actors across the fertilizer value chain, with the aim of accelerating the process. The SMaRT concept was presented and discussed at a pre-event of the African Green Revolution Forum (AGRF) in Abidjan, Côte d'Ivoire, on September 3, 2017. In attendance were over 50 participants, including donors, the International Fertilizer Association (IFA), African Fertilizer Agribusiness Partnership (AFAP), International Soils Resource Information Center (ISRIC), International Plant Nutrition Institute (IPNI), major fertilizer manufacturers, and research and development organizations. The concept was well-received, and follow-up activities were planned.

SMaRT was developed in recognition of many smallholder farmer realities, particularly in the sub-Saharan African context: lack of access to affordable, quality soil analyses (particularly the full soil analyses required for addressing secondary and micronutrient deficiencies); small farm size, which restricts manufacturers' ability to address field-specific needs due to low production volume, and difficulty in even application of micronutrients, often required at doses of 1 kg/ha or less. The commercial farmer model of obtaining a full soil analysis and a crop-specific recommendation for a yield target, then purchasing that fertilizer in large volume, is not applicable in this context.

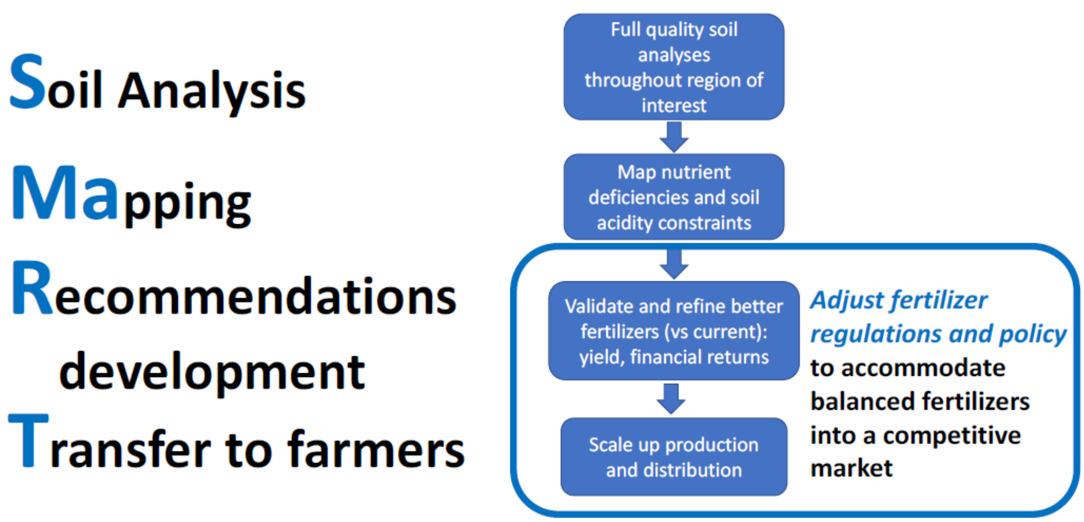

Figure 10. SMaRT Concept

SMaRT begins with soil analysis at a large scale – usually at a country or large region level (Figure 10). A full soil analysis using recognized methods and quality laboratories is required. While analysis at scale may seem costly, it is relatively inexpensive compared to individual farm analyses. The results are then mapped so that likely nutrient deficiencies and soil acidity constraints are identified on a regional level. In the recommendations development step, balanced fertilizers and lime recommendations, appropriate to farmer purchasing power, are developed and evaluated on-farm and compared to current fertilizer recommendations. Once superior formulations have been validated, they become recommendations. In the technology transfer step, coordinated plans are implemented for manufacturing or blending the fertilizers and exposing farmers to them. Often, fertilizer blending facilities will need to be established, which requires feasibility studies and finance support.

Effective implementation of the SMaRT concept requires the coordination of multiple participants who have various motivations and may be competing with one another for resources or business. Important stakeholders include donors, national and international research organizations, development partners, agribusiness support entities, soil and plant analytical laboratories, policymakers dealing with regulations and subsidies, the fertilizer industry (manufacturers and blenders), and agro-dealers. One outcome of the AGRF workshop was to initiate the process of coordinating the skills and knowledge of the various partners. A preliminary meeting of key partners will take place in Nairobi on November 8, 2017. The concept will gain exposure at a fertilizer workshop in Myanmar (October 18-20) and within IFDC at a scientific meeting in Muscle Shoals, Alabama, U.S.A. (October 30-31).

1.2.2 *Development of Soil Fertility Maps to Facilitate Site- and Crop-Specific Fertilizer Recommendations*

Soil fertility mapping was conducted to commence the development of site- and crop-specific fertilizer recommendations for the Feed the Future (FTF) zone of influence (ZOI) in northern Ghana. Despite advances in geographic information systems (GIS) mapping, remote sensing, and soil testing technology that can help in approximating soil fertility requirements at specific sites, most countries in sub-Saharan Africa continue to use blanket fertilizer recommendations based on soil tests and trials that are over two decades old. The soil fertility mapping, together with subsequent nutrient omission trials, is expected to provide research-based information to stakeholders in the fertilizer value chain and facilitate the development of appropriate fertilizer blends (imported or locally blended) for farmers in different agro-ecological regions to increase productivity and fertilizer efficiency.

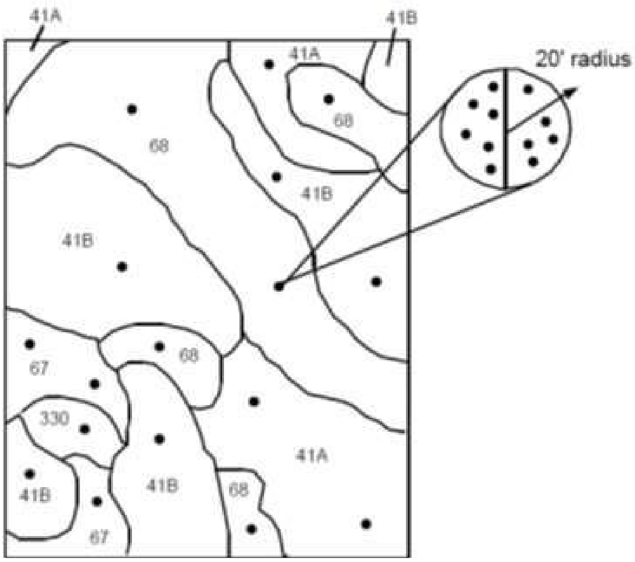

Figure 11. A Schematic Presentation of Sampling Points from Management Zones Created with a Grid (Cell)

During FY16, protocols for comprehensive and strategic soil sampling were prepared and used to collect geo-referenced soil samples in the FTF intervention zones of the three northern regions of Ghana. The Grid/Management Zone Hybrid Soil Sampling Method was used to collect the soil samples (Figure 11). Within each community, the fields were subdivided into an arrangement of cells that were 2-4 kilometers (km) apart. Within each cell, management zones were established using a variety of resources and/or datasets. These include soil surveys, past yield data, remote sensing imagery, landscape/topography, elevation, electrical conductivity, and/or past knowledge of field characteristics. Thus, the shape, size, and number of management zones within each cell varied depending on field variability and the information derived from datasets. The data from the soil chemical analyses were used to develop the initial soil fertility maps, which are constantly being updated as additional soil chemical analyses data become available.

In FY17, a total of 4,200 additional soil samples were analyzed for pH, organic carbon (and translated to organic matter content), the major nutrients nitrogen (N), phosphorus (P), and potassium (K), secondary elements sulfur (S), calcium (Ca), and magnesium (Mg), and micro elements zinc (Zn) and boron (B). These data were used to update the soil fertility maps using geostatistical tools. Soil pH was analyzed using the 2:1 deionized (DI) water method, total N using the Kjeldahl and combustion methods, SO_4-S using monocalcium phosphate (MCP) extraction, and “available” P mainly using the Bray-1 P method; in isolated cases in the Yendi, Savelugu-Nanton, Gushegu, Central Gonja, Sissala East and West, Wa West, and Lawra districts, where pH values > 7 were observed (Figure 12), the soil available P is being re-analyzed using the Olsen P method. Exchangeable K, Ca, and Mg were determined by the 1 N NH_4Cl extraction method, organic C by the Walkley and Black method, Zn by the diethylenetriaminepentaacetic acid (DTPA) extraction method, and B by the hot water procedure. All sample collection, handling, and chemical analysis were conducted according to standard quality assurance and quality control (QA/QC) protocols.

In FY17, 1,250 plant tissue samples were collected from selected sites simultaneously with soil samples to validate and complement the soil chemical analysis. Unlike soil testing, plant tissue analysis can account for the plant-available nutrient pools present at multiple soil depths, including deeper horizons. Because of the extensive root system in some plants, plant analysis is a complement to the soil test to better assess the overall nutrient status of a perennial system while revealing imbalances among nutrients that may affect crop production. The plant tissue samples collected are being analyzed.

The results obtained from the soil chemical analysis suggest that across the three northern regions of the FTF ZOI, particularly in the Upper East region and the northwestern corner of the Upper West region, the soils are generally acidic to slightly acidic with very few isolated cases where the soil pH is near neutral (Figure 12). Also, large portions of the total land area have soils deficient in P (< 10 milligrams [mg]/kg; Figure 13), S (< 6 mg/kg; Figure 14), Zn (< 1 mg/kg; Figure 15), and B (< 1 mg/kg; Figure 16). Therefore, to increase productivity in such soils, and to realize the full benefits of investments in fertilizers, efforts must be made by farmers to supply these essential plant nutrients to crops. However, quantities of the nutrients to supply will depend on the results of the nutrient omission trials. On the other hand, with the exception of a few isolated cases encountered so far, most of the soils in the entire ZOI have high potassium contents (Figure 17), which should be adequate for the production of most crops. Therefore, apart from those isolated cases, potassium should not be a limiting nutrient for most soils in the region. This hypothesis will be tested with nutrient omission trials being planned. Additional soil fertility maps are being developed for soil Ca and Mg.

In partnership with the Savanna Agricultural Research Institute (SARI), University for Development Studies (UDS), Soybean Innovation Lab (University of Illinois and Mississippi State University), and Ministry of Food and Agriculture (Ghana), a minimum of 150 nutrient omission trials will be established across the three northern regions to facilitate site-and crop-specific fertilizer recommendations. In collaboration with the FTF Ghana Agriculture Technology Transfer (ATT) project and Soybean Innovation Lab, a soil fertility workshop will be organized in northern Ghana to bring all stakeholders of the fertilizer value chain together to present the results of the soil mapping and to identify the way forward in developing appropriate fertilizer blends that will suit the region's different agro-ecological zones. An example application using the soil acidity data (Figure 12) with Phosphate Rock Decision Support System (PRDSS) and realizing the occurrence of P deficiency (Figure 13), a map showing the probability of P response to the application of Kodjari phosphate rock as P source was developed (Figure 18).

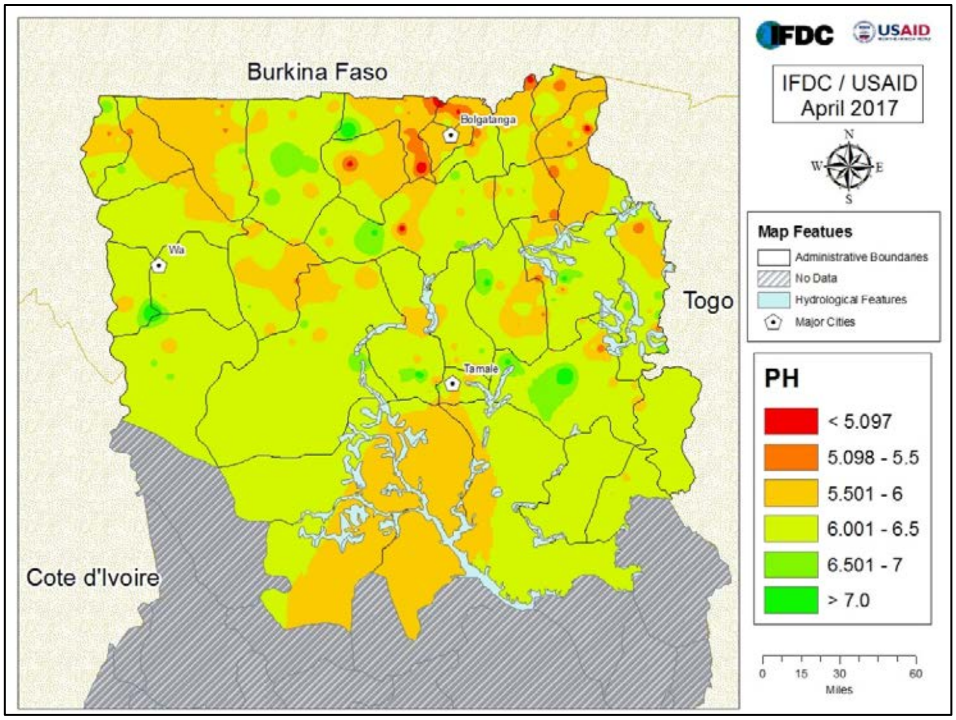

Figure 12. Soil pH Map of the Three Northern Regions of Ghana

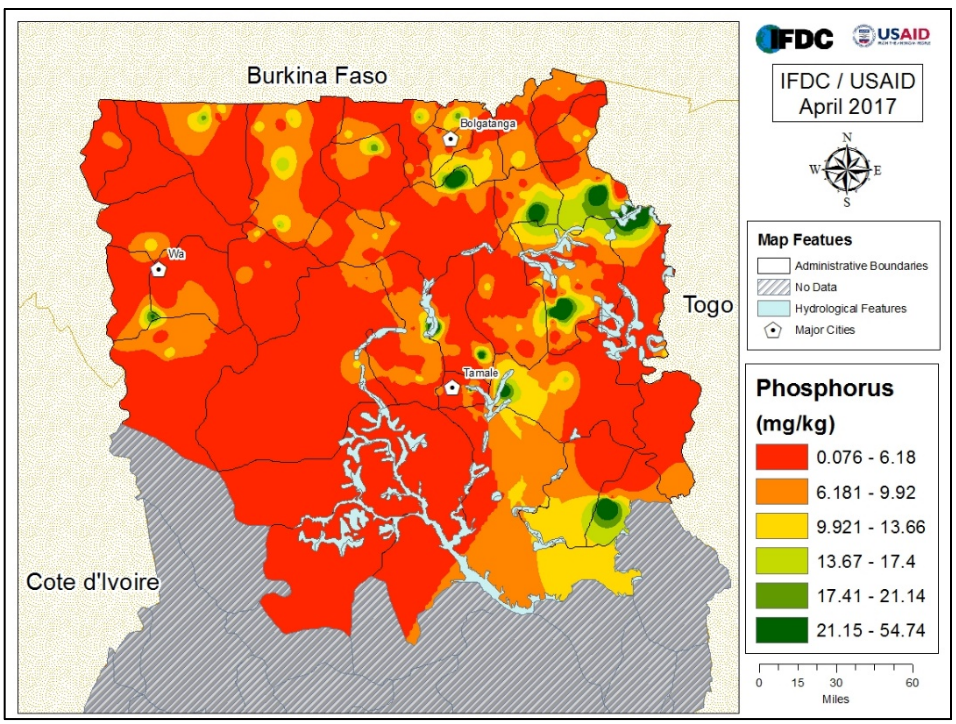

Figure 13. Soil P Map of the Three Northern Regions of Ghana

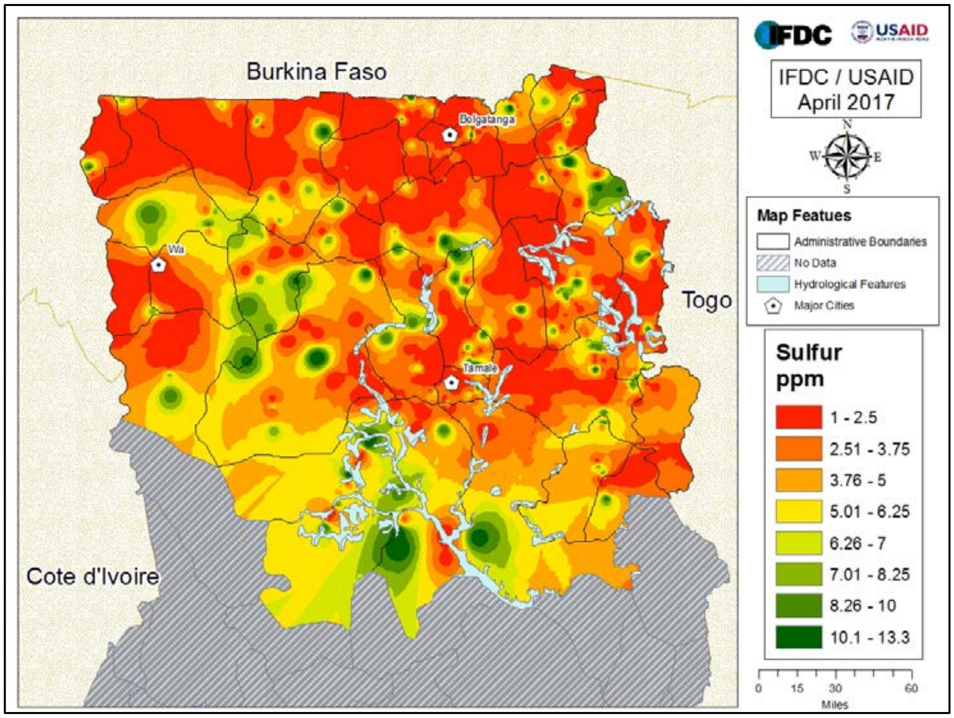

Figure 14. Soil S Map of the Three Northern Regions of Ghana

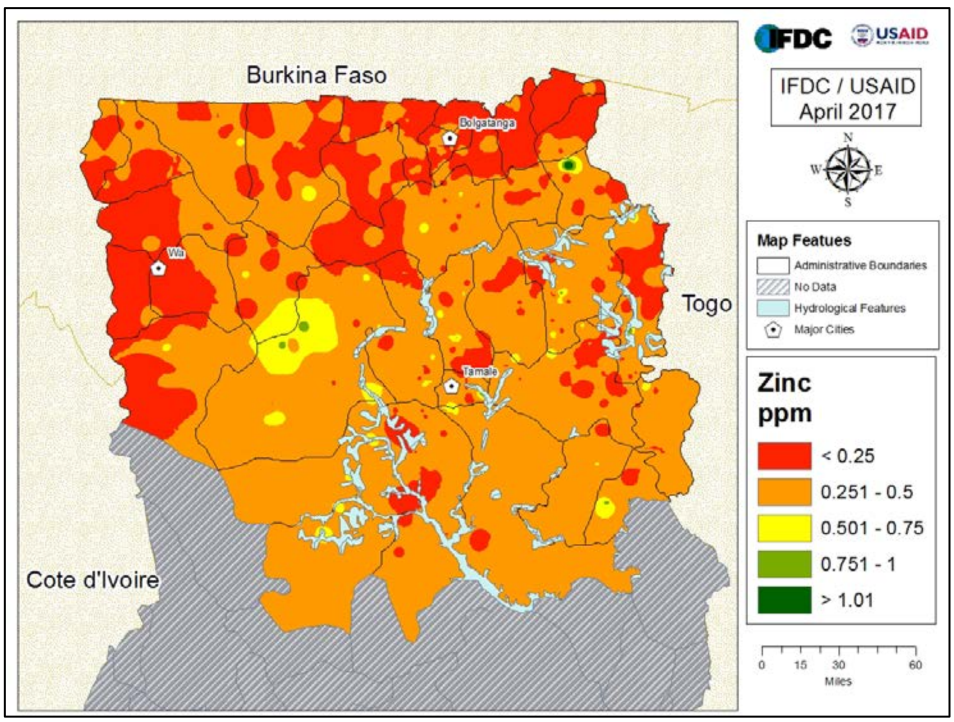

Figure 15. Soil Zn Map of the Three Northern Regions of Ghana

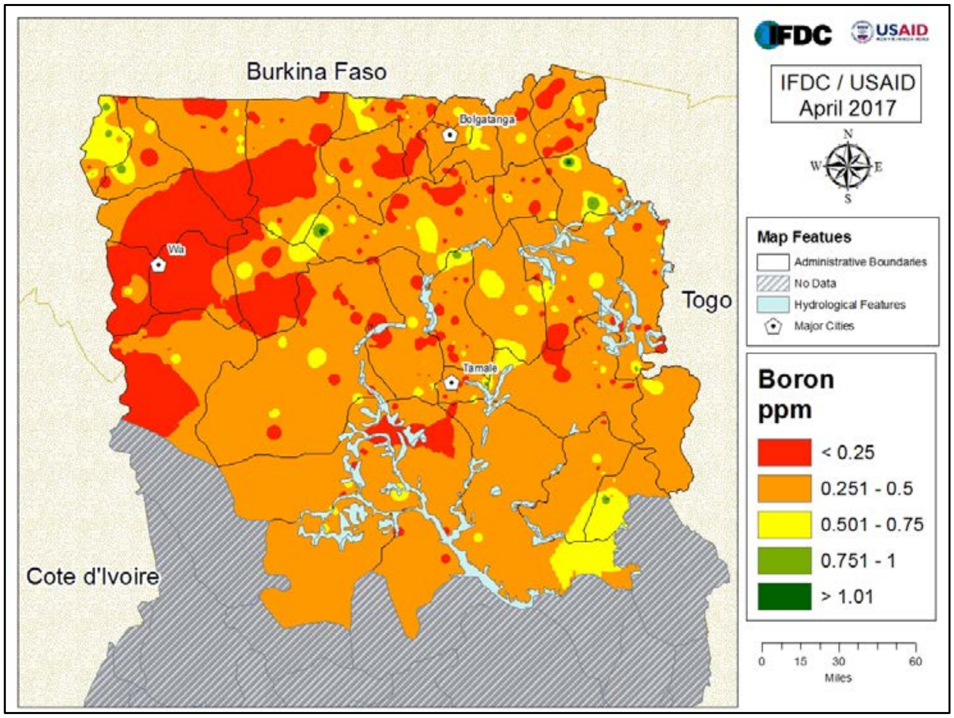

Figure 16. Soil B Map of the Three Northern Regions of Ghana

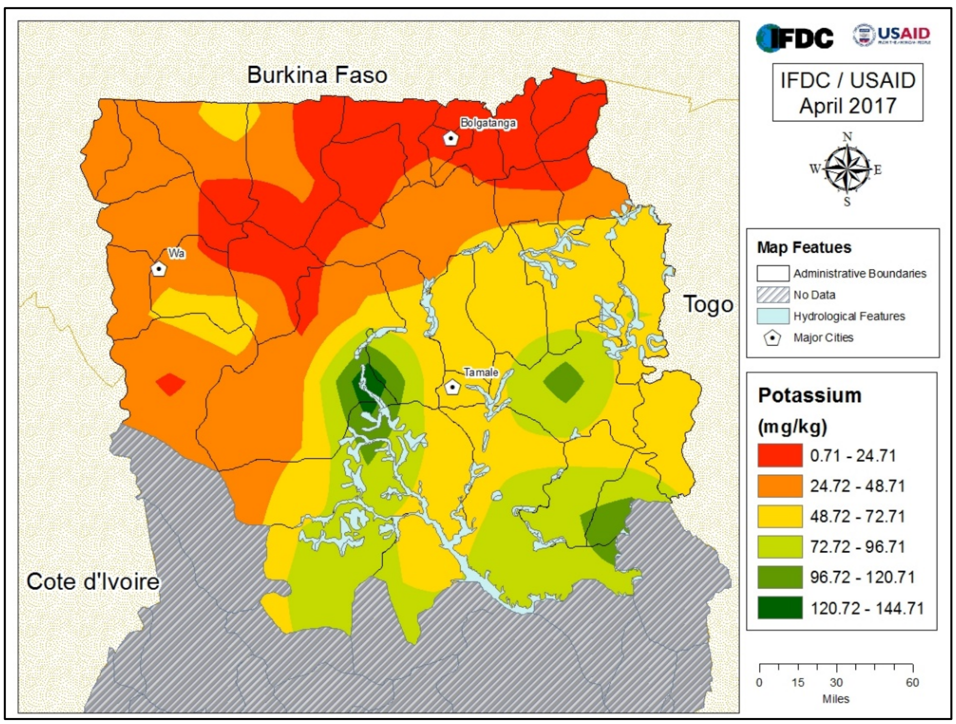

Figure 17. Soil K Map of the Three Northern Regions of Ghana

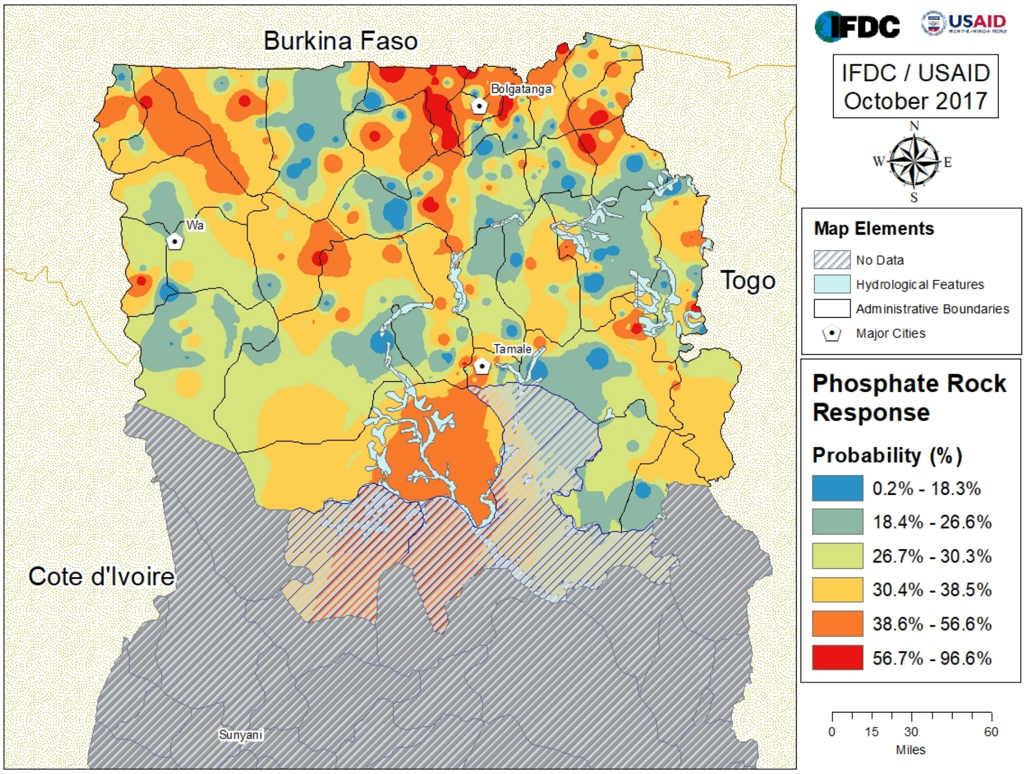

Figure 18. P Response Probability (%) to Kodjari Phosphate Rock Application in Three Northern Regions of Ghana

1.2.3 *Evaluation of Agronomic Effectiveness of Activated Phosphate Rock*

This research is evaluating the effectiveness of phosphate fertilizer produced through the compaction of a modest quantity of water soluble P fertilizer (diammonium phosphate – DAP) with phosphate rock (PR). Although SSA is endowed with PR resources, most of the PRs are non-reactive, making direct application inefficient for many places. The example application in Figure 18, showed Kodjari PR was not an ideal P source for some places. One innovative and practical approach to enhancing PR agronomic efficiency is the activation of the PRs with DAP. This approach is energy efficient and an environmentally desirable alternative to the current P fertilizer production technology. The method could improve P access and utilization for smallholder farmers thereby increasing productivity and household incomes.

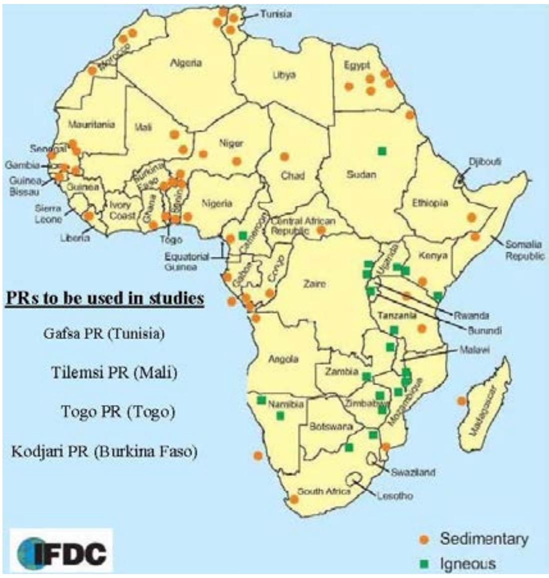

Figure 19. African Phosphate Rock Deposits

Activation of PRs with soluble P fertilizers such as DAP holds considerable promise in SSA countries and other regions that have deposits of low- to medium-reactive PRs (Figure 19). This low input technology could make locally available PRs viable for use by smallholder farmers to increase productivity. Soluble P fertilizer stimulates early growth and root development leading to increased effectiveness of PR as a P source.

In greenhouse studies, two PRs, one non-reactive (Idaho PR) and one reactive (North Florida PR) were each activated with a modest amount of DAP at a ratio of 20% DAP to 80% PR (4:1 PR/DAP ratio = "0.2 Activation"). The studies evaluated the agronomic effectiveness of the PRs using three soils of varying pH levels: acidic (Hiwassee pH 5.5), near neutral (Greenville pH 6.8), and alkaline (Sumter pH 7.6). During the winter season, the activated P products were evaluated using winter wheat as the test crop, and in the spring/summer seasons, soybean and rice were used as the test crops. Treatments were: (1) Idaho PR, (2) North Florida PR, (3) 0.2 Activated Idaho PR, (4) 0.2 Activated North Florida PR, (5) DAP, (6) 20% DAP, and (7) Control (no P). All other nutrients (including micronutrients) were applied at adequate levels to the respective plants so that P was the only limiting factor on crop growth. The experiments were laid out in a randomized complete block design with four replications for each treatment. All crops were grown to maturity to determine yields.

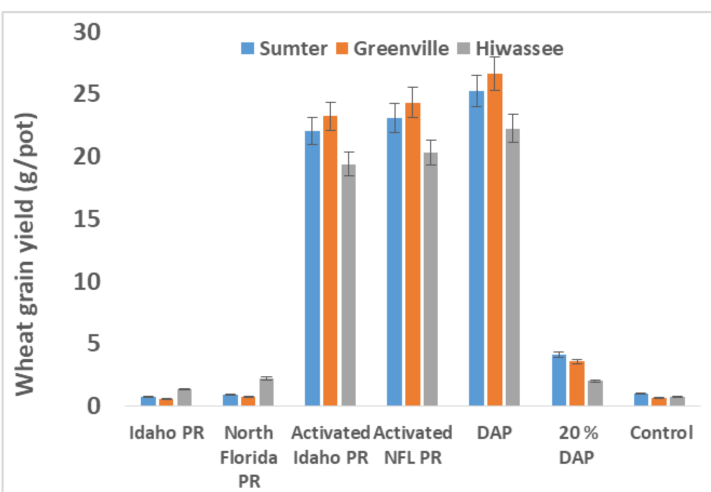

Figure 20. Wheat Grain Yield from Three Soils of Different pH Levels

Irrespective of the soil, crop, and planting season, "activation" of the PRs with a modest quantity of DAP (20%) resulted in significant improvement in the agronomic effectiveness of the PRs in terms of yield (Figures 20, 21 and 22), with an average relative agronomic effectiveness (RAE) value greater than 85% (Table 5). The combined results suggest that the combination of a modest amount of DAP with PR could be a cost-effective means of enhancing P availability in PRs without the soil pH constraining the agronomic effectiveness of PRs. Further studies will evaluate the effectiveness of the "activated" PRs under field conditions.

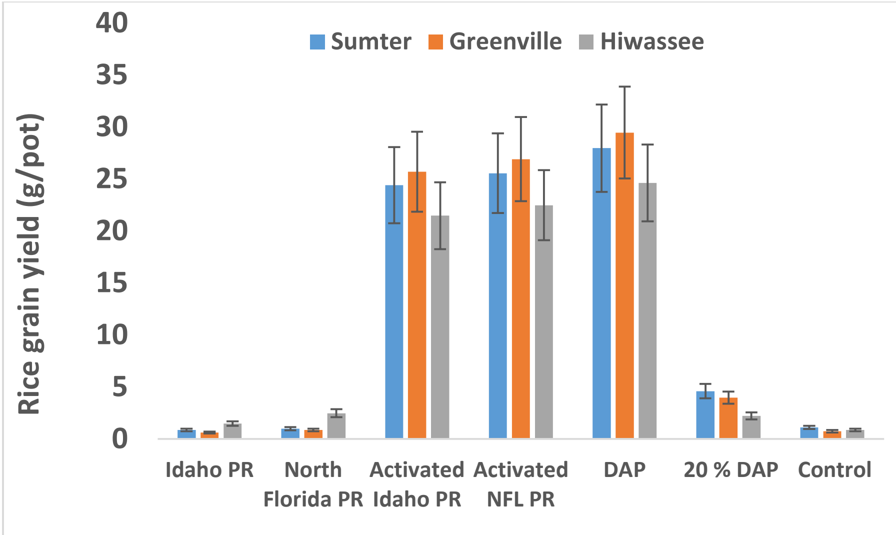

Figure 21. Rice Grain Yield from Three Soils of Different pH Levels

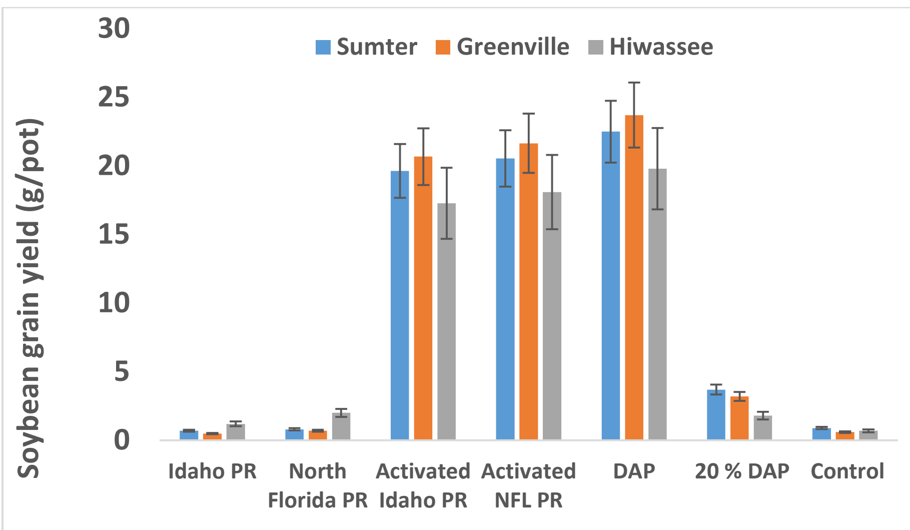

Figure 22. Soybean Grain Yield from Three Soils of Different pH Levels

Table 5. Relative Agronomic Effectiveness of "Activated" PRs and the Untreated PRs

Treatment	Wheat			Rice			Soybean		
	Sumter	Greenville	Hiwassee	Sumter	Greenville	Hiwassee	Sumter	Greenville	Hiwassee
	%								
Idaho PR	1.22	1.26	9.48	1.32	1.36	12.4	1.26	1.34	11.3
North Florida PR	8.13	8.87	22.4	9.21	8.96	25.4	11.7	12.9	24.0
0.2 Activated Idaho PR	86.3	86.8	86.7	88.5	89.2	90.3	85.1	86.5	89.3
0.2 Activated North Florida PR	87.3	87.5	89.1	88.9	89.6	88.7	88.2	88.8	90.6
20% DAP	31.2	31.7	33.4	32.8	31.8	34.0	34.8	37.5	36.7

1.2.4 *Improving Efficiency of Sulfur Fertilizers through Delivery with Urea*

The evaluation of innovative nitrogen and elemental sulfur (ES) fertilizers was conducted in partnership with Shell Thiogro Technologies for Sulphur-Enhanced Fertilizers. Refinements to the manufacturing of the patented Thiogro fertilizers were conducted at the IFDC pilot plant. Laboratory incubation and volatilization and incubation under field conditions demonstrated that the Thiogro products were an efficient sulfur (S) source with slow but adequate release of sulfate-S (SO_4-S) for plant uptake and reduced SO_4-S leaching and ammonia (NH_3-N) volatilization losses. The maize and the residual soybean field trials were conducted in partnership with the University of Tennessee.

Sulfur is a secondary macronutrient required to support and sustain agricultural productivity both in terms of increased yield and improved quality and nutrition. Plants require the same amount of S as they do phosphorus. S deficiency is also increasing because of cleaner air without sulfur dioxide and lack of S impurities in most NPK fertilizers. Plant-available SO_4-S is prone to leaching in coarse-textured soils when applied as sulfate fertilizer. The availability of SO_4-S to plants is also reduced by adsorption of SO_4-S in most clay soils. Application of ES will reduce leaching losses and adsorption; however, the release of SO_4-S to match plant demand may not be adequate. To address these issues, laboratory and field studies were conducted with the following S fertilizers: (1) ammonium sulfate (all SO_4-S); (2) Tiger 90CR (all ES); (3) micronized ES; (4) Thiogro-ES (urea as carrier with 13.8% ES); (5) Thiogro-ESS (urea with 9.1% ES and 4% SO_4-S); and (6) control (no S). All products were applied with urea so that S and N application rates were identical at 30 kilograms (kg) S per hectare (ha) and 87 kg N/ha, except for the control. ES must be oxidized by micro-organisms to SO_4-S before it becomes an effective source of plant nutrition. Applying with urea or urea as a carrier, as used in the Thiogro products, should enhance SO_4-S formation because the acidity generated by ES oxidation will be neutralized by urea hydrolysis.

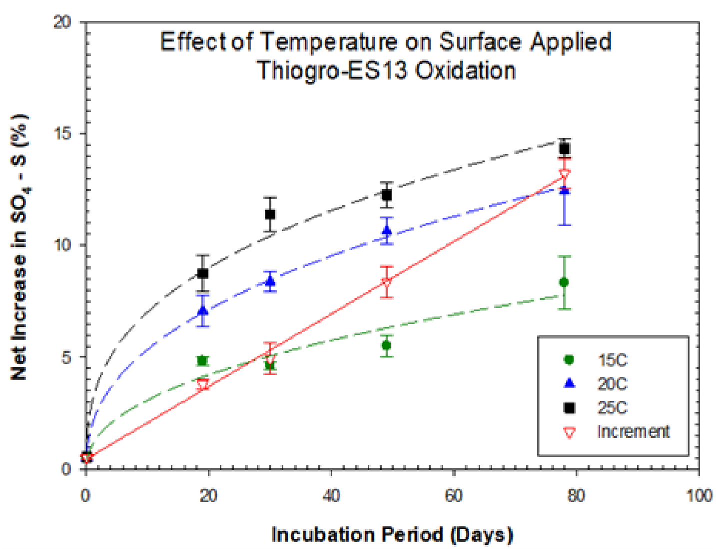

Figure 23. Effect of Temperature on ES Oxidation Under Controlled Laboratory Conditions

Table 6. Recovery of SO_4-S From Different S Fertilizers Under Field Conditions at Cherokee, AL

Products	Sulfate-S Recovery (% S Applied)				
	Incubation Period (Day)				
	0	18	30	42	53
Ammonium Sulfate	61.1 a	54.0 a	68.2 a	69.3 a	17.9 a
Micronized ES	0.2 c	43.7 b	50.3 b	44.7 b	7.7 c
Thiogro-ES 13%	0.6 c	2.6 d	6.6 d	8.1 d	13.7 b
Thiogro-ESS 13%	26.7 b	22.4 c	28.5 c	28.1 c	16.2 ab
Tiger-90CR	-1.6 e	-2.6 e	-3.0 e	-2.9 e	0.1 d

Incubation studies of urea enhanced with ES conducted under laboratory and field conditions without crops showed that:

1. ES oxidation increased with temperature (Figure 23).
2. ES should be surface-applied because banding was totally ineffective in oxidizing ES (data not shown).
3. The type of fertilizer strongly influenced S oxidation (Table 6).

Heavy rainfall after day 42 resulted in excessive SO_4-S leaching from ammonium sulfate as evident from lower SO_4-S in the soil at day 53 (Table 6).

The composition of the fertilizer products in terms of urea, ammonium sulfate, ES, and urease inhibitor had a significant effect on ammonia volatilization loss as determined by trapped ammonia-N. Urea combined with ES (Thiogro-ES13) and ES plus ammonium sulfate (Thiogro-ESS13) resulted in significantly lower ammonia volatilization losses than urea alone (Figure 24).

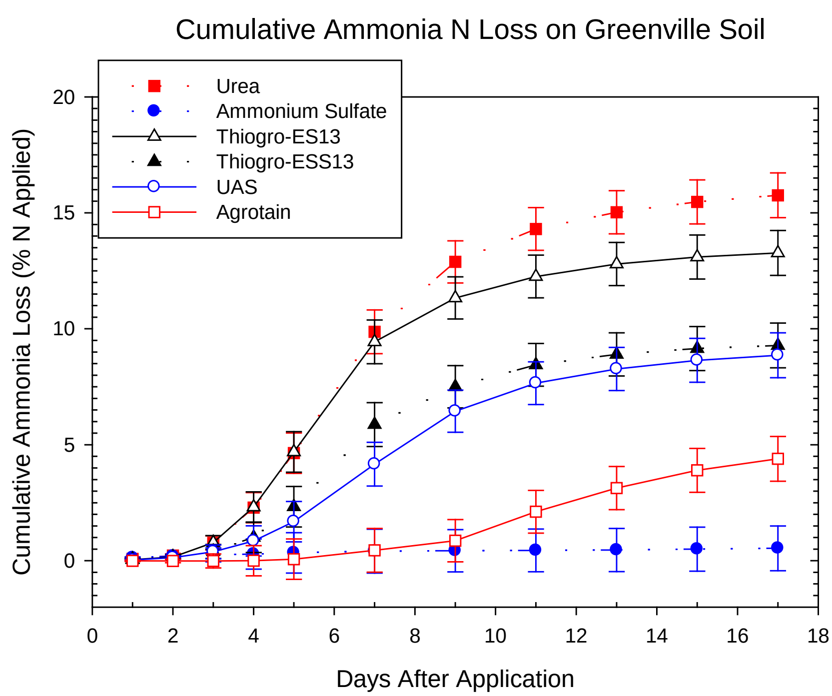

Figure 24. Cumulative NH_3-N Volatilization Loss (% N Applied) from N Fertilizer Products

Both Thiogro-ES and Thiogro-ESS products, particularly under conditions that favor higher ES oxidation (soil type, rainfall, temperature, and crop), can improve N use efficiency of urea with reduced volatilization loss and increase SO_4-S efficiency with a steady supply of SO_4-S that is more available for plant uptake and less prone to SO_4 leaching loss and soil adsorption. As a source for plant N and S, Thiogro-ESS13 appears to be well-suited to provide appropriate and timely N:S requirements of plants and may prove to be more economical than ammonium sulfate. An ongoing field experiment is testing the effect of the above products on maize and soybean in collaboration with the University of Tennessee. Field testing on S-deficient soils in sub-Saharan Africa, Bangladesh, and Myanmar are also being planned.

1.2.5 *Use of Zinc to Improve Yield, Nutrient Uptake, and Grain Nutritional Quality in Sorghum*

Micronutrients can influence crop yield responses in the presence or absence of macronutrients (NPK) globally. However, compared to yields, less is known regarding the effect of micronutrients on macronutrient (NPK) use and grain nutritional quality. Accordingly, a greenhouse study was conducted to evaluate the effect of zinc (Zn) on sorghum productivity and NPK use. Sorghum is an important crop cultivated globally, but it is particularly relevant in SSA agro-ecosystems due to its hardiness. The Zn amendments, 6 milligrams (mg) per kilogram (kg) of soil per plant, were made through soil or foliar pathways at a “low” (100:50:75) or “high” (200:100:150) N:P:K regime using two types of Zn: oxide Zn powder in nano form and Zn sulfate. The data showed that in soil and foliar amendments, grain yield was increased by both Zn types (Figure 25), albeit insignificantly with soil-applied Zn at low NPK levels. Across NPK levels and Zn exposure pathways, both Zn types increased accumulation (shoot + grain) of N (Figure 26) and K. Compared to N and K, both Zn types had a mixed effect on P accumulation, depending on NPK level and Zn exposure pathway, and permitted greater soil P retention. In addition, both Zn types significantly increased grain Zn content, irrespective of exposure pathway (Figure 27). More information on this study is presented in the recently published article in American Chemical Society’s *Journal of Agricultural and Food Chemistry*. Whereas the role of Zn in influencing crop yield is well-documented, we are only now gaining more comprehensive understanding about its role in regulating NPK use efficiency and grain nutritional quality. This study advanced knowledge on the role of Zn in enhancing crop productivity, in influencing NPK use by plants, and in improving the nutritional quality of produce, with potential implications for SSA and other agro-ecological conditions where sorghum is cultivated.

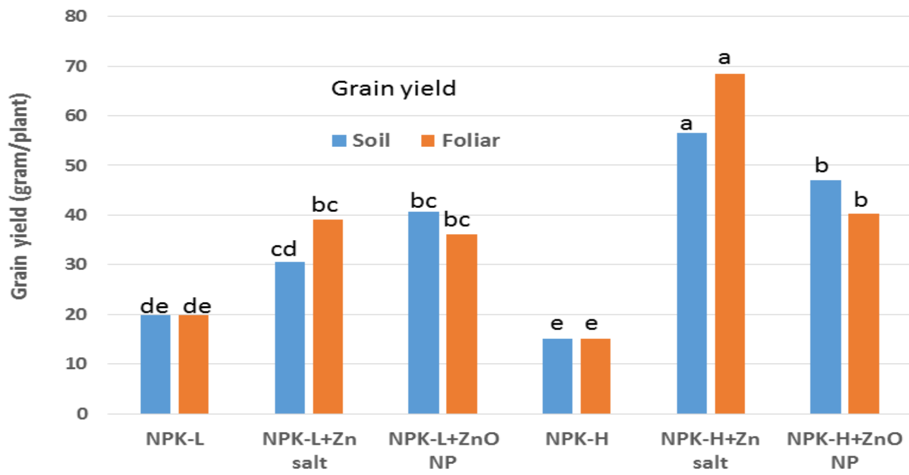

Figure 25. ***Effect of Soil or Foliar Zinc Salt and Nanopowder (NP) Fertilization on Grain Yield of Sorghum Under Low (NPK-L) and High (NPK-H) Nutrient Regimes. Letters on Bars Represent Statistical Differences (P≤0.05) Among Treatments, Differently for Soil or Foliar Application (n=4)***

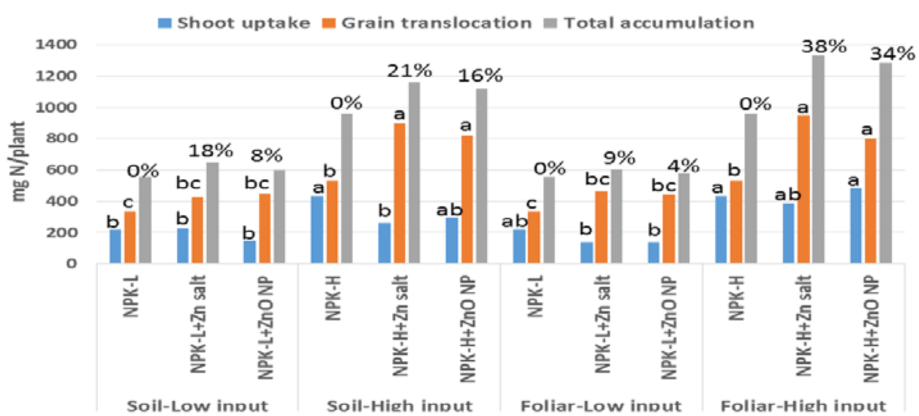

Figure 26. ***Effect of Soil or Foliar Zinc Salt and Nanopowder (NP) Fertilization on Nitrogen Accumulation of Sorghum Under Low (NPK-L) and High (NPK-H) Nutrient Regimes. Letters on Bars Represent Statistical Differences Among Treatments, Differently for Soil or Foliar Application. Percentage Increases in Zn-Induced Nitrogen Accumulation Are Relative to the Controls at 0% (n=3)***

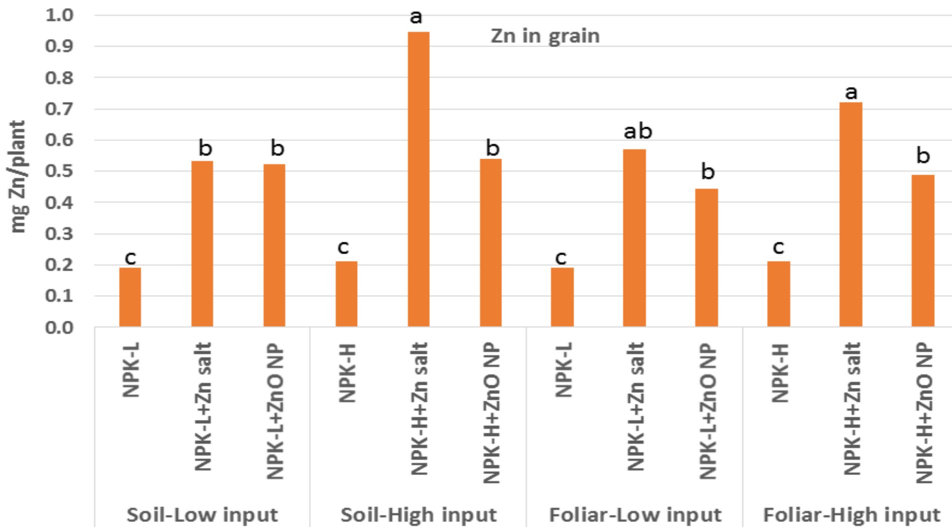

Figure 27. Effect of Soil or Foliar Zinc Salt and Nanopowder (NP) Fertilization on Grain Zinc Content of Sorghum Under Low (NPK-L) and High (NPK-H) Nutrient Regimes. Letters on Bars Represent Statistical Differences Among Treatments, Differently for Soil or Foliar Application (n=3)

Its broader impact is the potential global applicability of Zn to achieve multiple benefits simultaneously, namely, enhancement of crop productivity, enhancement of grain nutritional quality, and improvement of the use efficiency of N. Improved N uptake by crops evoked by Zn has the potential to lower N's contribution to climate change by permitting a reduction in N application rates and hence reduction in the emission of nitrous oxide. Improved Zn content of grains can be useful in addressing human Zn deficiency in parts of the globe where Zn-based malnutrition is of national or regional importance. Thus, in addition to economic gains from increased yield, there are both human and environmental health ramifications from Zn-based agronomic fortification. Due to differences in agro-ecological and production conditions, more studies are recommended under multiple field and crop conditions in order to firmly establish the scope of these broader impacts. In addition to a peer-reviewed publication of these results, two conference papers on the role of fertilizers in addressing climate change were developed, with significant emphasis on the contribution of balanced nutrition (with micronutrients) in that regard.

1.2.6 *Exploring the Effect of Zinc and Manganese on Wheat Productivity and Nutrient Use*

The objective of this ongoing greenhouse study is to evaluate the response of wheat to Zn and manganese (Mn) micronutrient fertilization as part of efforts to further our understanding of how micronutrients influence crops' use of NPK. The micronutrients were applied, respectively, as ZnO nanopowder (NP) or Zn-sulfate, and MnO NP, bulk MnO powder, and Mn-chloride. The rate of Zn used was 6 mg/kg soil, and that of Mn was 10 mg/kg soil. N, P, and K rates were 200, 75, and 200 mg/kg soil, respectively. Detailed methodology with the results will be presented in the next semi-annual report. Data are being generated from measurements of growth rates, harvests of above- and below-ground plant tissues, and grain weight measurements. N, P, K, Zn and Mn levels in the root, shoot, and grain are being determined, together with residual levels of these elements in the soil after plant harvest. Ultimately, by tracking N, P, K, Zn, and Mn from the soil through the root, to shoot, and grain, we hope to establish a mass balance of these nutrients through source to sink. Such outcomes can provide useful information for improving nutrient and fertilizer management in cropping systems. In the case of Zn, information pertinent to the frequency of Zn application will be gained from the residual studies. These findings will be published in appropriate scientific journals.

1.2.7 *Evaluation of Micronutrients to Increase Maize Yield and N Use Efficiency*

IFDC conducted field trials in Mozambique to demonstrate the benefits of balanced fertilizers and climate-smart agriculture practices in rainfed maize production. Mozambique has developed a Strategic Plan for Agricultural Development (PEDSA), which made increasing agricultural productivity of smallholder farmers its top priority. Despite favorable agro-ecological conditions for crop production, agricultural productivity in the country is poor; for example, 0.9 tons per hectare (ha) is the average yield for maize, the nation’s main staple crop. In addition, only 3% of the country’s smallholder farmers use fertilizers.

For the past 30 years, the primary fertilizer recommended in Mozambique for all crops, including maize, has been NPK 12:24:12. Farmer adoption of 12:24:12 fertilizer for maize production has been low. This formulation, however, is used by farmers, mainly for vegetable production. Maize responds poorly to 12:24:12 due to the following reasons:

a. The low N concentration is not sufficient for maize, which is an N-demanding crop.
b. The presence of K is generally unnecessary. Many years of research in Mozambique have shown poor maize response to K, because soils generally have sufficient K for maize production. While K does not reduce maize yields, its presence in the 12:24:12 formula represents an expenditure that could be better applied to other essential nutrients.
c. Soils in Mozambique are commonly deficient in sulfur (S), zinc (Zn) and/or boron (B), which are lacking in 12:24:12.

This research was conducted to: (a) demonstrate the benefits of using balanced fertilizers as an alternative to NPK 12:24:12 and (b) demonstrate climate-smart agricultural (CSA) practices for sustainable intensification of rainfed maize production. We targeted the maize-based farming systems in the plateau and multiple farm types to cover the existing biophysical and economic variation among farms. The Manica Plateau is of particular importance as maize is consumed locally and sold to southern Mozambique, which has a large population and low agricultural potential. Given that smallholder farmers in the plateau cultivate maize with more than one crop (e.g., pumpkin and pigeon pea) in the same field, we hypothesize that a system that simultaneously takes into account maize and more than one other crop is well-suited to smallholder farm conditions in the region. We call this a triple crop system.

A total of 24 on-farm trials were established on farmers’ fields. Fields were selected based on farmers’ willingness to participate as well as to capture as much variability as possible in the site. The following treatments were considered:

1. Maize with NPK 12:24:12.
2. Maize with improved fertilizer (15:31.6:10+5S+0.5Zn+0.2B).
3. Maize-pigeon pea with improved fertilizer (15:31.6:10+5S+0.5Zn+0.2B).
4. Maize-pigeon pea-pumpkin with improved fertilizer (15:31.6:10+5S+0.5Zn+0.2B).

This setup allows farmers to understand: (a) the value of an improved blend by comparing it to NPK 12:24:12; (b) the value of adding pigeon pea into the system in terms of both food security and income; and (c) the value of adding pumpkin to the maize-pigeon pea system. There is an economic component, and there is a food security component. Pumpkin is also a good cover crop and nutritious food. We used the same rate of 100 N kg/ha for basal and topdressing for both the improved blend and NPK 12:24:12.

The results showed that fertilizer formulation/treatment had a significant effect ($p< 0.0613$) on maize grain yield (Table 7). Maize yield was higher with the improved blend treatments than with the traditional blend of NPK 12:24:12 ($p<0.0096$). The performance of the improved blend was not affected by intercropping with pigeon pea alone or the combination of pigeon pea and pumpkin. The largest maize-only yield was 4,520 kg/ha, whereas the largest maize yield with intercropping was 4,305 kg/ha.

Table 7. Effect of Intercropping and Fertilizer Type on Maize Yield

Treatment	Yield (kg/ha)
Improved blend	4,520[a]
Improved blend with maize + pigeon pea intercropped	4,305[ab]
Improved blend with maize + pigeon pea + pumpkin intercropped	4,295[ab]
NPK 12:24.12	3,770[b]

Since the data on land preparation, weeding, and other crop management practices were not recorded, a full economic analysis was not possible. Nevertheless, the revenue resulting from the use of the improved blend and NKP 12:24:12 and the revenue resulting from intercropping was compared. The following ex-factory prices per 50-kg bag was used: U.S. $23 for improved blend, $22.50 for NPK 12:24:12, and $20 for urea. The maize farm-gate price at the harvest (low) was $0.08/kg. The revenue per hectare was $296 for the improved blend and $237 for NPK 12:12:12. Under the current price scenario, the improved blend increased farm revenue by 25%. The benefits from the improved blends may be attributed to the supply of S, Zn and B as well as additional P.

The high crop productivity and economic benefits of improved blends and the lack of difference between maize-only and maize-pigeon pea intercropping systems suggest that intercropping systems were attractive to farmers to address their critical objectives of food security and cash income. The measurement of pigeon pea yields is ongoing and will be used to calculate additional income from intercropping. Farmers did not record the quantities of pumpkin consumed by the household, which could have been included in the economic analysis.

Our results are based on one cropping season. A better conclusion can be drawn once the trials are repeated for one more cropping season. The size of the plots used is too small to quantify other inputs, such as labor for land preparation, weeding, and harvesting, which are important in calculating the return on investment. Using relatively large plots can help solve this weakness; alternatively, secondary data can be used.

1.2.8 *Balanced Crop Nutrition in Burundi*

IFDC, in collaboration with *l'Institut National des Sciences Agronomiques du Burundi* (ISABU), has developed five draft reports on balanced crop nutrition research in Burundi: one each on maize, rice, wheat, potato, and beans. These manuscripts, prepared in French, form the basis for a change in commodity fertilizers to balanced fertilizers targeted to crops, which will become part of Burundi's fertilizer subsidy program. In preparation, IFDC identified one regional blender capable of making the new fertilizers to specification. This blender delivered several thousand fertilizer small packs to Burundi, which were distributed to farmers in a promotion activity.

1.3 Fertilizer Quality Assessments to Support Policy Efforts to Harmonize Fertilizer Regulations in East and Southern Africa

IFDC is conducting a series of fertilizer quality assessments in East and Southern Africa with the purpose of making country fertilizer quality diagnostics and identifying factors, directly associated with fertilizer properties or with characteristics of the distribution chain, which help explain the quality problems and help to find solution for them. Information collected from these studies at the country level will be used by the Common Market for East and Southern Africa (COMESA) to develop and implement a harmonized fertilizer quality regulatory system for the Member States of the economic community.

1.3.1 *Fertilizer Quality Assessment in Kenya*

Kenya was selected to be the starting country in East and Southern Africa because its large fertilizer market and complex distribution chain provide a good opportunity to test and adjust the methodology, which initially was developed for West African countries.

In Kenya, the methodology included two basic sampling steps: the first was a random selection of a sample of fertilizer dealers across the country's fertilizer markets, and the second was the random selection of fertilizer samples and data collection in each dealer's shop selected in step one. The team collected data on fertilizer properties, characteristics of markets and dealers, and conditions of storage. The full methodology is depicted in Figure 28.

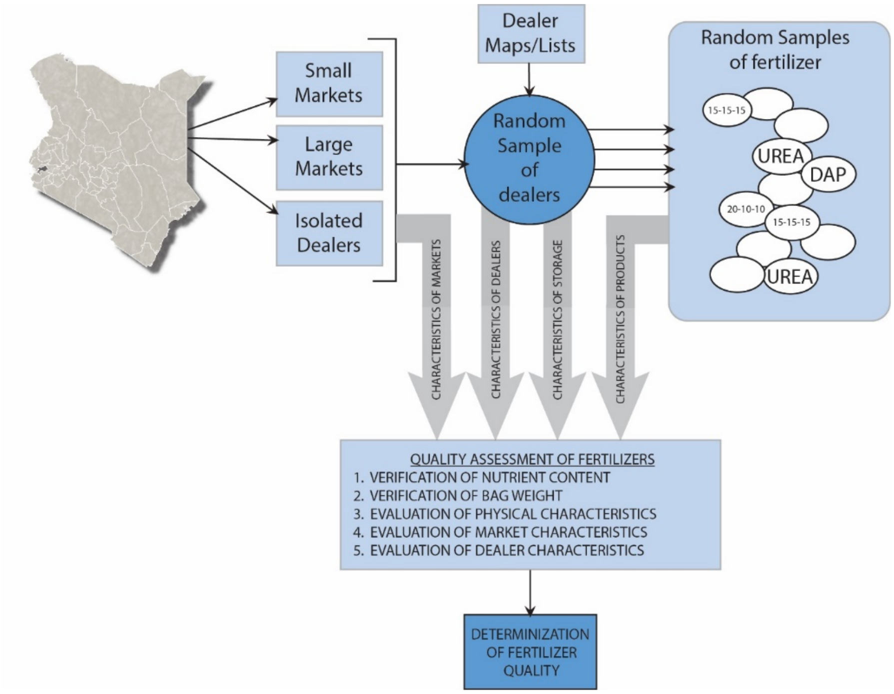

Figure 28. General Methodology for the Quality Assessment of Fertilizers Commercialized in Kenya

The analysis shows that DAP, calcium ammonium nitrate (CAN), urea, NPK 23-23-0, and NPK 17-17-17 represent nearly 90% of the fertilizer samples collected, reflecting the importance of these five products in the Kenyan markets.

The diagnostics on the quality of fertilizers are based on the frequency and severity of "out of compliance" (OOC) for individual nutrients in the fertilizer products. For the sample of urea, the analysis showed no total nitrogen (N) OOC, while for the rest of products, the OOC frequency ranged between 4% in DAP and 31% in NPK 17-17-17; the OOC frequency range for available phosphorus (P_2O_5) was between 12% in DAP and 36% in NPK 17-17-17; and soluble potassium (K_2O) OOC frequency was 63% for the NPK 17-17-17 sample. The severity of the nutrient OOC for the sample of each product is the average of the nutrient content values lower than the shortage tolerance limit (TL) of -1.1%. For N, the OOC severity ranges from 1.5% in DAP to 4.7% in NPK 23-23-0, and for P_2O_5, the range is 3.3% in NPK 17-17-17 to 4.6% in NPK 23-23-0, while K_2O severity was only recorded for NPK 17-17-17 at 1%.

No fillers or foreign substances that suggest adulteration of nutrients were found even for fertilizers products that were rebagged during distribution. No severe degradation of the fertilizers' physical properties were identified; samples did not contain granule fines or dust in high proportions and did not have high moisture content or caking, which could produce uneven distribution of nutrients in the bags. The only plausible explanation remaining for the nutrients being out of compliance in these granulated products is that the nutrient deficiencies originated during manufacture. It is therefore important to improve inspection of fertilizers during importation.

Quality problems were more pronounced for liquid and crystal fertilizers compared to granulated products. The analysis showed that all liquid fertilizers were out of nutrient content compliance for the three macronutrients, with frequencies ranging from 3.6% to 22.5% for total N, 3.8% to 18.8% for P_2O_5, and 2.2% to 19.6% for K_2O shortages. On average, the N, P, and K shortage severities in liquid fertilizers were four times higher than in the granulated fertilizers. All crystal fertilizers were out of compliance for total N and K_2O and presented macronutrient shortages with average severity two times higher than in conventional granulated fertilizers. It is not clear whether liquid and crystal fertilizers receive similar inspection as granular fertilizers from the regulatory agencies. Clearly, this is an area that requires closer inspection to prevent poor quality products from reaching farmers.

The maximum cadmium content found in fertilizers containing P_2O_5 traded in Kenya was 2.9 parts per million (ppm), which is well below the maximum allowances of 30 ppm recommended by Kenyan and international standards.

The frequency of underweight bags was found to increase with re-bagging of fertilizers along the distribution chain. Weight shortages of at least 1% of that specified on the label were found in 18% of the original 50-kg bags, in 26% of the 25-kg bags, and in 36% of the 10-kg bags (Figure 29).

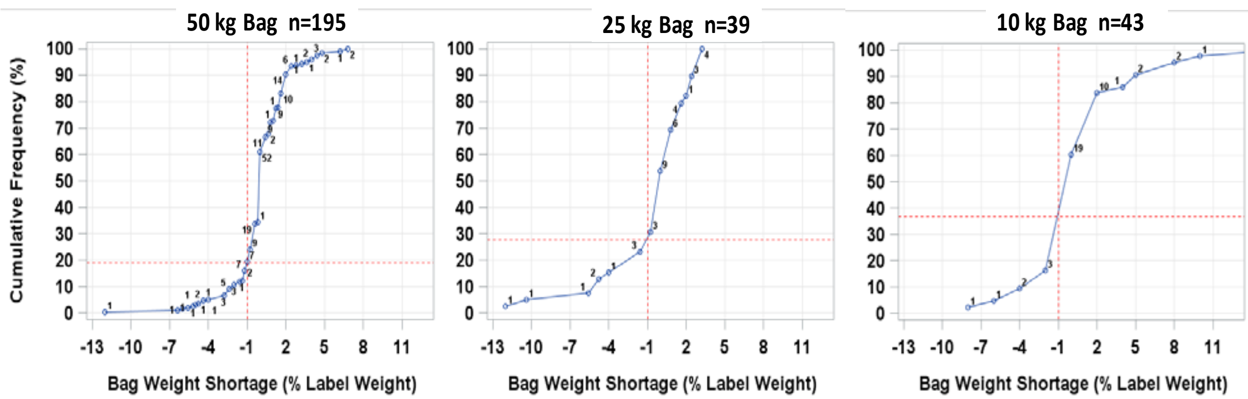

Figure 29. Cumulative Frequency Distribution Functions for the Weight Verification of the Most Common Bag Sizes. The Vertical Dotted Line Represents the Out-of-Compliance Boundary, and Horizontal Dotted Line Represents the Frequency for the Boundary

Low temperatures and low relative humidity are needed to preserve fertilizer quality during storage, but 50% of the warehouses or storage areas in retailers' shops do not reduce temperature relative to the temperature outside the building; similarly, 37% of the storage facilities do not reduce the relative humidity with respect to the relative humidity outside. Hot and wet storage conditions result from absent or insufficient ventilation and poor air circulation through the storage area because of limited or no use of pallets and because no space is left between bag stacks and walls and between stacks and the roof.

The majority of granulated fertilizers are bagged in impermeable bags that preserve the products from contact with water and from absorbing moisture from the environment. However, high moisture content was found in 7% of the DAP samples, 10% of the CAN samples, and 16% of the 23-23-0 samples as a result of non-impermeable bags used, torn bags, or loose bag seams in addition to the hot and moist conditions of many storage facilities.

Degradation of granular integrity of fertilizers is not a major concern in Kenya; the most widely used fertilizers had more than 90% of the material in granule sizes between 1.0 millimeter (mm) and 4.0 mm. Still, a maximum of 15% fines (granules between 1.0 and 2.8 mm) was found in urea, DAP, and 23-23-0. The percentage of fines found in fertilizers increased with distance from the port of entrance as a result of transportation and the manual and individual handling of fertilizer bags.

Market and fertilizer dealer characteristics may have a significant effect on the quality of fertilizers. Data from Kenya indicated that fertilizers sold in rural markets are less likely to comply with the nutrient content specified on the label than fertilizers sold in urban markets. Similarly, compliance with the nutrient content was lower in fertilizers sold in shops with only small-scale farmer customers than in shops with customers of all types of farmers and fertilizer retailers.

These results have implications for fertilizer policy, regulations, and institutional structure. First, it is important that a credible system be established to ensure more stringent pre-export verification of conformity (PVoC) carried out by reputable and internationally accredited companies. Part of the PVoC process is to assure conformity with the standards of the importing country. In some cases, this should be followed by additional inspections at the destination port, especially for products that have a history of poor quality or whose origins are suspect. Routine targeted inspections along the domestic value chain, particularly at retail, will help maintain quality; the inspections especially should capture re-bagged products, which are more likely to present nutrient and weight shortages. In addition, training of distributors and agro-dealers on best practices in handling fertilizers and maintaining appropriate storage facilities will provide further support. The capacities of agencies in charge of quality regulations, including laboratory equipment and human or technical expertise, need to be improved. Finally, it is crucial to have a mechanism in place for farmers and other stakeholders to share their complaints on quality to relevant authorities/agencies for action. Therefore, updating the current quality regulatory framework, with clear roles for relevant agencies, in addition to harmonizing regulations across countries will support the above recommendations and improve access to quality fertilizers.

1.3.2 *Fertilizer Quality Assessment in Fertilizer Markets of Uganda*

The same two-step sampling methodology used in Kenya was employed to assess fertilizer quality in Uganda. Fertilizer samples were evaluated for nutrient content and physical properties, and data on characteristics of markets and dealers and conditions of storage were collected.

Figure 30 shows the most commonly traded fertilizers in the markets of Uganda and their relative market share. Fertilizers that were collected with very low frequencies (e.g., one sample) are not shown in the figure. Note that urea may be underrepresented because the sampling was purposely adjusted to produce a smaller sample, because it is uncommon to find nitrogen content out of compliance for urea. Nearly 80% of the samples collected were in the granulated form, while the liquid fertilizers and the crystallized fertilizers accounted for 12% and 8%, respectively.

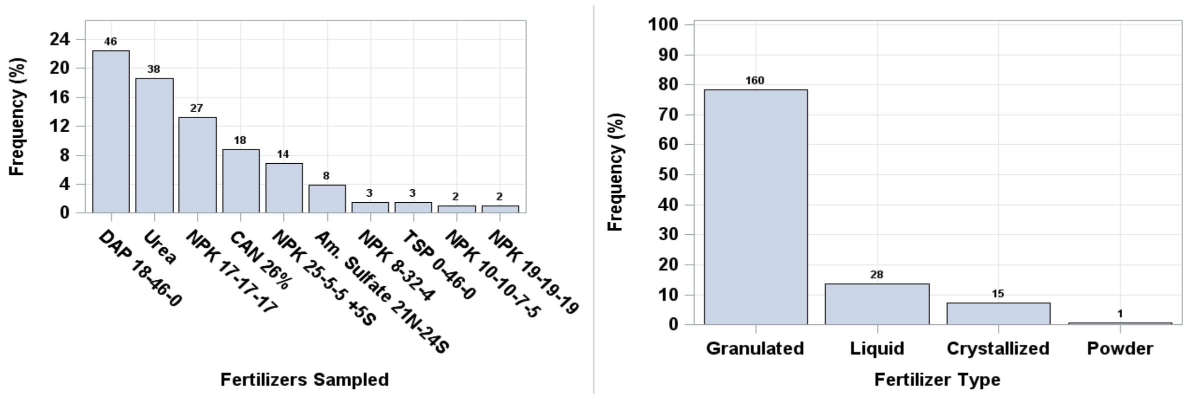

Figure 30. Frequency Distributions of Fertilizer Samples and Physical Presentations of Fertilizer Collected in Ugandan Markets

Nutrient content shortages in fertilizers were quantified in terms of frequency (how often they occur) and severity (how large they are). The frequency was estimated from the cumulative frequency distribution functions for each macronutrient for the three main NPK products, and the severity was estimated as the mean of the values OOC that are found to the left of the TL of -1.1%, which is the international standard for macronutrient content assessment.

A summary of the macronutrient shortages for the main fertilizers in Uganda is shown in Table 8. No total N shortages were identified in ammonium sulfate or DAP. Seven percent of the urea samples and 40% of the CAN samples were OOC for total N content with a severity of -1.25±0.5% and 1.01±0.5, respectively. The TL for fertilizers that provide only one macronutrient, such as urea, ammonium sulfate, or CAN, is -0.5%. The total N shortage OOC severities in urea and CAN are small and can be attributed mainly to the random variability of the chemical analysis around the rigorous TL of -0.5%. NPK 17-17-17 and NPK 25-5-5+5S presented total N shortage OOC with frequencies of 13% and 37%, respectively, and shortage OOC severities of -1.7±0.9% and -3.9±1.5%, respectively. The P_2O_5 shortages OOC in DAP, NPK 17-17-17, and NPK 25-5-5+5S occurred with frequencies of 5%, 10%, and 8%, respectively, and with OOC severities of -2.5±1.6%, -5.5±6.8%, and -2.3±1.9%, respectively. There were not K_2O shortages OOC in NPK 25-5-5+5S, and the K_2O shortages OOC in NPK 17-17-17 took place with a frequency of 10% and a severity of -5.5±5.5%. Total N shortages in NPK 25-5-5+5S, P_2O_5 shortages in DAP and the two main NPK products, and K_2O shortages in NPK 17-17-17 are of concern and require solutions.

Table 8. Frequency and Severity of Macronutrient Content for the Most Commonly Traded Fertilizers in Uganda

Fertilizer	N Samples	Total N Frequency (%)	Total N Severity (%)	P_2O_5 Frequency (%)	P_2O_5 Severity (%)	K_2O Frequency (%)	K_2O Severity (%)
Urea	38	7	-1.25±0.5	.	.	.	.
Amm Sulfate 21N, 24S	8	0	0	.	.	.	.
CAN 26N	18	40	-1.01±0.5	.	.	.	.
DAP 18-46-0	46	0	0	5	-2.5±1.6	.	.
NPK 17-17-17	27	13	-1.7±0.9	10	-5.5±6.8	10	-5.5±5.5
NPK 25-5-5 + 5S	14	37	-3.9±1.5	8	-2.3±1.9	0	0

No fillers or foreign substances that suggest adulteration by dilution of nutrients were found, not even for the few re-bagged fertilizers that were sampled. No severe degradation of the fertilizers' physical properties that could cause uneven distribution of nutrients inside the fertilizer bags were identified (Figure 31); fertilizers contained granule fines or dust in very low proportions relative to the regular size granules. Caking and high moisture contents that have the potential to affect nutrient distribution inside the bags were found with low frequencies (Figure 32). The most plausible explanation for the nutrients being out of compliance in the granulated products is that the nutrient deficiencies originated during the manufacture. The effective inspection of imported products in points of entrance to the country is necessary.

The TL for weight shortages in international regulatory systems is 1% of the weight reported in the fertilizer label. In Uganda, the 50-kg bags are dominant, and the maximum weight shortage allowed is 0.5 kg. Ten percent of the bags weighed during the survey in Ugandan fertilizer markets were OOC for weight shortages.

Low temperatures and low relative humidity are needed to maintain fertilizer quality during storage. Most of the storage areas used by retailers (53% of the Ugandan fertilizer dealers) have no means to reduce temperature and relative humidity with respect to the outside conditions during the afternoon hours. Still, the caking, moisture content of fertilizers, and granule degradation are at low levels of frequency and severity. This is explained by the dominant good quality of the bags used, as 90% of the bags have an inner impermeable layer and a strong woven exterior that allows the bag to withstand the rough treatment associated with the manual and individual handling of the fertilizer bags. The loose bag seam in 42% of the bags examined helps to explain the medium and low caking and the high fertilizer moisture content shown in Figure 32.

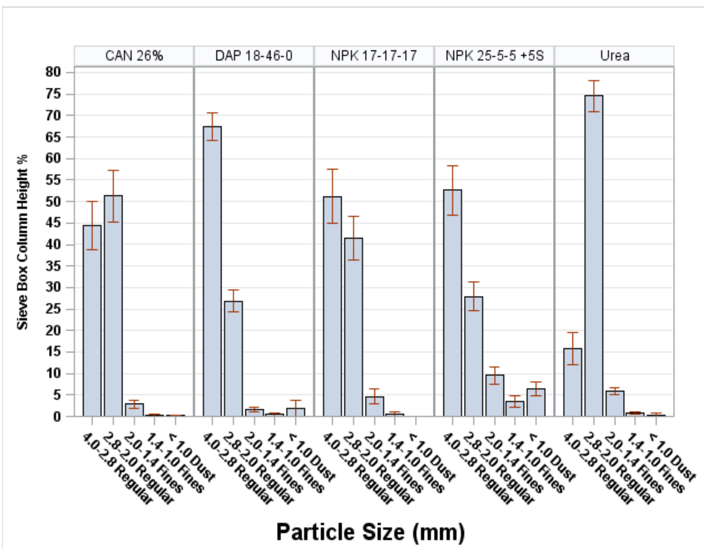

Figure 31. Frequency Distribution of Granule Degradation for the Most Commonly Traded Fertilizers in Uganda

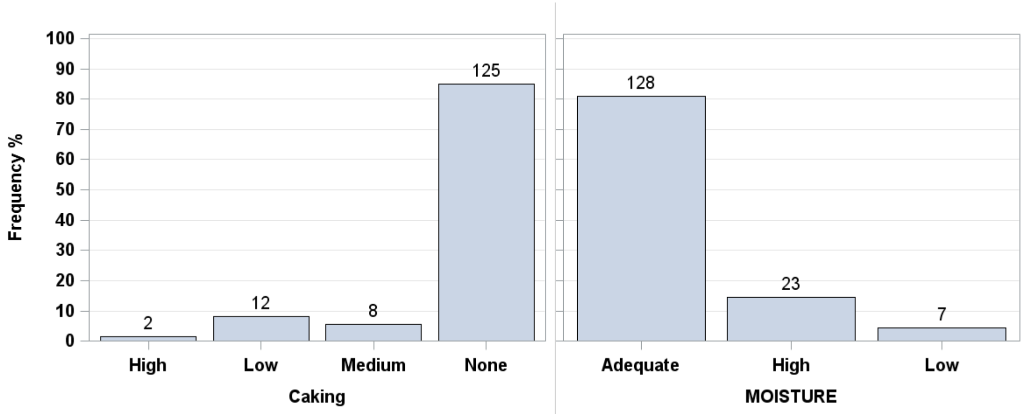

Figure 32. Frequency Distributions for Caking and Moisture Content of Fertilizers Traded in Uganda

Like the assessment results in Kenya, these results have implications for fertilizer policy, regulations, and institutional structure. It is important to establish a system that ensures PVoC is carried out by reputable and internationally accredited companies. This should be followed by confirmatory inspections at the destination port, especially for products that have a history of poor quality or whose origins are suspect. Routine targeted inspections along the domestic value chain, particularly at retail and particularly for re-bagged products, will help maintain quality. In addition, training of distributors and agro-dealers on best practices in fertilizer handling and storage will provide further support. The capacities of agencies in charge of quality regulations need to be improved. Finally, it is crucial to have a mechanism in place for farmers and other stakeholders to share their complaints on quality to relevant authorities/agencies for action. Therefore, updating the current quality regulatory framework in addition to harmonizing regulations across countries, will support the above recommendations and increase access to quality fertilizers.

1.4 Development of the IFDC Institutional Database

The development of an institutional database is a cross-cutting activity with Workstream 2. The initial plan was to develop an independent institutional database for IFDC. However, with staffing issues and the need to move quickly, the DevResults program was acquired for the Monitoring, Evaluation, Learning, and Sharing (MELS) component. Given these changes, IFDC, within the framework of a university partnership, opted to collaborate with the University of the Florida and the AgMIP team to modify and expand the existing AgMIP database as a common database of all the agronomic and socioeconomic data for AgMIP and IFDC.

The types of data produced by IFDC to be stored in the database include:

- Experiments related to soil fertility, crop nutrition, evaluation of fertilizer products, and environmental aspects of crop fertilization. Data produced by these experiments are representative of one or more of the following:
    - Soil characterization
    - Fertilizer product characterization
    - Description of treatments, management practices, and other components of the treatments
    - Experimental results
    - Crop simulation results

- Socioeconomic data from projects of a different nature, such as financial studies of crop production by smallholder farmers, surveys to assess level of technology adoption or upscaling of technology use, evaluations of socioeconomic impact of technology adoption by farmers, studies of agricultural input and output markets, economic policy studies, etc.

From October 2016 to September 2017, the diagrams of the database activities were developed (Figure 33), the structure of the database was built (Figure 34), and an online platform for interactions between database, database users, and database administrators was designed.

The testing and operation of the database focusing on the common needs, namely agronomic and socio-economic data, of the global AgMIP and IFDC will continue in FY 2018 as an enhancement of IFDC's capabilities through partnership with the University of Florida's AgMIP team.

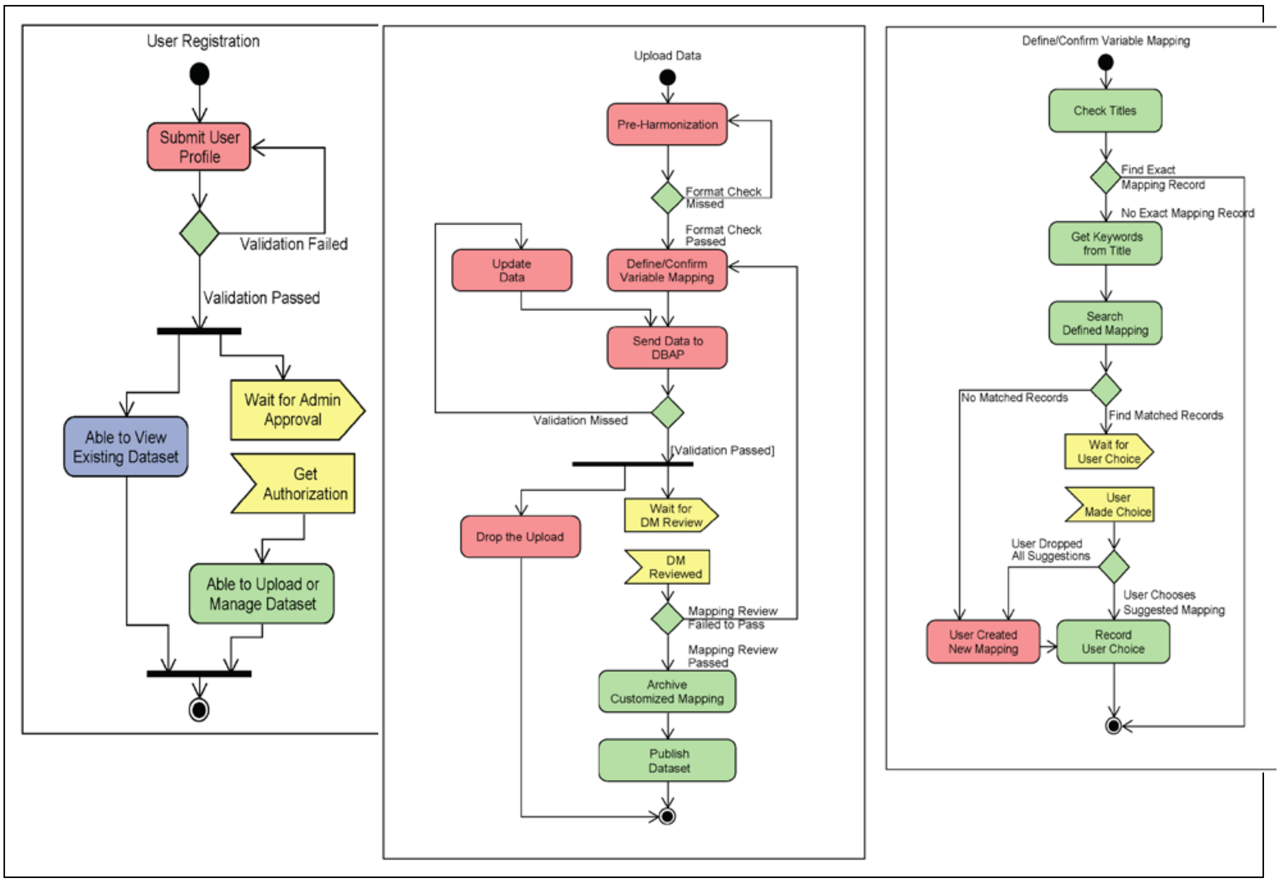

Figure 33. Flow Chart Activities for User Registration, Uploading and Mapping of Variables

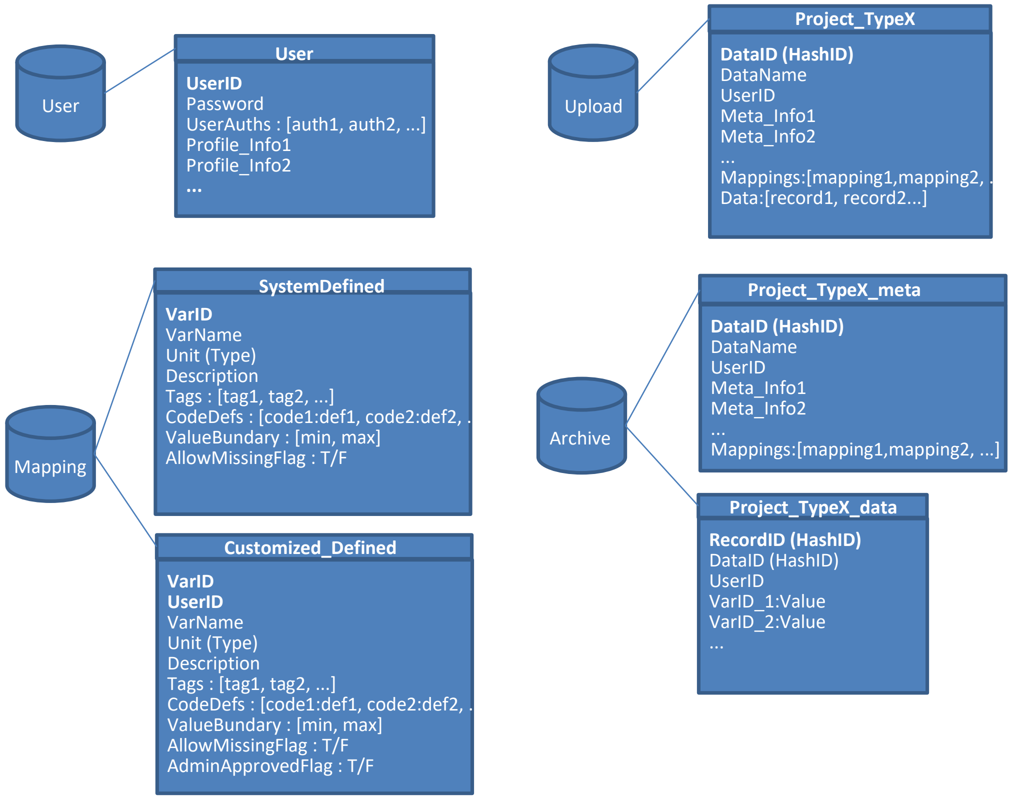

Figure 34. Database Description and Diagram

1.5 Lessons Learned from Evaluation of Soil Test Kits

Recently, IFDC evaluated three soil test kits (Table 9) against standard wet-chemistry laboratory procedure on a wide range of soils. The report on "Evaluation of Portable Soil Test Kits Promoted for Use by Smallholder Farmers to Make Site-Specific Fertilization Decisions" was submitted to USAID in May 2017. The major lessons learned from the study are presented.

Forty-eight well-characterized soils covering a wide range of soil properties (texture, soil pH, organic matter content, cation exchange capacity, and nutrient status) were used to evaluate the soil test kits. The performance of the kits is summarized in Table 9, with all of the kits having some serious flaws in terms of their N, P, and K analyses with respect to standard laboratory procedure. The initial soil N, P, and K analyses from the kits did not correlate well with plant response, except for plant K uptake with SoilDoc K content. In terms of the ease of use, as expected the Kasetsart soil test kit is very easy to use and could be conveniently used by most smallholder farmers for analysis. On the other hand, the SoilDoc kit is complicated to use and the user manual is not easy to follow; therefore, the kit must be handled by personnel trained in soil analysis.

The use of the low-cost kits by farmers who have no access to soil testing would, at least, help identify limiting macronutrients and, based on soil pH, potential micronutrient limitation within a field. The kits also may offer improvements over blanket recommendations. For example, blanket recommendations often include K, but the levels of K recommended are often excessive. Best case scenarios for soil test kits appear to be site-specific applications, particularly, on soils that do not have secondary- or micro- nutrient limitations. The soil test kits then must be calibrated and validated for N, P, and K response under field conditions. While the Kasetsart soil test kit did not perform well based on our test, after site-specific calibration, farmers using the kit in Thailand are earning higher profits from rice, maize, and cassava than they were using the blanket recommendations.

Considering the recent advances in scanner/spectral analytical techniques for soil and particularly for plant analyses, the use of a single soil test kit on a wide range of soils and cropping systems is questionable.

Table 9. Soil Test Kit Specifications

Soil Properties	SoilDoc	Hach	Kasetsart	Regression Coefficient (r)
Capabilities	NO_3-N, Ca, Mg, P, K, acidity, sulfate, EC, and active carbon	Inorganic N (NO_3 + NH_4), P, K, Ca, Mg, Na, acidity, salinity, gypsum and lime requirement, sulfate, EC, and active carbon	pH, NO_3, NH_4, P, K	-
Retail Price	$4,000	$1,300	$150	-

Soil Analyses				
pH	Excellent	Excellent	Excellent	0.79-0.83
Nitrate-N	Excellent (0.9)	Very Good (0.75)	Good (0.65)	(0.65-0.9)
Ammonium-N	-	-	Very Good (0.75)	0.75
Available P	Poor	Very Good (0.75)	Moderate (0.3)	0.01-0.75
Available K	Very Good (0.8)	Moderate (0.47)	Poor (0.01)	0.01-0.81

Plant Response with Initial Soil N, P, and K				
Dry Matter	Poor	Poor	Poor	
K Uptake	Very Good	Poor	Poor	
P Uptake	Poor	Poor	Poor	
N Uptake	Poor	Poor	Poor	
	 **SoilDoc**	 **Hach SW-1**	 **Kasetsart**	

1.6 Sustainable Soil Fertility Prioritization in Sub-Saharan Africa

Following second quarter discussions with USAID, IFDC provided a sub-award to Kansas State University (KSU) to conduct activities related to "Sustainable Soil Fertility Prioritization in Sub-Saharan Africa." KSU serves as the Feed the Future Innovation Lab for Collaborative Research on Sustainable Intensification. Under the sub-award, KSU led the effort to prioritize “critical” soil fertility issues in the SSA, focused around identifying key barriers and key “sustainable” solutions to overcome the barriers in four focus regions: West Africa (Burkina Faso, Ghana, Mali, Niger, Senegal); East Africa (Kenya and Tanzania); Great Lakes Area (Burundi, Malawi, Rwanda, Uganda); and Ethiopia. While distinct priorities/solutions are expected for each region, it is anticipated that one or more unified priorities will be identified across large geographical regions.

The initial scoping survey was conducted in June/July among a diverse number of stakeholders including public and private representatives and key organizations (e.g., IARCs, NARES, IFDC) from each region. Approximately 50% of the forwarded surveys were completed and returned. The regional highlights of the survey were discussed at the Dakar Summit (August 14-15, 2017). According to the survey highlights, the five most limiting factors across all regions were:

- Nitrogen deficiency
- Low soil organic matter content
- Phosphorus deficiency
- Acidity and
- Micronutrients

The clear consensus of the Summit was that fertilizer use in an integrated soil fertility management scenario was the common denominator to overcoming soil fertility issues in the SSA. Once the final report is completed it is expected to help USAID prioritize need for partnerships with on-going activities and/or to invest in new activities. IFDC looks forward to providing its expertise on soil fertility issues and implement new activities as needed.

2. Workstream 2 – Supporting Policy Reforms and Market Development

IFDC's work under policy and markets falls under three broad categories: policy reforms, impact assessments, and economic studies. IFDC's Market's Economics, and Policy team conducts evidenced-based policy analysis relevant for shaping the necessary changes in policy and market developments that will have significant impact on farmers' technology choices. The ultimate goal is to strengthen the capacity of value chain stakeholders to ensure farm households have better access to inputs. Activities conducted during the reporting period focused on documenting policy reform processes, particularly in Ghana, Uganda, and Tanzania; conducting impact assessments on fertilizer quality and agro-dealer programs; conducting fertilizer cost build-up analyses in Ghana and Kenya; and identifying indicators to denote fertilizer access across SSA countries. Details are provided below.

2.1 Policy Reform Process

IFDC has been involved in activities to support policymakers and other fertilizer sector stakeholders in SSA countries, by providing information and advice on options to improve the agriculture sector by means of developing agro-input markets. During the period under review, IFDC worked on building collaborations with partners, implementing fertilizer sector assessments and documenting experiences and lessons learned as a means to provide information and advice. Activities conducted under Workstream 2 are described below.

2.1.1 *Documenting Policy Reforms for Fertilizer Market Development*

A. Transitioning from Government Control to Larger Private Sector Participation in the Ghanaian Fertilizer Market

In efforts to promote economic growth and reduce poverty by increasing agricultural productivity and production, the Ministry of Food and Agriculture (MoFA) of Ghana instituted a Fertilizer Policy with the vision of developing a competitive fertilizer sector, capable of supplying adequate quantities of quality and affordable fertilizer, especially to smallholder farmers.

Agronomic experimental research findings suggest that increasing fertilizer consumption and use is necessary to address low productivity and declining soil fertility. Therefore, as an integral part of the fertilizer policy, MoFA also instituted the Fertilizer Subsidy Program (FSP) as a mechanism to provide incentives for smallholder farmers to start using or increase the use of fertilizer in their production activities. In addition, recognizing that private initiatives are key to drive overall economic and agriculture sector growth, the Government of Ghana (GoG) approved the Plants and Fertilizer Act (Act 803). This Act calls for the private sector to take a larger role in procurement, importation, and distribution of all agro-inputs, including subsidized fertilizer, and relegates the MoFA to the role of facilitator in support of agricultural sector and agro-input markets development. Since the introduction of the FSP and increased participation of the private sector, the total quantity of fertilizer supplied and consumed in Ghana has increased (Table 10). It is in this context that this brief provides a short analysis of the effect of the MoFA fertilizer policy with respect to the FSP and Act 803, on fertilizer use increase and agricultural productivity with a focus on the FSP target crops.

Table 10. Estimated Quantities and Cost of Subsidized Fertilizer in Ghana, 2008-2015

	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16
Consumption (mt)	125,567	261,057	324,399	129,668	372,680	288,874	143,451	289,822
Subsidized (mt)	43,176	72,795	91,244	176,278	173,755	166,807	0	90,000
Cost (U.S. $ x 1,000)	14,356	23,958	19,301	41,834	57,022	54,098	0	10,135

Source: FAO, CountryStat, MoFA

Despite the increase in fertilizer consumption, analyzed data suggest that not much progress has been achieved in terms of increasing application rates and overall cereal yield. Recorded increases in output are attributed to cropland expansion and, to a minor extent, to increases in yield (Table 11). Although productivity has increased in some of the FSP target crops, overall productivity among those crops has been marginal and achieved at a substantial cost that perhaps does not justify the GoG commitment to the FSP. Moreover, the opportunity cost of devoting public funds to subsidizing fertilizer, instead of investing in other rural and agricultural development projects, can be substantial.

Table 11. Percentage Change in Cereal Production, Planted Area, and Yields (2008-2015)

	2008-2015 Percentage Changes in:		
	Production	Planted Area	Ave Yield
Maize	15.1%	4.0%	10.7%
Millet	-19.1%	-11.0%	-9.1%
Rice	112.3%	75.2%	21.2%
Sorghum	-20.5%	-17.4%	-3.8%

Source: MoFA (2015).

Note: Average yield was estimated by dividing total production by planted area.

Perhaps the key message drawn from the analysis is that the FSP, on its own and with the participation of the private sector, is necessary but not sufficient for a sustainable increase in fertilizer use and intensity as a means to improve smallholder crop productivity in Ghana. Overall, a strategy congruent with Ghana's Medium-Term Agriculture Sector Investment Plan (METASIP) should seek to transform the agriculture sector by training farmers on sustainable land use and the proper use of productivity-enhancing inputs; but, more importantly, the strategy must focus on increasing public investment in infrastructure to incentivize private investment to expand businesses into rural areas to provide services and supply productivity-enhancing technology closer and at lower costs to farmers. These investments will also help reduce costs related to long-distance travel, allowing farmers better access to agro-dealers, to extension services to seek advice, and more importantly, to output markets to increase farmers' income. In addition, government policies should aim to increase farmers' access to credit by supporting credit programs for the use of fertilizer and other agro-inputs, and to address the macroeconomic imbalance which is greatly impacting high interest rates and reducing access to credit by smallholder farmers.

B. Increasing Fertilizer Consumption through Government Programs, Leading to Agriculture and Private Fertilizer Sectors Growth in Uganda

In Uganda, recent statistics show that agriculture is characterized by low productivity growth relative to the government development plan's target growth. Low productivity is attributed to, among other factors, soil degradation due to poor soil management resulting in nutrient depletion (Table 12), and Uganda has one of the highest rates of nutrient depletion in SSA. To address this situation, IFDC provided technical assistance to the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) and to the World Bank by envisioning a strategy and plan under The National Fertilizer Policy (NFP). The aims were for a program to incentivize the use of fertilizer that involves the private sector in the financing, procurement, and distribution of fertilizer to retail; to facilitate better market development; and to bring about more effective delivery of fertilizer and the incentivizing program.

Table 12. Annual Estimates for Nutrient Depletion in Uganda

Nutrient	Average Balance (kg/ha)
N	-38.1
P_2O_5	-16.5
K_2O	-32.2
Total[1]	**-86.8**

Source: MAAIF, 2006.

The NFP supports the chief challenges facing the agriculture sector, supports CAADP, and is in compliance with the *Abuja Declaration on Fertilizer*, ratified by the *Malabo Declaration*. In addition, the NFP addresses issues related to fertilizer adulteration and the emergence of new organic fertilizers and their potential effect on the environment and on crop production. Furthermore, the NFP is the foundation for a complementary policy that makes farmer training a priority, which includes fertilizer use demonstrations and the utilization of locally available resources as fertilizer.

Given fertilizer's importance in increasing crop productivity and production, public support has been given through the Fertilizer Market Stabilization Program (FMSP), put in place to operationalize the NFP and make fertilizer available to resource-poor farmers at affordable prices by means of market-friendly mechanisms. This approach makes it imperative to devise targeted purchasing power support (PPS) instruments for farmers. Consequently, in the context of the FMSP, the Government of Uganda (GoU) requested support to envision and propose a fertilizer market development strategy and an implementation plan, taking into consideration a farmer PPS program.

Based on IFDC's lessons learned, a market-friendly PPS program was proposed. The proposed program rationale is based on the principle that PPS should be directly targeted to beneficiary farmers and to the product itself (at the demand end of the market) rather than at the product source (the supply side of the market). The strategy does not ignore the supply side of the market; rather, it calls for indirect support by creating a favorable fertilizer business environment and market development and making the PPS program more effective. The chief idea behind this strategy, congruent with the NAP, is that the government should not interfere with the normal conduct of fertilizer supply but should influence better private sector performance.

[1] According to recent estimates, total nutrient losses have slightly improved in Uganda, estimated at 80 kg/ha/year (http://allafrica.com/stories/201706060375.html). The most limiting nutrients in Ugandan soils are nitrogen and phosphorus.

Under the proposed strategy, the roles of the government and private sector are well-defined. Fertilizer procurement, importation, transportation, and distribution must be carried out by the private sector and the government's role should be to create a business conducive policy and regulatory environment. As such, the market-friendly purchasing power support strategy must have the following three key components:

1. A targeting instrument and mechanism to deliver purchasing power support to farmers. To avoid displacement of commercial purchases of fertilizer, the purchasing power support should focus primarily on farmers who are not using the optimal amount of fertilizer or not using it at all but can afford it and are willing to pay a portion of the fertilizer price in advance. The hypothesis behind this approach of partial advanced payment is that it can be used as a proxy of demand to send positive signals to suppliers on the actual amount of fertilizer needs.
2. A time-limited PPS, which implies an exit plan by gradually reducing the rate of PPS over a pre-determined period of time, taking into consideration continuous farmer profitability before completely phasing out the support, as illustrated in Figure 35. For an effective program exit plan, the support rate reduction is achieved in coordination and simultaneous implementation of a program of linking farmers' output to markets. The idea is that sufficient time should be allowed for farmers to adapt to using fertilizer in their productive activities and experience economic gains and for suppliers to adapt to increasing demand.

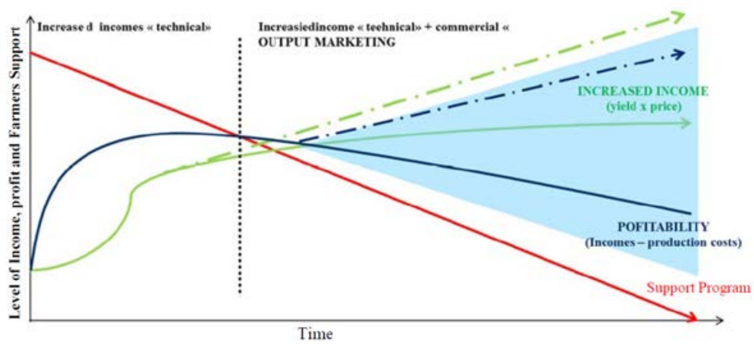

Figure 35. Illustration of the Purchasing Power Support Program Exit Strategy Rationale

3. The implementation of purchasing power support effectiveness-enhancing policies, programs, and investments that address key market failures that are restricting the supply, availability, and accessibility of fertilizer by farmers, such as access to credit, research and extension, provision of technical assistance and trainings, improvements in productive infrastructure for better input and output market access, and a conducive legal and regulatory framework for private sector and market development.

2.1.2 *Technical Support for Fertilizer Subsidy Reforms and Market Development in Tanzania*

Under a Memorandum of Understanding (MOU) with the Monitoring and Analyzing Food and Agricultural Policies (MAFAP) program of the Food and Agriculture Organization of the United Nations (FAO), IFDC provided technical assistance to the Ministry of Agriculture, Livestock and Fisheries (MALF) of Tanzania. MALF planned to reduce the cost of fertilizer procurement and importation while continuing to supply fertilizer needs to Tanzanian farmers at reasonable prices and to help reduce or eliminate the government fiscal burden from the current subsidy program. IFDC technical assistance was provided in two stages: a) through a workshop to launch the MALF initiative and discuss the plans and b) through broad consultations among stakeholders on the government plans.

The workshop was attended by 25 representatives of key public and private fertilizer sector stakeholders in Tanzania, including the MALF, FAO-MAFAP, IFDC, private importers and distributors, and farmers' organizations, among others. The main points addressed during the workshop were:

- The intention of MALF to institutionalize a process for consolidating the country's fertilizer needs that would lead to bulk procurement of fertilizer in the international market by one private company selected by a tender-bid process.
- Present the intentions of drafting regulations for fertilizer bulk procurement based on the petro-fuels procurement model, which presumably has resulted in substantial savings due to economies of scale and in port demurrage charges and on better prices to consumers. The petro-fuels procurement model restrains other companies from directly importing petro-fuels products.
- Present different models of fertilizer procurement in other SSA countries and their associated cost structures and, more so, how those costs are being affected by policies and procurement and importation modalities. An example of a market information system based on AMITSA was also presented.

The meeting was followed by broad consultations among stakeholders to assess the fertilizer market during early 2017 and discuss the bulk procurement. Over 100 stakeholders from both public and private sectors, including the farming community in Tanzania, were interviewed. Debriefing meetings were organized with the MALF Department of Policy and Planning (DPP) and the Tanzania Fertilizer Regulatory Authority (TFRA). An assessment report was issued with the following observations and recommendations:

1. The proposed fertilizer bulk procurement model (FBPM), may not achieve the intended effect of reducing fertilizer prices for farmers since it has the potential to disrupt the existing fertilizer marketing system and substantially alter the indicative price set under the FBPM, ultimately compromising freedom of decision making, competition, and innovation in the fertilizer market. Consequently:
   a. It is advised that the implementation of the FBPM be suspended pending further research and consultation of stakeholders.
   b. Rather than establishing an indicative price, government should implement a fertilizer market monitoring and information system (MIS) at the district level. The MIS would help identify regions where substantial differences in retail prices exist. Therefore, it is also advised to envisage a mechanism to investigate regions with substantial price differences and potential measures to be taken, including policies and programs to address the causes of substantial price differentials and, if necessary, punitive measures for market agents involved in collusion or exploitative behavior.
2. Should the government chooses to implement the FBPM, it is advised to:
   a. Implement a pilot of FBPM with one or two widely used fertilizer products.

b. Independently evaluate the pilot program with consultation with public and private sector stakeholders involved.

c. Establish mechanisms for independent oversight and arbitration of the tender procedures for FBPM.

3. As an alternative to implementing regulated bulk procurement for fertilizers, it is advised to adopt the following short-term measures to increase the efficiency of the value chain and reduce prices:

   a. Allow priority discharge at port of vessels over 25,000 tons capacity to encourage and facilitate larger bulk procurement and shipping by eliminating the risk associated with shallow berths.

   b. Accelerate the establishment of the "one-stop clearance center" in the Port of Dar es Salaam, accompanied by a reduction in on-vessel quality inspections to reduce port time and therefore transaction costs, and an intensification of quality inspections at the retail level.

   c. Conduct a detailed study to estimate the costs, margins, and profits at each stage of the supply chain to retail for a better reference retail price for MIS.

   d. Explore and assess different fertilizer delivery models, including tripartite agreements between financial institutions, farmers, and processors, to facilitate financing for inputs, which is, according to many stakeholders, the key constraint in Tanzania.

In addition, the report makes the following medium-term recommendations:

- Improve the draft of berths in the Port of Dar es Salaam to increase capacity for larger ships.
- Develop innovative solutions to reduce collateral requirements for increased access to finance.
- Encourage TAZARA to increase their handling capacity for transporting fertilizer from the port to the main consumption regions.
- Strengthen agro-dealer networks.

It is recognized that some recommendations do not offer immediate solutions to address the issue of reducing fertilizer retail prices nor eliminate the government fiscal burden from the current subsidy program. However, if the solutions are implemented, the sector is expected to continue expanding and become more competitive to the benefit of farmers and food security for Tanzanians. Finally, a stable policy environment, infrastructure improvements, and exchange rate stabilization will be fundamental in the effort to ensure the lowest possible fertilizer prices for farmers.

2.1.3 *Engagement with Partners in Support of Policy Reforms at Country and Regional Level*

A. Technical Support to CAADP-Malabo

Under the African Union CAADP-Malabo Technical Networks of the AU Commission (AUC)/Department of Rural Economy and Agriculture (DREA), IFDC was invited in September 2016 to the launching of Technical Networks (TNs) in support of the Malabo Implementation Strategy in Nairobi. These networks are collaborative platforms for harnessing and channeling technical support from the different development institutions in Africa for capacity development to relevant CAADP implementation agencies.

One objective of the CAADP-TNs is to develop mechanisms and support tools for the implementation of the *Malabo Declaration* through trainings and technical advice in specific areas to national and regional agriculture sector governance entities. This includes support policies, programs, and practices that can accelerate achievement of national, regional, and continental agriculture productivity and production and, therefore, contribute to achieve food security goals related to the *Malabo Declaration* and CAADP.

IFDC is a member of three technical networks supporting the AU CAADP Malabo Implementation Strategy:

- Markets and regional trade.
- Resilience, risk management, and natural resources management.
- Knowledge management, policy analysis, and accountability for results.

IFDC Markets, Economics, and Policy (ME&P) staff participated in virtual meetings and discussions of the TNs during 2017, on Knowledge Management, Policy Analysis, and Accountability, and the Markets and Regional Trade TNs. Discussions aimed at strengthening the Country National Agricultural Investment Plans in alignment with the CAADP Compact signed by these countries. In the context of the Markets and Regional Trade TN, a document on "Regionalization of Agro-Inputs Markets" in SSA is being prepared for publication on the IFDC website. This document may be useful as a tool for training and capacity building under the Markets and Regional Trade TN activities.

B. Input Subsidy Studies

In SSA, there is a growing interest in improving the delivery of subsidies on fertilizer through better planning, management, and implementation of subsidy programs, in efforts to lessen the burden on public budgets and encourage larger private sector participation and investments in fertilizer markets. IFDC has been collaborating with researching fertilizer subsidies and contributing financial resources from this Cooperative Agreement to complement resources from the Alliance for a Green Revolution in Africa (AGRA) and the fertilizer industry.

AGRA-IFDC Africa Subsidy Review

Under an MOU, AGRA and IFDC collaborated on assessing subsidy programs in 10 African countries. IFDC supported country consultants by reviewing their draft reports and the final consolidated report. A validation workshop was held in Nairobi in November 2016 with the participation of ministry of agriculture representatives and country consultants from the 10 assessed countries, including international organizations, such as IFDC, International Food Policy Research Institute (IFPRI), African Development Bank (AfDB), and World Bank. A synthesis report capturing key aspects from the 10 countries, as well as country-specific draft reports, were finalized during early 2017.

The study assessed the existing inputs distribution systems and subsidy approaches, where applicable, in Burkina Faso, Ghana, Malawi, Mali, Mozambique, Nigeria, Kenya, Rwanda, Tanzania, and Uganda in efforts to identify best practices for improving the design and implementation of agro-input distribution and subsidy programs. The specific objectives of the activity were to:

1. Analyze the performance of input distribution systems and subsidy programs.
2. Identify bottlenecks constraining distribution of fertilizer and subsidy programs.
3. Propose pragmatic measures that can strengthen agro-input subsidy programs while increasing the participation of private business and investments in the fertilizer market.
4. Envision a fertilizer subsidy model to be piloted in at least one SSA country.

Based on the assessments, the following models were recommended, to be adapted according to specific country characteristics:

- An electronic voucher scheme for countries with good infrastructure (IT, banking, telecommunication, storages, road network, etc.), and a conducive policy and regulatory framework to incentivize private sector participation. Potential countries were Nigeria, Tanzania, Rwanda, and Kenya.
- Improved paper voucher scheme for countries with modest infrastructure and private sector development, recommended for Malawi, Ghana, Mali, and Burkina Faso.

2.2 Impact Assessment Studies

To support the development of input markets and value chains, IFDC conducts impact studies to provide feedback on market performance resulting from policy reforms, to support programs implementation, and to capture lessons learned for future policy reforms and program implementation. During the reporting period, the following activities were conducted.

2.2.1 *Fertilizer Quality Assessment/Survey to Support Policy Efforts to Harmonize Regulatory Standards in East and Southern Africa*

The ME&P unit backed the Fertilizer Quality Assessments (FQA) undertaken under Workstream 1 to support the development of a fertilizer quality regional regulatory framework for COMESA (see complete reporting under Workstream 1). The ME&P contributed with training inspectors in policy and regulatory aspects and with a rapid assessment to identify challenges constraining the markets. Three fertilizer quality assessment have been conducted in East and Southern Africa.

The Kenya report contains policy and regulatory issues affecting the fertilizer market that have implications on fertilizer quality with recommendations to address the identified quality problems, especially with liquid fertilizers:

- Based on the analysis of sampled fertilizer, points to the need of establishing a credible and reliable monitoring system to ensure more stringent pre-export verification of conformity (PVoC) to be carried out by reputable and internationally accredited companies.
- PVoC should be followed by inspections at the destination port, especially for products that have a history of poor quality or whose origins are dubious. Targeted random inspections along the domestic value chain will help maintain quality. Inspections are especially important at blending facilities and retail where re-bagging products have higher likelihood of adulteration.
- In addition, training of distributors and agro-dealers on best practices in handling fertilizers and maintaining appropriate storage facilities will further help to maintain quality. The capacities of agencies in charge of quality regulations, including laboratory equipment and human or technical expertise, need to be improved.
- Finally, it is crucial to have a mechanism in place for farmers and other stakeholders to file complaints on quality to relevant authorities/agencies for action.

Therefore, updating the current quality regulatory framework, with clear roles for relevant agencies, in addition to harmonizing regulations across countries, will support the above recommendations and increase access to fertilizers.

This report was shared with the Ministry of Agriculture of Kenya in May 2017. For more details on these activities, see Workstream 1 narrative, under section 1.3.1.

2.2.2 *Assessment of Agro-Dealer Development Programs in SSA*

The team planned a series of assessments on agro-dealer development programs in selected countries, following the Mozambique study during 2015-16 under BFS funding. During FY17, it was planned to conduct an extensive assessment among agro-dealers to determine their effectiveness in Rwanda. Due to logistical difficulties and uncertain conditions in Rwanda, we could not proceed as planned. We have already initiated discussions with the key organizations implementing agro-dealer programs in Rwanda and also donors involved in such activities, such as AGRA/COMESA. We further plan to proceed with the survey-assessments with detailed impact assessment methodology in FY 2018. Not to lose momentum, we instead conducted a rapid review of all the agro-dealer capacity-building programs implemented by IFDC over the span of 15 years in 14 different countries in Asia and SSA. We further documented a small brief on lessons learned and our IFDC approach (described below) for the agro-dealer program resulting from implementing such programs.

Implementing Agro-Dealer Development Programs: Key Lessons Learned

IFDC takes a holistic, market-oriented approach to agro-dealer development and also builds capacity along both the agricultural input and output value chains. Whether the challenge is to enhance efficiency in public systems or strengthen the capacity of private agro-dealers, a key priority is improving the performance of value chain members, thereby achieving operational and cost efficiencies that directly benefit farmers. In all activities directed at capacity building and promotion, IFDC's approach to agro-dealer development incorporates the marketing concept that *an agro-dealer's long-term success can best be achieved through better servicing the needs of his or her farmer customers*.

Figure 36. Inputs to Consumer Value Chain

IFDC has implemented 14 agro-dealer development programs over the past two decades in several SSA and Asian countries,[2] including most recently in Rwanda, Mozambique, Ghana, and Nigeria. The organization has learned important lessons about the impact these activities can achieve and

[2] Bangladesh, Kyrgyzstan, Tajikistan, Kenya, Rwanda, Uganda, Tanzania, Mozambique, Ethiopia, South Sudan, Ghana, Burkina Faso, and Nigeria.

has also identified certain aspects of such programs that are critical to success and others that should be avoided to achieve maximum effectiveness.

The basic rationale for strengthening agro-dealers is that they can provide sound technical advice as well as serve as the key suppliers of needed inputs in a timely manner to *last-mile customers*, i.e., farmers. Through our experience in many countries, IFDC has gleaned several key points of learning that we incorporate into the planning of similar projects to achieve the best results and ensure sustainability of agro-input enterprises.

1. *Training and Capacity Building*
   IFDC's approach to successful agro-dealer programs centers on inclusiveness (particularly the involvement of women and youth) as well as adaptability to the agro-ecological and business environment of the country as a whole and also with a regional/location-specific focus that takes into account the needs of the farmers and agro-dealers. IFDC's training curriculum provides extensive and practical training on state-of-the-art agricultural input technologies, applications, business management, and safe input handling, storage, and application practices. These topics are presented through a "learning-by-doing" approach, extensive field visits, and on-farm demonstrations. IFDC also uses a "train the trainer" approach in which we design the appropriate curriculum and work with master trainers who then train groups of existing or emerging agro-dealers.

2. *Enterprise Diversification – Input Bundling and Output Market Linkages*
   IFDC's past experiences with agro-dealer development programs show that input enterprises are more sustainable if dealers are able to bundle more than one input and offer additional services through their shops. There are advantages to encouraging agro-dealers to carry a wide array of inputs (i.e., seed, fertilizer, crop protection products, irrigation equipment, tools, small mechanized equipment, livestock feed supplies, veterinary supplies for livestock health, supplies for fencing or building materials). A broad portfolio of products allows the agro-dealer to provide a "one-stop shop" service to clients. It also extends the seasonal nature of the business, which may be limited to several weeks or months if the dealer specializes in only a few products. To diversify their business focus, some agro-dealers may choose to extend their line of products to include hardware or even [non-perishable] food and grocery items. Our experience further highlights the importance of enterprise diversification in terms of building linkages with output markets. In this regard, having storage facilities for grain also plays a crucial role.

3. *Accreditation of Agro-Dealer Enterprises by Authorized Entity*
   A certification system, such as government accreditation of agro-dealers, should be used to confer a seal of approval for properly trained agro-dealers. Normally, trained agro-dealers receive a certificate linked to a national accreditation program, which allows them to participate in various government development schemes for input promotion, such as an input voucher program. Also, certified agro-dealers can be linked to major agricultural input supply firms with credit guarantees to supply inputs using financing and credit mechanisms. Therefore, certified agro-dealers tend to have a greater input demand and profit margin for supplying farm inputs in rural areas, which reduces risks and uncertainties in their business and increases business working capital. The accreditation also helps agro-dealers build trust among the farming community that they will supply quality inputs and services. Accreditation also helps the authority to occasionally trace product quality to avoid the sale and delivery of fake inputs.

4. *Linkages to Credit and Other Financing*
   Credit access for inputs (both for input purchases and delivery) is a major operational constraint agro-dealers face concerning expansion of business activities and attracting farmers to their shops. IFDC experiences indicate that agro-dealer shops with access to financing for input purchases often were able to expand their business operations rapidly and supply inputs extensively in a timely manner, even in remote areas. This can include access to bank loans, microfinance institutions, and other credit guaranteed mechanisms (e.g., AGRA/Ministry of Agriculture and Animal Resources in Rwanda). In many cases, the agro-dealers also could extend input credit to farmers in communities where they serve. Trained agro-dealers who were linked to input voucher programs that served as an input guarantee (i.e., credit) were also successful in sustaining their business operations.

5. *Formation of Input Trader Associations*
   Agro-dealer accreditation programs combined with the formation of agro-dealer associations/organizations are also key elements for most successful agro-dealer programs. The association can allow member companies to access credit, source inputs at a lower cost (wholesale), hold better bargaining power, and advocate for and influence policies affecting the input sector. This also promotes the image and reputation of agro-dealers as knowledgeable and professional suppliers of effective products that can be used to raise productivity while safeguarding public health and the environment. Trader associations also provide opportunities for members to share market information periodically and further improve networking opportunities with reputable suppliers of genuine and high-quality inputs.

   To successfully increase agricultural productivity in a sustainable manner, development and adoption of best agricultural practices and enhanced technologies are absolutely necessary. Millennium and Sustainable Development Goals also articulate the need for building efficient input delivery mechanisms and improved technologies to poor farm households to improve food security. In this regard, agro-dealer development programs play a crucial role in developing such sustainable networks toward improved agro- inputs and services to farmers. In addition to the lessons learned from our work to date, IFDC has also been increasingly shifting its focus from large-scale agro-dealer development programs (i.e., training in large numbers) to creation of more focused “input dealer hubs” and “input agents” in developing supply networks. One key aspect of the network approach is building more effective linkages with finance institutions and other sources of credit and to achieve efficiencies of scale in developing distribution networks or input hubs.

2.3 Economic Studies

IFDC’s economic studies provide useful information for public and private decision making and identify areas for policy actions to facilitate the flow of fertilizers at reduced costs and prices for smallholder farmers. These economic studies include assessments of the supply cost build-ups to identify market and value chain constraints affecting fertilizer supply and the development of indexes for supporting policy and business decisions.

During the current reporting period, one cost build-up study was finalized (Ghana), and another is in a draft stage undergoing an internal peer review (Kenya). Progress has been made on building The African Fertilizer Access Index (TAFAI). It is expected that activities related to cost build-ups as well as TAFAI will be expanded in FY 2018.

2.3.1 *Fertilizer Cost Build-Up Studies*

A. Ghana Fertilizer Cost Build-Up

IFDC carried out a study to update and analyze the current fertilizer supply structure and its associated costs in Ghana. Results from this study are expected to shed light on current issues facing the fertilizer market and be useful to regional and country-specific initiatives aimed at increasing fertilizer use by improving the policy and regulatory framework and governance in support of public and private investments.

The premise of this work is based on the fact that the final cost, and therefore the retail price paid by farmers in the domestic market, is affected by the costs of products and logistics in the international market and by factors affecting logistics in the domestic market. At the same time, the efficiency of domestic logistics is influenced by the importing country physical, political, institutional, and regulatory environment. Consequently, improving these domestic factors will positively affect the fertilizer supply chain by reducing transaction costs while improving efficiency in the market.

In markets affected with subsidies, increasing the efficiency of the supply chain could reduce or eliminate the need for subsidies. However, if subsidies are necessary, these improvements would lower the cost of such programs, increasing their effectiveness as well as reducing the fiscal and budgetary burden on public resources.

Simulation results show that MoFA-private importers negotiated retail prices are substantially lower than the estimated cost of supplying it. This implies that negotiated prices do not cover all the costs incurred by traders along the domestic supply chain. The simulation also shows that the average cost of fertilizer across all products considered in the analysis, on average, increases by 159% (or U.S. $21.3 per 50-kg bag), more than double the product's cost, insurance, and freight (CIF). Of this cost increase, 45% (U.S. $9.6 per 50-kg bag) is absorbed by importation (difference between cost at Greater Accra [GA] storage and CIF), and the 55% difference (U.S. $11.7 per 50-kg bag) is absorbed by the domestic supply chain after importation, from GA storage to retail.

Table 13. Summary of Estimated Costs at Retail, and 2015-16 Negotiated and Subsidized Prices

Costs	Urea		NPK		NPK-B	
	U.S. $	GHS	U.S. $	GHS	U.S. $	GHS
Estimated Non-Subsidized	32.5	126	38.7	150	34.9	135
Estimated Subsidized	26.1	101	31.0	120	28.0	108
MoFA-Importer Negotiated Price	26.0	100	31.2	125	31.2	125
MoFA Subsidized/Farmers' Price	20.8	80	22.1	95	23.1	89

When comparing estimated fertilizer supply cost with the MoFA-importer negotiated retail prices, such prices are lower by an average of 17%, or U.S. $7 per 50-kg bag, apparently achieved at the expense of the domestic distribution and retail network. The MoFA-importer negotiated price apparently does not take into consideration the full operational cost and the financial/opportunity cost of capital tied up in fertilizer inventories along the domestic supply chain, other than transportation and storage costs to retail. Consequently, this lower artificial price set by MoFA-importers negotiation has an implicit de-facto blanket subsidy applicable to all fertilizer products at the expense of the domestic distribution and retail network, presuming that the MoFA-importer negotiated retail prices are enforced, which they are not. We observed situations in which NPK formulation products were sold at prices above the MoFA-importers negotiated prices, still below the estimated cost of supply at retail.

When comparing estimated fertilizer supply cost with the MoFA-established subsidized price/cost to subsidy beneficiary farmers at retail, the subsidized price is lowered by an average of U.S. $14.1 per 50-kg bag. This implies that the real subsidy to farmers, which is the difference between the estimated cost and the subsidized price at retail, is 66%; and the nominal subsidy, which is the difference between the MoFA-subsidized price at retail and the MoFA-importer negotiated retail price, is an average of 25%, or U.S. $7.1 per 50-kg bag. The real subsidy is in part at the expense of the taxpayers through the subsidy programs, complemented by a de-facto subsidy at the expense of the domestic distribution and retail network.

In the case of NPK products, the nominal and real subsidy rates for blended NPK (23-10-05) for the cocoa sector are lower than the rates for NPK formulation due to higher subsidized price of blended NPK and lower estimated cost relative to the complex NPK formulations and negotiated price. The lower cost of the blended vs. imported NPK complex formulations implies that perhaps there is preferential treatment for locally blended products in efforts to support the domestic blending industry, to reduce the cost of blended NPK products to the benefit of the Ministry of Finance (MoF) subsidy program, and to increase the amount of subsidized products in favor of cocoa production as one of the agriculture subsectors with a large contribution to the foreign currency generation through exports.

An important and perhaps relevant observation based on the costs estimation results is that when comparing the cost of supplying fertilizer at one stage relative to the previous stage of the supply chain, the largest domestic cost increase occurs between CIF and storage in the GA area, due to port charges (stevedores and other port related charges), and to a lesser extend due to government charges (taxes, tariffs, and levies). This is an average increase of U.S. $9.6 per 50-kg bag across all products. The smallest increase of U.S. $5.1 per 50-kg bag is between wholesale and retail.

Table 14. Estimated Cost Increases of Fertilizer Along the Supply Chain to Farmers in Ghana, in U.S. $ per 50-kg bag

	Products	GA vs. CIF	Wholesale vs. GA	Retail vs. Wholesale	Farmer vs. Retail	Farmer vs. CIF
Open Market	Urea	9.4	6.4	4.8	5.7	26.3
	TSP	8.8	6.7	5.2	6.1	26.9
	KCl	8.4	6.4	4.8	5.7	25.4
	NPK	11.0	7.0	5.5	6.6	30.1
	NPK-B	10.4	6.6	5.1	6.0	28.1
	Average	**9.6**	**6.6**	**5.1**	**6.0**	**27.3**
Subsidized	Urea	9.4	3.5	1.4	4.8	19.0
	TSP	8.8	3.5	1.4	5.1	18.8
	KCl	8.4	3.5	1.4	4.8	18.0
	NPK	11.0	3.5	1.4	5.5	21.3
	NPK-B	10.4	3.5	1.4	5.1	20.2
	Average	**9.6**	**3.5**	**1.4**	**5.1**	**19.5**

Although most cost build-up analyses stop short at retail, in this case we also present the cost build-up at the farm gate. The reason for this is to recognize that there is an opportunity cost of capital invested in the purchase of fertilizer by farmers, in addition to other non-tangible costs, which are not typically considered in a cost analysis, especially for the purpose of subsidy programs.

Estimations show that the cost of fertilizer to farmers increases by 17-18% between retail and farm gate, or about U.S. $5.5 per 50-kg bag, on average, of subsidized fertilizer cost at the farm gate. This increase is absorbed by the transportation of fertilizer from the retail point to the farm gate (about 12%) and by interest payment / farmer's opportunity cost of financing for the capital tied up in the product throughout the planting-to-harvesting season. Other than the costs associated with the product itself, this cost increase does not include other non-tangible costs, such as the income lost as a result of taking time off from regular activities and the associated travel costs of the farmer to seek fertilizer at the nearest agro-dealer. The implication of this is that the rather large "last-mile" additional cost due to high transportation and finance costs might be among the reasons why farmers do not purchase or make use of fertilizer even if it is subsidized, particularly considering that the farmers targeted by the subsidy programs are cash-poor, farm in marginal land in remote areas, and typically do not have access to formal credit.

When comparing the estimated final cost of fertilizer at the farm gate, such cost increases by an average of U.S. $17.8 per 50-kg, relative to the cost at the GA storage facility, and by U.S. $27.3 per 50-kg, or just above 200% relative to the CIF cost. In the case of the subsidized fertilizer scenario, the estimated cost increases along the domestic supply chain are substantially lower compared to the open market. The estimated final cost of subsidized fertilizer closely resembles the retail price estimation and the price negotiated between MoFA and private importers.

The main findings of the assessment are the following:

- A key issue facing the fertilizer supply chain in Ghana is the high cost of finance and access to credit, particularly by agro-dealers and smallholder farmers. High cost and low access to finance are explained in part by the crowding-out effect from the GoG borrowing in the domestic financial market to finance the fiscal and budgetary deficit. The low access to credit is also explained, in part, by the high risk inherent in agricultural activities, which compels financial institutions to lend funds for investments in activities that offer higher rates of return and are less risky, in an effort to protect their lending portfolio.

- The subsidy program, intended to increase the use of fertilizer among smallholder farmers in Ghana, is not serving its intended purpose because the market/retail prices negotiated by MoFA and importers are presumably much lower than the actual/estimated cost of supplying fertilizer all the way to retail. Although these prices might be enough to provide importers incentive to import the fertilizer under the GoG subsidy programs, it does not provide incentives for the domestic supply chain to deliver all the fertilizer where and when it is needed most, apparently creating a supply crunch at the importer and/or wholesale level. Furthermore, these prices provide even less incentive to private stakeholders, to deliver fertilizer quantities beyond what the GoG can afford under the subsidy program.
- The process of negotiating prices between MoFA and importers and the system of delivering fertilizer allows importers and wholesalers to reduce their costs, and more importantly, it allows importers to transfer the inherent risk of the domestic market to the domestic distribution network. The domestic distribution network is expected to cover their combined costs and risks of delivering fertilizer to farmers, with a commissions of GHS 7-9 allotted under the MoFA-importer negotiated retail price, for every fertilizer bag sold after importation to retail.

B. Kenya Fertilizer Cost Build-Up

In FY16, data and information on cost build-up were collected for Kenya toward the end of the reporting period and continued into the current reporting period. The initial draft was written during the current FY17. The objective of the activity is to assess the cost of supplying fertilizer from procurement to distribution to farmers and to identify constraints that are contributing to higher transaction costs and recommend policies and strategies to address them.

The Kenya fertilizer law and regulations are outdated and need updating; there is a draft policy document that has been put together with stakeholder consultations but is yet to be signed and gazetted. Kenya has a fairly evolved fertilizer market with a competitive private sector consisting of several importers and distributors and many retailers or agro-dealers. The fertilizer market was liberalized in early 1990s, and prices are determined by private sector players in a competitive market. Kenya also provides the seaport through which landlocked countries procure their fertilizers; about 30,000 tons of fertilizers are re-exported to other East African countries. The main crops that use fertilizer in Kenya include; maize, coffee, tea, sugar, and horticultural crops. Kenyan national consumption of fertilizers is approximately 600,000 metric tons (mt) mostly consisting of DAP and CAN, and about 90,000mt going to the tea sector (NPK 25:5:5). There are a number of blending facilities in the country that produce balanced fertilizers.

Though the market is liberalized, the government runs subsidy programs that raise risks for the private sector, creating uncertainty in timing of procurement, delivery time, and level of subsidy provided. There are two subsidy programs: the National Accelerated Agricultural Inputs Access Program (NAAIAP), a voucher-based program targeting smallholder farmers through the private sector distribution system, and the Fertilizer Subsidy Program, a government-run program selling fertilizers at reduced prices to all farmers at their stores, mostly in high potential agricultural areas. The initial analysis of the collected data and information provides a few key results with implications for improving markets and raising access to fertilizers:

- Logistics: Road transport is the main mode of transporting fertilizers in Kenya. Transport to Nairobi is approximately Shs 180 per 50-kg bag of urea, Shs 250 per bag to Nakuru, and Shs 300 per bag to Kitale on the other side of the country.[3] This is 12% of the retail price at Kitale or viewed as a percentage of domestic costs (post-CIF) this is 30% of domestic components of retail prices. Kenya is currently constructing a Standard Gauge Railway from Mombasa to the border with Uganda. Already the Mombasa-Nairobi portion has been completed. The cost of transport by rail has been estimated at a third of the cost of road transport.
- Approximately 41% of the retail price at Kitale is the domestic component, implying that domestic costs and margins are significant parts of the price to farmers. Therefore, as a cost-cutting strategy, ways of reducing these costs should be explored, since international costs are fixed and not influenced by countries that consume relatively small quantities of fertilizers
- Financing: Financing costs consist of acquiring a letter of credit (LC) and interest rates on LCs for about three months, which amount to approximately 7% of the domestic components of the retail price at Kitale. Interest rates are usually above 10% and can rise as high as 30%; however, recently, the government has put a cap on interest rates at 4% above the base lending rate from the central bank. This has caused a number of banks to lay off staff blaming the tight lending rules. This is not sustainable; financing mechanisms that do not burden businesses and farmers with high charges need to be explored and implemented.
- About 22% of the internal component is composed of clearing and forwarding (C&F) charges. The major elements in C&F include: import declaration form (IDF), shore handling, and wharfage. The Kenya Bureau of Standards (KBS) fee and radiation inspection account for 10% of clearing and forwarding costs. Therefore, reduction in these fees and other costs can reduce farm-gate prices.
- The Kenyan fertilizer market is well-developed and has enough investors to take care of not just the Kenya market but regional markets if the regulations and policies are harmonized to allow for trade.

2.4 Identification of Fertilizer Trends and Outlook for Sub-Saharan Africa

IFDC ME&P staff, along with colleagues and partners in the field, continue to collect, analyze, and provide market information on the supply and demand of fertilizers in a number of countries in SSA. This information was conceived to contribute to a collaborative effort being initiated with AFAP in developing a comprehensive index on the access to fertilizers in sub-Saharan Africa.

2.4.1 *TAFAI-The African Fertilizer Access Index*

The TAFAI initiative has continued to make progress since the preliminary workshop among collaborators in March 2017. The proposed TAFAI index will be a consolidated measure of various factors influencing and responsible for creating an enabling environment for fertilizer markets (research and development, fertilizer policy and regulatory frameworks, market access, industry competitiveness, fertilizer quality) and those that can be used to assess fertilizer use (farm-gate price, input-output ratios, fertilizer consumption rates and levels, nutrient appropriateness). The goal is to establish and maintain a simple, transparent, accurate, up-to-date index of measurement that keeps a running scoreboard on fertilizer sector development in Africa. The overall objective is to promote the creation of an enabling environment for competitive private sector-led fertilizer

[3] Exchange rate is U.S. $1 = 100 Shillings.

market systems that improves smallholder farmers' access to fertilizers at affordable prices and quality, available at the right time and place, and suitable for their crop and soil nutrition.

Activities April-September 2017

Following the TAFAI group meeting among the collaborators (IFDC and AFAP) in Nairobi during March 28-30, 2017, it was further decided that TAFAI as a concept will be derived as a closely related and complementary measure, which is currently in operation, i.e., The African Seed Access Index (TASAI), and was conceptualized and implemented by Cornell University, AGRA, and Market Matters. Ideally, once the indicators of seed and fertilizer access are completed, both TASAI and TAFAI will be viewed as credible and viable instruments by stakeholders and will become the go-to instruments for continental bodies like the African Union (CAADP, Malabo Declaration) to monitor and report on performance of the seed and fertilizer industries in Africa. In addition, they can become a part of the input strategy of the respective organizations involved in the process, including donors and implementing institutions. A joint work plan between IFDC and AFAP was developed toward implementing TAFAI. During this work plan period, we documented extensive literature related to fertilizer access, measurement of concepts, and approaches used for measuring the fertilizer access.

The proposed indicators on fertilizer access and use will draw upon methodologies from similar initiatives to measure various aspects of development, governance, institutional performance, and other policy-related aspects of human development in general. In recent years, specific measures of interest related to measuring agriculture and related services (policies, markets, and institutions) have been developed by international institutions, such as the World Bank, USAID, and AfDB. For instance, in 2010 USAID commissioned the Enabling Agricultural Trade (EAT) project to develop and pilot the Agribusiness Regulation and Institutions (AGRI) Index. This index was piloted in a handful of Asian and African countries to study different aspects of trade-related factors affecting agricultural inputs and commodities in general. Also in 2010, the World Bank group piloted the Agribusiness Indicators (ABI) in eight countries in SSA, which has identified and focused directly on increasing the competitiveness of agricultural production in sub-Saharan Africa. This work (which is still in progress) was further extended by the World Bank to establish the Enabling Business in Agriculture (EBA) index, which has been implemented in 100 countries since 2012-13. The EBA measures laws and regulations that impact the enabling environment for agribusiness markets and aims to inform and encourage policy decisions that support inclusive participation in agricultural value chains. It has developed fertilizer indicators that measure laws and regulations on registration, import and quality control of fertilizer products.

Of most relevance for the TAFAI work is a similar initiative that has been established to measure the factors influencing access to seed viz., TASAI, as indicated above. The TASAI was developed in 2013 under the intellectual leadership of Cornell University (TASAI, www.tasai.org) and was piloted in four countries in East and Southern Africa in 2014-15. The TASAI experience on formulating a comprehensive index on access to seeds in SSA will be of great relevance for this work, namely in building a similar measure on access to fertilizers. From extensive initial consultations with stakeholders during the fertilizer stakeholder forum at the West Africa Fertilizer Program workshops in Abidjan in May 2017 and further through consultations over phone and email, we developed an initial set of 22 indicators, classified under four major categories that have implications for fertilizer access and use to an extent in SSA countries. The list is given in Table 15, and it is still under review and being finalized.

Table 15. Set of Preliminary Indicators Identified to Denote Fertilizer Access Across SSA Countries

Group	Proposed Set of Indicators
A. Research and Development	# of active blending/granulation plants
	Availability of research and development systems and programs
	Availability of recent soil maps
	Availability of recent fertilizer recommendations for food crops
	% of food crops receiving balanced nutrition
B. Industry Competitiveness	# of registered fertilizer companies
	Requirements to import and distribute fertilizers
	Market share of top 4 companies
	Market share of public/subsidized fertilizers
	Tariffs on fertilizer (import, export) and taxes on trade
C. 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
D. Services	Availability of extension services for smallholder farmers
	Existence and efficiency of national fertilizer/agro-input dealer 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

We have further initiated brainstorming sessions with stakeholders on proposed indicators. Information from the stakeholders are being documented and will be refined further to design formal surveys through online and through other fora from key stakeholders. In addition, in the FY 2018 workplan, we envisage finalization of the tools of measurement for indicators and the methodological approach, followed by piloting the indicators in selected countries in East, Southern, and West African countries.

3. Cross-Cutting Issues: Organizational Learning and Sharing Through Enhanced Knowledge Management Systems

Through mutual agreement with USAID BFS, IFDC is undertaking additional actions that will allow the organization to document and share information generated from USAID BFS funding for this CA. During the reporting period, IFDC further captured, documented, and analyzed the knowledge that resulted from the many soil fertility systems and the associated activities and technologies that the organization employs to improve productivity and increase food security.

Some of the knowledge management methods adopted for BFS Soil Fertility Technology (SFT) project include:

1. Designing exclusive M&E systems for continuous monitoring and improved accountability to donors through an exclusive project management platform, IFDC-DevResults. The platform was initiated at the start of the reporting period and will be hosted by December 2017.
2. Systematic collection and documentation of data on agronomic and socio-economic research activities generated through BFS SFT project implementation. This cloud-based data management system is being undertaken with University of Florida-AgMIP collaboration.
3. Capacity building of researchers and stakeholders through institution-wide research internships, training programs, and university partnerships.

   Major partnerships in science and economics have been initiated with six land-grant universities during the reporting period. Progress in terms of research partnerships and outputs is expected to continue in successive reporting periods.
4. In addition, IFDC researchers were actively engaged in major outreach activities through publishing in peer-reviewed journals as well discussion papers and policy briefs; scientists and economists also participated in major fora of symposiums, conferences, and workshops. Several opportunities also emerged in partnering with major stakeholders for collaborative research/advocacy or additional funding opportunities and outreach.

Monitoring, Evaluation, Learning, and Sharing (MELS) Systems: IFDC has been involved in building a knowledge management platform using a state-of-the-art cloud-based program, DevResults, to collect, analyze, and visualize data for just-in-time learning purposes. Such a platform allows for the decentralized monitoring of results on a nearly real-time basis and informs decision-making to course correct as projects are implemented over time.

The ultimate goal of the MELS platform is continuous shared knowledge and learning among stakeholders through an adaptive management approach for maximum impact. In this context, the IFDC MELS system is also working closely with the IFDC Communication and Training Unit to design learning and sharing platforms for the institution and at the individual project level using various communication- and media-related tools.

The IFDC DevResults project management system also enables synchrony with the International Aid Transparency Initiative (IATI) reporting standards.

The outputs/outcomes generated during the reporting period are listed in Table 16 with detailed descriptions of those activities in Annexes 1 and 2.

Table 16. Cross-Cutting Issues: Activities Carried Out Under Organizational Learning and Sharing Through Enhanced Knowledge Management Systems

Theme/Activities	Countries	Output/Deliverable
Conduct systematic data collection and analysis of IFDC information		
MELS System – IFDC	Global	An IFDC institution-wide data management site on Monitoring, Evaluation, Learning and Sharing (MELS) systems is under development using the project management software tool DevResults for better accountability.
"Environmental Impacts and the Role of Fertilizers in Promoting Crop Resilience" in Myanmar Fertilizer Conference	Global, with focus on Myanmar	• Four papers presented under conference Theme 3, which covered the role of fertilizers in crop resilience. • Myanmar Soil Fertility and Fertilizer Management Conference held October 18-19, 2017, in Nay Pyi Taw, Myanmar • Partners: USAID, Myanmar Ministry of Agriculture, ACIAR
Collaboration with universities initiated (U.S. land-grant universities)		
Economics of soil- and fertilizer-related technologies (in collaboration with BFS Workstream 1 activity on the GHG emissions study in Bangladesh)	Bangladesh	A graduate student from Rutgers University will work on a life-cycle analysis of urea deep placement beginning in Fall 2017.
IFDC-Michigan State University – Alliance for African Partnership (AAP): A partnership (Partnership for Enabling Market Environments for Fertilizer in Africa, or PEMEFA) consisting of IFDC, AFAP, Regional Network of Agricultural Policy Research Institutes (ReNAPRI), and New Markets Lab (NML)	SSA	Regular meetings have been held electronically toward the implementation process. A draft proposal will be submitted by 2018 to conduct advocacy on an enabling fertilizer policy environment.
Exploring conducting a joint Fertilizer Quality Assessment with the University of Illinois, Urbana-Champaign	SSA	Preliminary discussions are ongoing with the Department of Agricultural and Consumer Economics to explore collaboration in fertilizer quality surveys in Africa.
Partnership with University of Georgia	SSA	Modeling on fertilizer market supply and demand in SSA.
Partnership with University of Tennessee on Enhanced Efficiency Fertilizers	Global	Field evaluation of N- and S-efficient fertilizers. Outputs include three field trials, two publications, one manuscript under review, and one presentation.

Theme/Activities	Countries	Output/Deliverable
Partnership with University of Florida on Database Management and Decision Support Systems	Global	Database system for agronomic and socioeconomic data formulated and expanded from existing AgMIP database. Decision support systems (DSS) improved and geo-referenced DSS evaluated. Two training programs (in Arusha, Tanzania and Griffin, Georgia) and a workshop (at IFDC Headquarters) were conducted on DSS application and improvement.
Trainings/Publications/Symposiums and Other Forms of Outreach		
A. Trainings/Capacity-Building Activities		
1. International Training on "Promoting Agriculture Technology to Improve Productivity and Net Returns for Smallholder Farmers," Accra, Ghana, January 23-27, 2017.	Global/SSA	• 43 participants (9 women) • 9 countries (Ethiopia, Ghana, Kenya, Lesotho, Mozambique, Nigeria, Rwanda, Uganda, and USA) • Partners in training (other organizations)
2. International Training and Study Tour on "Technology Advances in Agricultural Production, Water and Nutrient Management," (Alabama, Arkansas, Tennessee, Missouri, Illinois, and Washington, D.C.), August 21-September 2, 2017.	Global	• 17 participants (1 woman) • 10 countries (Australia, Ethiopia, Ghana, India, Kenya, Malawi, Nigeria, South Sudan, Tanzania, and Uganda) • Partners in training: University of Tennessee, fertilizer industries
3. International Training on "Assessing Crop Production, Nutrient Management, Climatic Risk, and Environmental Sustainability with Simulation Models," University of Georgia, Griffin, Georgia, May 15-20, 2017.	Global	• 49 participants (18 women) • 17 countries (Brazil, Canada, Colombia, France, Israel, Italy, Jamaica, Japan, Korea, Mexico, Mozambique, South Africa, Taiwan, Tanzania, United Kingdom, USA, and Vanuatu) • Partner: University of Florida, Auburn University, University of Georgia
B. Internships (Students, Researchers, and Others) – USA / SSA / Asia		
Auburn University Research Focus: Soil and plant nutrition and lab analyses	USA	• Number of students: 2 • Months of internship: 3

Theme/Activities	Countries	Output/Deliverable
University of North Alabama Research Focus: Greenhouse and lab	USA	• Number of students: 2 • Months of internship: 6
Mississippi State University/University of Georgia Research Focus: Data analysis and writing draft reports on policy and fertilizer cost build-ups	USA	• Number of students: 2 • Months of internship: 2
University of Ghana, Legon-Accra Research Focus: Sampling techniques and econometric analysis	Ghana – IFDC	• Number of students: 2 • Months of internship: 2
Bangladesh Agricultural University Research Focus: Quantifying GHG emissions	Bangladesh	• Number of students: 2 • Months of internship: 3
Agriculture and Forestry University Research Focus: Balanced nutrition	Nepal	• Number of students: 1 • Months of internship: 3
C. Publications (journal articles, reports) (List enclosed in Annex 2)	Global	• Number of publications: 21 • Number of reports: 4 • Number of policy briefs: 3
D. Workshops/Meetings/Conference Participation (Bangladesh, Myanmar, Nepal, Mozambique, Kenya, Tanzania; Regional – West and East Africa, Asia) (List enclosed in Annex 2)	Global	• Participated in 7 workshops • Participated in 19 conferences • Number of meetings and presentations: 4 • Other types of “significant” consultations/meetings, etc. (Ministry level, etc.): 6 at the national level and 3 at the regional level

Theme/Activities	Countries	Output/Deliverable
E. Other outreach activities (MoUs/partnership agreements, etc.)	Global	• Number of concept notes written: 20 (including public-private partnerships) • Countries of focus: Mozambique, Nepal, Myanmar, Niger, Kenya, Iraq; Regional: SSA, Asia; Private sector firms • Number of proposals won: 11 • Number of technical collaborations achieved/pursued: AGRA, FAO, World Bank, AFAP, MCC-Niger, TASAI-Cornell, Ministry of Agriculture – Kenya, Uganda, Tanzania.

Annex 1. Summary of Activities and Deliverables for Workstreams 1 and 2 for April 1, 2017 to September 30, 2017

Theme/Activities	Countries	Output/Deliverable
Workstream 1: Developing and Validating Technologies, Approaches, and Practices		
1.1 Technologies Refined and Adapted for Climate Resilience		
Technologies and best management practices developed and validated for climate resilience in Asia and SSA	Bangladesh, Myanmar, Nepal, SSA	Protocols, field trials to identify appropriate nutrient management strategies promoting climate resilience in rice, maize, and vegetables, scientific publications
Quantifying climate mitigation role of enhanced efficiency fertilizers and practices	Global	Protocols for rice and wheat, quantification of N_2O and NO emissions for specific management practices Two trainings conducted in Bangladesh on “GHG sampling and measurement from rice based cropping systems.” Protocols for CO_2 emissions developed. Publications and presentations.
Decision support tools developed and validated for rice: CERES-Rice Model	Global	Literature Review conducted. Article in preparation for Agrilinks and IFDC’s *Perspectives* magazine.
1.2 Balanced Plant Nutrition Through Improved Fertilizer Product Recommendations		
Development of conceptual framework for balanced fertilizer delivery	Global	SMaRT concept developed for delivering balanced fertilizers to smallholder farmers. Presentations made at the African Green Revolution Forum (AGRF) and Myanmar Fertilizer and Soil Fertility Conference.
Development of soil fertility maps to facilitate site- and crop-specific fertilizer recommendations for smallholder farmers for increased economic and environmental benefits from fertilizer use	Ghana	Soil maps completed and collection of tissue samples and their analysis in progress. Using Ghana soils data and PRDSS to determine expected relative agronomic efficiency of Kodjari phosphate rock (PR) as a source of P.
Improved agricultural efficiency of locally available phosphate rock (PR) to cost effectively improve agricultural productivity in marginal soils	Global	Improved effectiveness of PR by compacting with DAP on a wide range of soils and crops. Presentations made, application for patent.

Theme/Activities	Countries	Output/Deliverable
Improving efficiency of sulfur fertilizers through delivery with urea	Global	Protocols developed and field trials conducted. Presentations made, manuscript in preparation. Partnership developed with University of Tennessee and Shell. Leverage USAID funds for PPP and scaling in SSA and Asia.
Evaluation of micronutrients to increase yield, nutrient uptake, grain nutritional quality, and N use efficiency	Global	Protocols, greenhouse and field trials evaluating the impact of secondary and micronutrients on macronutrient (NPK) use, N use efficiency, and evaluation of micronutrient formulations and methods of application. Publication in scientific journals and conference presentations. Draft reports on crop nutrition in Burundi.
1.3 Fertilizer Quality Assessments to Support Policy Efforts to Harmonize Fertilizer Regulations in East and Southern Africa		
Fertilizer quality assessments (FQA) to support policy efforts to harmonize fertilizer regulations	Kenya, Zambia and Uganda	Presentation of the Kenya Fertilizer Quality Assessment Report to the Kenya Ministry of Agriculture (MoA); modifications suggested by MoA were applied in the final report; completion of Zambia FQA survey, analysis of Zambian fertilizer samples; Uganda FQA was conducted, samples and data analyzed, preliminary report submitted to MoA.
1.4 Development of the IFDC Institutional Database		
Development of an institutional database (cross-cutting with Workstream 2)	Global	Cloud-based data management system for agronomic and socioeconomic research in development through a partnership with the University of the Florida’s AgMIP team.
1.5 Lessons Learned from Evaluation of Soil Test Kits		
Soil test kit evaluation and presentation of lessons learned	Global	Report prepared for USAID. Exploring opportunities for site- and region-specific applications in SSA, Nepal, and Myanmar.

Theme/Activities	Countries	Output/Deliverable
1.6 Sustainable Soil Fertility Prioritization in Sub-Saharan Africa		
Sub-award to Kansas State University (KSU) to prioritize soil fertility issues in SSA, identifying key barriers and sustainable solutions	West Africa (Burkina Faso, Ghana, Mali, Niger, Senegal); East Africa (Kenya and Tanzania); Great Lakes Area (Burundi, Malawi, Rwanda, Uganda); and Ethiopia	Surveying, reporting, and workshop led by KSU.
Workstream 2: Fertilizer Market Development, Policy Reforms, and Regulatory Structures Promoted		
2.1 Supporting Policy Reform Processes and Market Development		
Documenting policy reform processes and fertilizer market development	SSA	Two policy briefs – Ghana and Uganda
Providing technical support to policy reform and fertilizer market development processes (country level) FAO/IFDC collaboration to assess impact of centralized procurement of fertilizers in Tanzania	Tanzania	IFDC participated in discussions with Ministry of Agriculture and FAO officials and presented preliminary findings at a stakeholder workshop. One final technical report shared with Ministry of Agriculture and donors.
Engagement with partners in support of policy reforms (both country and regional level) • African Union Commission (AUC) – Malabo-CAADP technical network	SSA	Participation in three policy and accountability meetings with AU CAADP networks for technical support activities to implement the Malabo Strategy.

Theme/Activities	Countries	Output/Deliverable
Fostering policy dialogue – A joint policy workshop with AGRA on various models of fertilizer subsidies and the way forward in implementing fertilizer subsidies in Africa and Asia	SSA and Asia	Presentation and participation in discussions on fertilizer subsidy approaches and best modality in SSA at the AGRA workshop on fertilizer subsidies (1).
Collaboration with AGRA to assess/review fertilizer subsidy implementation in 10 countries in SSA		One synthesis report on fertilizer subsidy model(s) with recommendations in SSA (in partnership with AGRA). 10 country draft reports assessing subsidy programs.
Support to ECOWAS countries on fertilizer policies and input subsidy issues		Participation in USAID West Africa Fertilizer Program (WAFP) workshop on "Fertilizer Subsidy Programs: How Can Better Use of the So-Called 'Necessary Evil' Be Made?" to share experiences from East and Southern Africa.
Collaboration with Fertilizer Association of India (FAI) to compare Asian subsidy programs and experiences in Africa		IFDC-FAI Asia-Africa Subsidy Review published (1).
2.2 Impact Studies		
Harmonization of fertilizer quality and regulatory frameworks (in collaboration with BFS Workstream 1 activity on fertilizer quality), focusing on status of fertilizer quality regulatory frameworks in the East and Southern Africa region, specifically Kenya and Zambia, to identify potential benefits and costs of reforms	Kenya, Zambia, Uganda	Two meetings held with Kenya's Ministry of Agriculture to discuss key findings from quality survey and also plans for stakeholder meeting in 2018. One draft report on fertilizer quality assessment in Kenya. Conducted national quality survey in Uganda (April/May). Zambia and Uganda – laboratory analysis ongoing.
Agro-dealer development on input adoption, input market development, and access and sustainability	Global	One synthesis brief on lessons learned from IFDC's experience in implementing agro-dealer development programs.

Theme/Activities	Countries	Output/Deliverable
Collaboration with Michigan State University toward assessment of second generation fertilizer subsidy models across SSA countries	SSA	MSU-IFDC Subsidy Review published (1).
IFDC received an award for policy impact work with MSU researchers	SSA	Bruce Gardner Memorial Prize for Applied Policy Analysis for farm input subsidy programs in sub-Saharan Africa, 2017 AAEA Annual Meeting, Chicago.
2.3 Economic Studies		
Fertilizer cost-build-up/market margin analysis	Ghana, Kenya	Two reports on fertilizer cost build-up
2.4 Document Data on Fertilizer Markets and Trade		
The African Fertilizer Access Index (TAFAI) – Identification of preliminary set of indicators through peer consultations and literature review	SSA	One IFDC/AFAP work plan meeting. Preliminary report on literature review and set of indicators identified.

Annex 2. List of Publications and Presentations

Publications List

Agyin-Birikorang, S., J. Fugice, U. Singh, J. Sanabria, and S. Choudhuri. 2017. "Nitrogen Uptake Kinetics of Key Staple Cereal Crops in Different Agro-Ecological Regions of the World," Journal of Plant Nutrition, 40(7):995-1023. doi: 10.1080/01904167.2016.1262408.

Synopsis: Existing complete experimental data and an extensive literature review were utilized together with crop simulation models (CSMs) to synthesize yield and N uptake profiles of key staple cereal crops in selected agro-ecologies. The study shows that: (a) N uptake continued to increase with time until physiological maturity with adequate N supply; (b) N uptake profile was influenced by the planting date; (c) field methods of N application influenced N uptake kinetics; (d) N uptake was dependent on crop cultivars; and (e) predictions suggested that modest changes in ambient temperature and atmospheric carbon dioxide concentrations would not significantly alter the N uptake kinetics, with the uptake rate expected to increase under future climate change scenarios. The combined data suggest that no one N uptake kinetic pattern fits all crops under all environments and management practices.

Agyin-Birikorang, S., J.H. Winings, X.H. Yin, U. Singh, and J. Sanabria. *In Review*. "Agronomic Effectiveness of a Multi-Nutrient Fertilizer Briquettes for Upland Crop Production," *Nutrient Cycling in Agroecosystems*.

Synopsis: An organically enhanced N fertilizer was used as an alternative N source to commercially available N fertilizers. The combined data suggest that the organically enhanced N fertilizer could be an alternative N source for crop production, with additional environmental benefits, including encouraging recycling of municipal and domestic waste and as sources of N, P, S, Fe, and organic matter.

Angle, J.S., U. Singh, C.O. Dimkpa, P.S. Bindraban, and D.T. Hellums. 2017. "Role of Fertilisers for Climate-Resilient Agriculture," *Proceedings of the International Fertiliser Society*, 802.

Synopsis: Both chemical and organic fertilizers impact upon the release of greenhouse gases into the atmosphere, increasing or decreasing emissions depending on how they are used. This study assesses their impact and analyzes fertilizer management practices and products, such as enhanced efficiency fertilizers, balanced fertilizer formulations, and microbes (biofertilization), that increase food production and mitigate climate change.

Confaloneiri, R., S. Bregaglio, M. Adam, F. Ruget, T. Li, T. Hasegawa, K. Boote, U. Singh, J. Fugice, et al. 2016. "A Taxonomy-Based Approach to Shed Light on the Babel of Mathematical Models for Rice Simulation," *Environmental Modelling and Software*, 85:332-341. doi: 10.1016/j.envsoft.2016.09.007.

Synopsis: For most biophysical domains, differences in model structures are seldom quantified. A taxonomy-based approach was used to characterize 13 rice models. Results indicated that differences in structure often resulted in similar predictions and similar structures can lead to large differences in model outputs. User subjectivity during calibration may have hidden expected relationships between model structure and behavior.

De Boef, Walter S., Latha Nagarajan, and Carl Pray. 2016. "Promoting Commercial and Sustainable Supply of Early Generation Seed of Food Crops in Sub-Saharan Africa," Synthesis of joint activities implemented by the Bill & Melinda Gates Foundation, U.S. Agency for International Development (USAID), and Alliance for a Green Revolution in Africa (AGRA).

Dimkpa, C.O., and P.S. Bindraban. 2017. "Nanofertilizers: New Products for the Industry?" *Journal of Agricultural and Food Chemistry*. doi: 10.1021/acs.jafc.7b02150.

Synopsis: Nanotechnology can both enhance crop productivity and reduce nutrient losses. Here, we highlight the science-based evidence and outstanding concerns for motivating fertilizer industry production of nanofertilizers, including the notion of toxicity associated with nano-scale materials; scant nanofertilizer research with key crop nutrients; inadequacy of soil- or field-based studies with nanofertilizers; type of nanomaterials to produce as fertilizers; how to efficiently and effectively apply nanofertilizers at the field-scale; and the economics of nanofertilizers. It is anticipated that the development and validation of nanofertilizers that are non-disruptive to existing bulk fertilizer production systems will motivate the industry's involvement in nanofertilizers.

Dimkpa, C.O., P.S. Bindraban, J. Fugice, S. Agyin-Birikorang, U. Singh, and D.T. Hellums. 2017. "Composite Micronutrient Nanoparticles and Salts Decrease Drought Stress in Soybean," *Agronomy for Sustainable Development*, 37(5). doi: 10.1007/s13593-016-0412-8.

Synopsis: Drought decreases crop productivity, with economic consequences for farmers. In this paper, we evaluated the mitigation of drought stress in soybean using composite formulations of three micronutrient nanoparticles, ZnO, B_2O_3, and CuO, and their salts: $ZnSO_4.7H_2O$, H_3BO_3, and $CuSO_4.5H_2O$, in a greenhouse. On average, the formulations reduced drought effects by increasing shoot growth by 33% and grain yield by 36%. On average, the formulations increased shoot N by 28%, K by 19%, Zn by 1080%, B by 74%, and Cu by 954%. Likewise, the formulations on average increased grain N by 35%, K by 32%, Zn by 68%, B by 56% and Cu by 13%. In contrast, drought did not alter shoot P, but the formulations on average reduced shoot P by 33%. Whereas micronutrient salts are known to reduce drought effects in plants, our findings demonstrates for the first time a novel use of micronutrient nanoparticles to boost crop performance and N and P uptake under drought stress.

Dimkpa, C.O., P.S. Bindraban, J.E. McLean, L. Gatere, U. Singh, and D.T. Hellums. 2017. "Methods for Rapid Testing of Plant and Soil Nutrients," *Sustainable Agriculture Reviews*. 25:1-44. doi: 10.1007/978-3-319-58679-3_1.

Synopsis: In this review paper, we identified rapid soil and plant nutrient testing technologies, currently in the market, based on a web search, and evaluated the basis for deploying them as alternative nutrient analytical systems. Thirty six of such applications were identified, out of which only 5 are dedicated solely to plant analysis. Collectively, the functioning mechanisms of most of the products were found to be based on colorimetry, spectroscopy or sensor technology. However, in comparison with traditional wet chemistry methods, the accuracy of the products is yet to be fully resolved, given the paucity of data in that regard. Subsequently, we reflected upon the effectiveness of the products in generating relevant information to guide rationale fertilizer recommendations, and in that context discussed the concept of balanced fertilizer regimes that consider soil levels of different nutrients; associated soil factors that determine nutrient bioavailability and actual uptake by crops; and complex farming systems that may undermine the precision and efficiency of fertilizer application.

Dimkpa, C.O., J.C. White, W.H. Elmer, and J. Gardea-Torresdey. 2017. "Nanoparticle and Ionic Zn Promote Nutrient Loading of Sorghum Grain Under Low NPK Fertilization," *Journal of Agricultural and Food Chemistry*, 65 (39):8552–8559. doi: 10.1021/acs.jafc.7b02961.

Synopsis: This study evaluated the effects of ZnO nanoparticles (NP) or Zn salt amendments on sorghum yield, macronutrient use efficiency, and grain Zn-enrichment. Across NPK levels and Zn exposure pathways, both Zn types increased N and K accumulation relative to control plants. Compared to N and K, both Zn types had a mixed effect on P accumulation, depending on NPK level and Zn exposure pathway, and permitted greater soil P retention. Both Zn types significantly increased grain Zn content, irrespective of exposure pathway. The findings of the study suggest a nano-enabled strategy for enhancing crop productivity, grain nutritional quality, and N use efficiency based on Zn micronutrient amendments, with potential implications for improved human and environmental health.

Elmer, W., R. De La Torre-Roche, L. Pagano, S. Majumdar, N. Zuverza-Mena, C. Dimkpa, J. Gardea-Torresdey, and J.C. White. *In Review*. "Effect of Metalloid and Metallic Oxide Nanoparticles on *Fusarium* Wilt of Watermelon," *Plant Disease*.

Synopsis: Nanoparticles (NP) of metallic oxides have great potential in agriculture as a means to deliver micronutrients, such as Cu, Mn, and Zn. A series of greenhouse trials were conducted to assess the effectiveness of NPs of metallic oxides and a source of micronutrients and disease suppression agents. In all studies, NP CuO reduced disease progression (area under the disease-progress curve [AUDPC]) and increased fresh plant mass when compared to untreated controls, other NPs, or to the corresponding bulk oxide equivalents. A single application of CuO NPs to the seedlings produced a mean 53% increase in fruit yield when compared to untreated controls. Results from the various evaluations suggest that NP CuO could serve as a highly effective micronutrient and disease suppression agent. Additional work is needed to optimize potential treatment platforms.

Fuentes, P. 2017. *In Review*. "Expected Effects and Benefits of Regional Economic Integration for Agro-Inputs and -Output Trade," *Perspectives*, IFDC Quarterly Magazine, Muscle Shoals, AL, USA.

Synopsis: The article provides a brief description of what regional economic integration is and the economics implications of its implementation at a country and regional levels, to then lay out the expected social and economic benefits from increasing trade of agro-inputs and of agricultural products among the regionally integrate countries and the region as whole.

Fuentes, P. 2017. "Transitioning to Market-Oriented Fertilizer Distribution Systems: Transitioning from Government Control to Larger Private Sector Participation in the Ghanaian Fertilizer Market," IFDC-SFT policy brief series.

Fuentes, P. 2017. "Transitioning to Market-Oriented Fertilizer Distribution Systems: Increasing Fertilizer Consumption through Government Programs, Leading to Agriculture and Private Fertilizer Sectors Growth in Uganda," IFDC-SFT policy brief series.

Gaihre, Y.K., U. Singh, I. Jahan, and G. Hunter. 2017. "Improved Nitrogen Use Efficiency in Lowland Rice Fields for Food Security," *Fertilizer Focus*, March/April.

Synopsis: Fertilizer use has played a crucial role in meeting the food demand of a growing world population. Among the fertilizers, N fertilizer is the main driving force to produce large rice yields under irrigated and favorable rainfed conditions. Farmers usually apply urea as a broadcast method. Much research conducted across countries reported that more than 50% of applied nitrogen is not utilized by crops and lost to the environment as reactive forms (ammonia, nitrate, nitrogen oxides) through volatilization or surface water runoff, contributing to greenhouse gas emissions and other environmental problems such as eutrophication and groundwater pollution. This also results in higher costs for farmers given that N fertilizers generally represent over 10-15% of crop production costs. Therefore, fertilizer management should consider the 4R concept – right methods, right time, right rates, and right sources – to increase use efficiency, crop yield, soil health, and farm profits and to reduce negative environmental effects.

Gaihre, Y.K., U. Singh, S.M.M. Islam, A. Huda, M.R. Islam, J. Sanabria, M.A. Satter, M.R. Islam, J.C. Biswas, M. Jahiruddin, and M.S. Jahan. *Under Revision*. "The Effect of Nitrogen Placement on Nitrous Oxide and Nitric Oxide Emissions and Nitrogen Use Efficiency in Lowland Rice Fields," *Nutrient Cycling in Agroecosystems*.

Synopsis: Urea deep placement (UDP) has demonstrated its benefits of saving N fertilizer and increasing nitrogen use efficiency (NUE) and grain yields. However, studies on its environmental impacts, particularly on nitrous oxide (N_2O) and nitric oxide (NO), are limited. We conducted multi-location field experiments in Bangladesh to determine the effects of UDP versus broadcast prilled urea on N_2O and NO emissions, NUE, and rice yields. Of the N placement methods, UDP increased grain yields by 13% during the *Aman* season and gave similar yields in spite of lower N application during the *Aus* season. UDP increased N recovery from 25% and 16% of broadcast PU to 61% and 73% during the *Aus* and the *Aman* seasons, respectively, in one site, but recovery was similar at another site. On the other hand, alternate wetting and drying irrigation reduced grain yield and N recovery at the Bangladesh Rice Research Institute (BRRI) site during the *Aman* season.

Gaihre, Y.K., R. Wassmann. G. Villegas-Pangga, J. Sanabria, E. Aquino, P.C. Sta. Cruz, and E.P. Paningbatan. 2016. "Effects of Increased Temperatures and Rice Straw Incorporation on Methane and Nitrous Oxide Emissions in a Greenhouse Experiment with Rice," *European Journal of Soil Science*, 67:868-880. doi: 10.1111/ejss.12389.

Synopsis: Greenhouse gas (GHG) emissions were measured from flooded rice soil under elevated temperatures. Temperature, straw incorporation, and rice plants affected daily variation in methane emissions. An increase in temperature increased methane emissions by up to 91%. Increased temperature decreased methane emissions when background temperature was above 34-35°C.

Gisselquist, David, Latha Nagarajan, Carl Pray, and Anwar Naseem. 2017. "Synthesis of EGS Studies for Ghana, Malawi, Mozambique, and Tanzania," Policy brief submitted to USAID funded Scaling Seeds for Technology Partnership (SSTP).

Islam, S.M.M., Y.K. Gaihre, J.C. Biswas, M.S. Jahan, U. Singh, S.K. Adhikary, M.A. Satter, and M.A. Saleque. *In Review*. "Different Nitrogen Rates and Methods of Application for Dry Season Rice Cultivation with Alternate Wetting and Drying Irrigation: Fate of Nitrogen and Grain Yield," *Paddy and Water Environment*.

Synopsis: Fertilizer deep placement (FDP) and alternate wetting and drying (AWD) improve both fertilizer and water use efficiency in rice production. Field experiments were conducted in the dry seasons during 2014-2016 to determine the interaction effect of fertilizer x water regime on N losses as floodwater ammonium and ammonia volatilization, grain yields, and NUE. Deep placement of urea briquettes (UB) and NPK increased N recovery up to 57-66% from 36% of prilled urea. These results suggest that UB and NPK can be utilized under AWD not only for increased grain yield and NUE but also to reduce additional pumping cost for growing dry season irrigated rice in Bangladesh. When combined with deep placement, the reported advantages of AWD for improving water use efficiency and methane emissions become a more attractive option. However, the effects of NPK on yield under AWD condition varied with years, suggesting the need for long-term experiments on site-specific nutrient management across different rice-growing areas and seasons to reach conclusive results.

Islam, S.M.M., Y.K. Gaihre, A.L. Shah, U. Singh, M.I.U. Sarkar, M.A. Satter, J. Sanabria, and J. Biswas. 2016. "Rice Yields and Nitrogen Use Efficiency with Different Fertilizers and Water Management Under Intensive Lowland Rice Cropping Systems in Bangladesh," *Nutrient Cycling in Agroecosystems*, 106:143. doi: 10.1007/s10705-016-9795-9.

Synopsis: Optimum nitrogen rates and methods of application increase crop productivity and farm income while reducing negative environmental effects. Field experiments were conducted during four consecutive rice-growing seasons in 2012-2013 to determine the effects of different N rates and methods of fertilizer application on floodwater ammonium concentration, rice yields, and N use efficiency under two water regimes: continuous standing water (CSW) and alternate wetting and drying (AWD). Fertilizer treatments included the use of deep-placed urea briquettes (UB) and NPK briquettes (NPK), broadcast prilled urea (PU), and a control (without nitrogen). Deep-placed fertilizer treatments, irrespective of N rates and water regimes, reduced floodwater ammonium similar to the control treatment, while the broadcast PU treatment caused floodwater ammonium to increase as N rates increased. Deep placement of fertilizer above 52 and 78 kg N/ha during the *Aus-Aman* seasons (wet seasons) and the *Boro* season (dry season), respectively, had no significant effects on grain yields but reduced N recovery. Deep placement of 30% less N compared to broadcast PU significantly increased N recovery (30-35% versus 48-55%). AWD irrigation increased grain yield by 16%, along with increased harvest index, particularly under deep-placed treatments.

Jayne, T.S., N.M. Mason, W. Burke, and J. Ariga. 2017. "Taking Stock of Africa's Second-Generation Agricultural Input Subsidy Programs, 2000–2015," *Feed the Future Innovation Lab for Food Security Policy Research Brief 34*, East Lansing: Michigan State University.

Jayne, T., N. Mason, W. Burke, and J. Ariga. 2017. *In Review*. "Taking Stock of Africa's Second-Generation Agricultural Input Subsidy Programs, 2000-2015," *Food Policy*, submitted October 2017.

Input subsidy programs (ISPs) have proven effective in raising national food production quickly, but by considerably less than was originally envisioned. Hence, most recent ISPs in Africa have had contributed only weakly to economic growth processes. Nevertheless, there remains strong potential for ISPs to more effectively catalyze farm productivity growth and contribute to other development goals such as resilience and climate smart agriculture if

ISPs were part of a more comprehensive strategy that focuses on helping farmers to use fertilizer more efficiently and profitably.

Nagarajan, L., A. Naseem, and C. Pray. 2016. "The Political Economy of Genetically Modified Maize in Kenya," *AgBioForum*, 19(2):198-214.

Synopsis: Genetically modified (GM) crops have never been approved for commercialization in Kenya, but debates on their suitability have been going on for more than a decade. This article explores these debates in the context of GM maize in Kenya to better understand the positions of the different groups, and whether there is scope for policy change that would lead to the cultivation of GM crops. A multimarket economic surplus approach is employed to estimate disaggregated benefits. The results of the surplus analysis modeling are evaluated in the context of the wider GM crop debate in Kenya and the stated positions of the different stakeholders.

Nand, M.M., V. Iese, U. Singh, M. Wairiu1, A. Jokhan, and R. Prakash. 2016. "Evaluation of Decision Support System for Agrotechnology Transfer SUBSTOR Potato Model (v4.5) Under Tropical Conditions," *The South Pacific Journal of Natural and Applied Sciences*, 34:1-11.

Synopsis: Potato is gaining popularity in many tropical countries. SUBSTOR potato model was calibrated for local conditions. The study showed that the SUBSTOR Potato model has good potential to simulate potato in Fiji and can assist farmers to optimize conditions to increase and sustain yield.

Raliya, R., V. Saharan, C.O. Dimkpa, and P. Biswas. 2017. "Nanofertilizer for Precision and Sustainable Agriculture: Current State and Future Perspectives," *Journal of Agricultural and Food Chemistry*. doi: 10.1021/acs.jafc.7b02178.

Synopsis: Due to resource constraints and low use efficiency of fertilizers, the cost to the farmer is increasing dramatically. Nanotechnology offers great potential to tailor fertilizer production with the desired chemical composition, improve the nutrient use efficiency that may reduce environmental impact, and boost the plant productivity. A review of nanotechnology-based smart and precision agriculture is discussed in this paper. Scientific gaps to be overcome and fundamental questions to be answered for safe and effective development and deployment of nanotechnology are addressed.

Rietra, R.P.J.J., M. Heinen, C.O. Dimkpa, and P.S. Bindraban. *In Review*. "Effects of Nutrient Antagonism and Synergism on Yield and Fertilizer Use Efficiency," *Communications in Soil Science and Plant Analysis*.

Synopsis: Interaction among plant nutrients can yield antagonistic or synergistic outcomes that influence nutrient use efficiency. To provide insight on this phenomenon, a comprehensive literature review was carried out to quantify the interaction effects of nutrients on crop yield levels. The general findings were: (a) when the availability of two nutrients is characterized as deficient, a large increase in yield can be expected by diminishing these deficiencies; (b) for most macronutrients, the mutual interactions on yield levels are synergistic; and (c) antagonistic effects on yield are often found for divalent cations. Knowledge of nutrient interactions can guide fertilizer design and optimization of fertilization strategies for high yields and high nutrient use efficiencies.

Romasanta, R.R., B.O. Sander, Y.K. Gaihre, M.C. Alberto, et al. 2017. "How Does Burning of Rice Straw Affect CH4 and N2O Emissions? A Comparative Experiment of Different On-Field Straw Management Practices," *Agriculture, Ecosystems and Environment*, 239:143-153. doi: 10.1016/j.agee.2016.12.042.

Synopsis: Open-burning of rice straw residues pollutes the air and contributes to global warming through GHG emissions. In this study, we determined the emission factor of methane and nitrous oxide emissions from burning rice straw. At constant straw moisture of 10%, the mass-scaled Emission Factors (EF_m) were 4.51 g CH_4 and 0.069 g N_2O per kg dry weight of straw.

Winings, J.H., X. Yin, S. Agyin-Birikorang, U. Singh, J. Sanabria, H.J. Savoy, F.L. Allen, and A.M. Saxton. 2017. "Agronomic Effectiveness of an Organically Enhanced Nitrogen Fertilizer," *Nutrient Cycling in Agroecosystems*, 108(2):149-161. doi: 10.1007/s10705-017-9846-x.

Synopsis: With tighter environmental regulations and increasing energy costs over time, approaches to minimize losses from commercially available N fertilizers have become more critical in recent times. An organically enhanced N fertilizer (14.9% N, 4.3% P_2O_5, 18.1% S, 0.6% Fe, and 3.3% organic C) was used as an alternative N source to commercially available N fertilizers. The combined data suggest that the organically enhanced N fertilizer could be an alternative N source for crop production, with additional environmental benefits, including encouraging recycling of municipal and domestic waste and as sources of N, P, S, Fe, and organic matter.

Winings, J.H., X. Yin, S. Agyin-Birikorang, U. Singh, J. Sanabria, H.J. Savoy, F.L. Allen, A.M. Saxton, and J.L. DeForest. 2016. "Changes of Soil Microbial Population and Structure Under Short-Term Application of an Organically Enhanced Nitrogen Fertilizer," Soil Science, 181(11/12):494-502. doi: 10.1097/SS.0000000000000182.

Synopsis: Interest in the use of alternate fertilizers has increased during recent years to improve soil productivity. An organically enhanced N fertilizer, containing 14.9% N, 4.3% P_2O_5, 18.1% S, 0.6% Fe, and 8% organic C, which was produced from a sterilized organic additive extracted from municipal wastewater biosolids and chemical fertilizers, was evaluated to determine its effects on soil microbial populations and abundances. Results from the studies suggest that long-term application of the fertilizer product could have a positive influence on soil health and improve soil productivity.

Wohab, M.A., Y.K. Gaihre, A.T.M. Ziauddin, and M.A. Hoque. 2017. "Design and Field Evaluation of Manual-Operated Applicators for Fertilizer Deep Placement in Puddled Rice Fields," *Agricultural Research*. doi: 10.1007/s40003-017-0267-5.

Synopsis: Urea deep placement increases nitrogen use efficiency, rice yields, and farm profitability compared to conventional broadcast urea. However, labor shortages for deep placement pose constraints to wider adoption. Therefore, two types of manually operated applicators, an "injector-type" (non-continuous operation) and "push-type single row" (continuous operation), were designed to deep-place fertilizer briquettes in puddled rice fields. Applicators consistently placed urea briquettes at proper depth (5-7 cm) and spacing under most rice field conditions. Grain yields of applicator-placed urea briquettes were similar to hand-placed urea briquettes.

Presentations at Professional Meetings

Agyin-Birikorang, S., F. Bidjokazo, A. Mando, and R. Issahaku. 2016. "Evaluation of the Effectiveness of Urea Deep Placement (UDP) Technology for Upland Maize Production," Presented at the 2016 ASA, CSSA and SSSA International Annual Meetings, Phoenix, AZ, USA.

Field trials were conducted in three communities in northern Ghana to evaluate effectiveness of UDP technology for upland maize production, using three maize varieties of differing maturity periods (early, medium- and late-maturing varieties) as test crops. Urea briquettes were applied at two time periods (4 and 6 weeks after planting) to evaluate the effects of application time on the briquette's effectiveness. Results showed that time of briquette application is critical to the effectiveness of the UDP technology for upland maize production and, for medium- and late-maturing maize varieties, the briquettes must be applied to the maize plants by the fourth week after planting.

Agyin-Birikorang, S., W. Dogbe, and C. Boubakary. 2017. "Climate-Resilient Soil Fertility Management Strategy for Rice Production in Submergence-Prone Areas in Northern Ghana," Submitted for presentation at the 2017 ASA, CSSA and SSSA International Annual Meetings, Tampa, FL, USA.

Frequent flooding occurring in some parts of northern Ghana has negatively affected lowland rainfed rice production. Previous efforts to mitigate the problem focused mainly on varietal improvement. However, there is the need to find a technological fit between genotypes and nutrient management strategies to ensure sustainable production. Adaptive trials were established in seven communities in northern Ghana to evaluate the effectiveness of UDP technology in improving productivity in submergence-prone areas using the submergence-tolerant rice varieties, NERICA L-19 and NERICA L-49 as test varieties.

Agyin-Birikorang, S., U. Singh, J. Fugice Jr., W. Bible, J. Sanabria, and V. Henry. 2016. "Evaluation of Agronomic Effectiveness of Activated Phosphate Rock," Presented at the 2016 ASA, CSSA and SSSA International Annual Meetings, Phoenix, AZ, USA.

Unlike water soluble phosphorus (P) fertilizers, most phosphate rocks (PRs) are relatively insoluble and non-reactive in agricultural soils, particularly in neutral to alkaline soils. One innovative and practical approach to enhancing PR agronomic efficiency is "activation" of the PRs with water soluble P (WSP) fertilizers. In greenhouse studies, unreactive PR was activated with a modest amount of WSP at a ratio of 20% WSP to 80% PR (4:1 PR/WSP ratio = "0.2 Activation") and evaluated on three soils with varying acidity/alkalinity level (Hiwassee loam – 5.49, Greenville loam – 6.80, and Sumter – 7.57) using rice and soybeans during the spring/summer seasons and wheat during the winter season. Irrespective of the soil, crop, and planting season, significant improvement in the agronomic effectiveness of the "activated" PR was observed, with an average relative agronomic effectiveness (RAE) value greater than 80%. The combined results suggest that the combination of a modest amount of WSP with PR could be a cost-effective means of enhancing P availability in PRs without the soil pH constraint on the agronomic effectiveness of PRs.

Ariga, J. 2017. "Insights on SSA Fertilizer Subsidies: Lessons Learned and Way Forward," Presented at WAFP Regional Result and Experience Sharing Workshop on Results and Lessons Learned from West African Countries' Fertilizer Subsidy Programs, Bamako, Mali.

Ariga, J. 2017. Participated in the conference on The Role of Agri-Food Systems in Promoting Industrialization in Tanzania, organized by USAID, the World Bank, JICA, and Michigan State University, Dar es Salaam, Tanzania.

Ariga, J., and P. Fuentes. 2016. "Insights on Sub-Saharan Africa Subsidies: Lessons Learned and Way Forward," Presented at the AGRA subsidy study in SSA validation workshop, Nairobi, Kenya.

Bible, W., U. Singh, Y. Gaihre, J. Sanabria, and R. Austin. 2016. "Quantifying Nitric Oxide Emissions Under Rice-Wheat Cropping System," Presented at the 2016 ASA, CSSA and SSSA International Annual Meetings, Phoenix, AZ, USA.

Enhanced-efficiency fertilizers (EEF) and enhanced-efficiency fertilizer application (EEFA) are effective for mitigating N2O and NO emissions. NO is an environment pollutant that participates in photochemical reactions in the troposphere that produces ozone. NO also contributes to the formation of fine particles (PMStudies on the effects of EEF and EEFA on NO emissions are lacking, particularly in flooded rice fields and in rice-based cropping systems where soils alternate between anaerobic and aerobic conditions.   NO results for flooded rice followed by wheat is presented for treatments comprising EEFA, conventional N application, and alternate-wetting and drying. Overall NO emission factor for flooded rice ranged from -0.006-0.02% compared with 0.02-0.15% for wheat.

Dimkpa, C.O. 2016. "Nanotechnology in Crop Fertilization: What Would Motivate the Fertilizer Industry?" Presented at the International Conference on Nanotechnology Applications and Implications of Agrochemicals Toward Sustainable Agriculture and Food Systems, Beijing, China.

The high bioreactivity of nanomaterials (nanoparticles) has led to the potential for their application in a variety of systems, including agriculture and food. Currently, nanofertilizers as a concept is still at the rudimentary stage. This presentation provides existing evidence to motivate industry investment in the technology while addressing concerns of practical applicability of the technology to the fertilizer industry.

Dimkpa, C.O. 2017. "Impact of Nanomaterials in Soils," Presented at the XXXVI Brazilian Congress of Soil Science, Belém City, Brazil.

The extensive use of nanomaterials implies that they have the potential to become constituents of the soil either by deliberate use, or inadvertent contamination during production or from disused nano-containing products. Due to their smaller size and greater surface area, nanomaterials readily react with, and affect, biological systems to greater extents than bulk materials of similar chemistry. This presentation explores the effects of soil on metallic nanoparticles, in order to understand how specific soil properties can transform nanoparticles and modulate their impacts on soil-based Biosystems.

Dimkpa, C.O., D.T. Hellums, U. Singh, and P.S. Bindraban. 2017. "The Role of Mineral Fertilizers in Climate-Resilient Agriculture: Focus on Myanmar," Presented at the Myanmar Soil Fertility and Fertilizer Management Conference, Nay Pyi Taw, Myanmar.

Use of mineral fertilizers has permitted at least 50% of global food production. However, use of fertilizers could have negative environmental consequences contributing to climate change. Appropriate use of existing N fertilizers, development of new N fertilizers with improved uptake efficiency, and balancing fertilizer composition to include secondary and

micronutrients can mitigate both the contribution of fertilizer to climate change and the impact of climate change on agriculture. This paper addresses the role of fertilizers in a changing climate where drought, salinity, pests, and diseases incidences are heightened. Strategies to enhance fertilizer use efficiency toward engendering a climate-resilient production system are discussed for rice, the predominant crop in Myanmar.

Fuentes, P. 2016. "Fertilizer Bulk Procurement, Supply Cost Build-Up, and Cost Savings Transmission Monitoring System for Tanzania," Presented and led discussions at a MALF-FAO-IFDC-Industry and other stakeholders meeting in Dar es Salaam, to kickstart technical assistance to the MALF/Government of Tanzania on policies addressing the consolidation of national procurement of fertilizer.

Fuentes, P., 2016. "Proposed Subsidy Model for Mozambique and Uganda," Presented as Mozambique and Uganda group moderator during the AGRA subsidy study in SSA validation workshop, Nairobi, Kenya.

Fugice Jr., J., U. Singh, S. Agyin-Birikorang, and W. Bible. 2016. "Comparison of Portable Soil Test Kits for Smallholder Farmers," Presented at the 2016 ASA, CSSA and SSSA International Annual Meetings, Phoenix, AZ, USA.

Based on the recognition that portable soil test kit would facilitate smallholder farmers to have an onsite capability for soil analyses the following soil test kits were evaluated against standard laboratory tests: Hach, SoilDoc, and Kasetsart University (KU) soil test kits. The comparison of results from these soil test kits and wet-chemistry method is presented for a wide range of soils. Modifications to improve the kits are also discussed.

Gaihre, Y.K., S.M.M. Islam, U. Singh, M.R. Islam, and J.C. Biswas. 2017. "Producing More Rice with Less Fertilizers: Determining Optimum Nitrogen Rate and Placement Method for Lowland Rice Cultivation," Presented at the International Conference on Innovative Solutions for Sustainable Management of Nitrogen, Aarhus University, Denmark.

Field studies were conducted across different locations in Bangladesh using different N rates and methods of application (deep placement versus broadcast). Grain yields, NUE, and nitrogen loss as ammonia volatilization, N_2O, and NO emissions were measured continuously throughout rice-growing and fallow seasons using an automated gas sampling and analysis system under two irrigation regimes – alternate wetting and drying (AWD) and continuous flooding (CF). Results of multi-location experiments confirmed the multiple benefits of UDP, including reduced nitrogen losses through ammonia volatilization and greenhouse gas N_2O and NO emissions. Across the years and sites, UDP increased yield on average by 21% as compared to broadcast urea while using at least 25% less fertilizer. The magnitude of increase was larger under AWD, because AWD significantly reduced grain yields (8%) compared to CF at broadcast urea. However, yields with UDP were similar between AWD and CF. UDP reduced N_2O emissions by up to 80% as compared to broadcast urea under CF irrigation. The effects of UDP on N_2O emissions under AWD irrigation practices were site-specific, depending on the duration and intensity of soil drying; emissions were reduced under mild soil drying but increased with more intense soil drying. With the reduction of losses and increased plant uptake, UDP increases N use efficiency up to 80% compared to 30-45% with broadcast application. These results, along with other studies conducted across different locations in Bangladesh, suggest that UDP could be one of the

best management techniques to achieve the multiple benefits of increasing grain yields, farm profits, and nitrogen use efficiency while reducing negative environmental effects.

Gaihre, Y.K., U. Singh, A. Huda, S.M.M. Islam, M.R. Islam, J.C. Biswas, and J. DeWald. 2016. "Nitrogen Use Efficiency, Crop Productivity and Environmental Impacts of Urea Deep Placement in Lowland Rice Fields," Presented at the International Initiative Conference on Solutions to Improve Nitrogen Use Efficiency for the World.

UDP in lowland rice fields is one of the best currently applicable management techniques to increase N use efficiency (NUE) and crop productivity. Multi-location experiments conducted in Bangladesh in 2014-2015 have demonstrated several benefits of UDP use, including reduced N losses through ammonia volatilization and greenhouse gas N_2O and NO emissions. Across the years and sites, UDP increased yield, on average, by 21% as compared to broadcast urea while using at least 25% less fertilizer. UDP reduced N_2O emissions by up to 80% as compared to broadcast urea under continuous flooded (CF) conditions. These results confirm that UDP not only increases NUE and grain yields but also reduces negative environmental impacts, including N_2O emissions.

Gaihre, Y.K., U. Singh, S.M.M. Islam, A. Huda, M.R. Islam, and J.C. Biswas. 2017. "Efficient Fertilizer and Water Management in Rice Cultivation for Food Security and Mitigating Greenhouse Gas Emissions," Presented at the Myanmar Soil Fertility and Fertilizer Management Conference, Nay Pyi Taw, Myanmar.

Increasing nitrogen fertilizer application has increased crop productivity and met the food demands of growing populations, but its use efficiency is very low. FDP is one of the best currently applicable management techniques to achieve these multiple benefits. Multi-location experiments were conducted in Bangladesh to determine the effects of UDP and multi-nutrient fertilizer briquette (NPK) deep placement versus broadcast prilled urea (PU) on rice yields, nitrogen use efficiency, and nitrogen losses, including floodwater ammonium, ammonia volatilization, and nitrous oxide emissions. Deep placement of both urea and NPK briquettes in the dry (*Boro*) season increased grain yields. Across the years, the average observed yield increase was 30% compared to broadcast PU. Deep placement significantly reduced nitrogen losses compared to broadcast PU. Moreover, UDP reduced nitrous oxide emissions by 70% as compared to broadcast PU.

Hellums, D.T. 2017. Participated in the Sustainable Soil Fertility Prioritization in Sub-Saharan Africa, organized by KSU-Feed the Future Innovation Lab for Collaborative Research on Sustainable Intensification, to discuss and prioritize survey results on critical soil fertility issues in Sub-Saharan Africa, Dakar, Senegal.

Nagarajan, L. 2016. "ATT-Ghana Project Initiative of IFDC," Presented at the USAID-IFPRI Start-up Workshop and Roundtable Discussions on the G-CAN Initiative: Gender-responsive and Climate-Resilient Agriculture for Nutrition, Washington, D.C., USA.

Nagarajan, L. 2016. Participated in the two-day BFS-USAID workshop on Agri-Food System Policy for the Global Food Security Strategy, Washington, D.C., USA.

Nagarajan, L., R. Jones, and V. Rweyendela. 2017. "Comparative Analysis of Early Generation Legume Seeds Production and Delivery in Seed Channels in Tanzania," Presented at the conference on New Models for Legume Seed Business: Resilience, Nutrition, and Reaching Farmers at the Last Mile, Washington, D.C., USA.

Nagarajan, L., R. Jones, and V. Rweyendela. 2017. "Efforts to Promote Quality Seed Supply in Legume Crops: Models in Practice in Tanzania," Presented at the AGRILINKS/MICROLINKS–BFS USAID Special Policy Seminar on Not All Seed Is Declared Equal: Improving Access Washington, D.C., USA. https://agrilinks.org/events/not-all-seed-declared-equal-improving-access

Nagarajan, L., A. Naseem, and C.E. Pray. 2017. "An Economic Analysis of Early Generation Seed (EGS) Production and Delivery in Sub-Saharan Africa Seed Systems," Presented at the annual meetings of the International Consortium on Applied Bioeconomy Research (ICABR), University of California, Berkeley, CA, USA.

Nagarajan, L., C. Pray, and R. Jones. 2016. "Synthesis of EGS Country Studies: Ghana, Malawi, Mozambique and Tanzania," Presented at the AGRILINKS–BFS USAID Policy Seminar on Strengthening Early Generation Seed (EGS) Systems in Africa and Beyond, Washington, D.C., USA. https://agrilinks.org/events/strengthening-early-generation-seed-systems-africa-and-beyond

Naseem, A., J. Anderson, J. Oehmke, L. Nagarajan, C. Pray, C. Moss, and L. Post. 2017. "Measuring Agricultural and Structural Transformation," Selected paper prepared for presentation at the 2017 Agricultural & Applied Economics Association Annual Meeting, Chicago, IL, USA.

Naseem, A, L. Nagarajan, and C.E. Pray. 2017. "Impact of Seed Innovation and Polices on Maize Productivity in Kenya," Presented at the annual meetings of International Consortium on Applied Bioeconomy Research (ICABR), University of California, Berkeley, CA, USA.

Pray, C.E., and L. Nagarajan. 2017. "Policies and Incentives for Private Agricultural R&D and Innovation: Experiences of Brazil, China and India," Presented at the symposium organized by USDA-ERS, OECD and Farm Foundation on Research and Innovation policies for sustainable productivity growth in agriculture, National Press Club, Washington, D.C., USA.

Pray, Carl, Latha Nagarajan, and Anwar Naseem. 2017. "The Role of Multinational Corporations in the Supply of Agricultural Production Technology in China & India," Presented at the 2017 World Food Policy Conference, The Royal Society of Thailand (RST) and Committee on Foreign Affairs of National Assembly of Thailand and the Policy Studies Organization (PSO), Bangkok, Thailand.

Sanabria, J. 2016. "Fertilizer Quality Assessment in the Myanmar Dry Zone," Presented at the Myanmar Soil Fertility and Fertilizer Management Conference, Nay Pyi Taw, Myanmar.

The Dry Zone Agro-Input and Farm Services project, which is funded by the Livelihoods and Food Security Trust (LIFT) Fund consortium and implemented by IFDC, carried out a fertilizer quality assessment in the Dry Zone of Myanmar. The four fertilizers of highest commercialization in Myanmar's Dry Zone – NPK 15:15:15, NPK 10:10:5, NPK 15:7:8, and NPK 16:16:8 – presented out-of-compliance shortages (OOCS) with frequencies of 9%, 19%, and 23% of the samples for total N, P_2O_5, and K_2O, respectively.

Singh, U., and J. Fugice. 2016. "CERES-Rice Model Improvement Using AgMIP Data," Presented at the 2016 Annual AgMIP-Rice Team Meeting, Nanjing, China.

Increase in climate variability and the greenhouse gases, AgMIP rice team is trying to evaluate the uncertainty of the models to respond to climate variations. CERES-Rice has been adapted to better respond to temperature, CO_2. CERES-Rice has also added the capability to simulate CH4 and N2O emissions.

Singh, U., M. Aung, and J. Fugice. 2017. "Role of Yield Potential and Yield-Gap Analyses on Resource-Use Efficiency Improvement," Presented at the Myanmar Soil Fertility and Fertilizer Management Conference, Nay Pyi Taw, Myanmar.

A systems approach is used to show the effect of genotypic, environmental and management factors on potential yield of rice and maize and the role yield potential and yield-gap analysis plays in fertilizer recommendations. Examples from Myanmar are presented for determining yield potential, yield-gap analyses and identifying appropriate management strategies taking into consideration climatic, soil and management inputs.

Singh, U., D. Hellums, W. Bible, V. Henry, J. Sanabria, and F. Yin. 2017. "Performance of Urea Enhanced with Sulfur," Submitted for presentation at the 2017 ASA, CSSA and SSSA International Annual Meetings, Tampa, FL, USA.

Under field conditions, temperature, rainfall, tillage, and residue management affected the dispersion of ES fertilizer granules. Incubation studies of urea enhanced with ES conducted under laboratory and field conditions also showed that the method of application and the type of fertilizer strongly influenced S oxidation. The effect of ES and ammonium sulfate (AS) on NH_3 volatilization loss following urea application was quantified. Field trial response of S on maize yield and nutrient uptake on application of urea with S is also presented.

Wendt, J. 2017. "Objectives and Overview: The Process from Soil Analyses to Delivering Better Fertilizers to Farmers," Presented at the West Africa Fertilizer Forum, Lomé, Togo.

Synopsis: In this forum overview presentation, the primary objective of the forum was elucidated: to examine ongoing initiatives, and to agree on a more systematic approach to delivering better fertilizers to African farmers. Despite increasing investments, better fertilizers are not reaching smallholder farmers rapidly. This is due to poor coordination, lack of understanding of those involved in the steps needed to get fertilizers developed and delivered, policy and regulatory impediments, lack of product validation, and diverse and sometimes unproductive approaches, resulting in different recommendations. We propose four essential steps to developing and delivering better fertilizers: soil analysis and nutrient deficiency/soil acidity mapping on a macro scale, developing and validating soil- and crop-specific fertilizers, developing the means to produce and deliver better fertilizers with manufacturers, and addressing regulatory issues and policy constraints.

Wendt, J. 2017. "Practical Examples of Nutrient Omission and Best-Bet (Validation) Trials," Presented at the West Africa Fertilizer Forum, Lomé, Togo.

Synopsis: Examples of best-bet and nutrient omission trials from various countries in East Africa are presented, including economic analysis and lessons learned from conducting the trials. One key lesson is that while soil analyses are indicative of deficiencies, economic yield responses were often obtained in soils with nutrient levels well above what was considered "critical". This shows the need to consider soil analysis as indicative only, as leaving out nutrients based on soil analysis alone may result in yield losses.

Wendt, J. 2017. "Principles, Objectives, and Characteristics of Successful Trials," Presented at the West Africa Fertilizer Forum, Lomé, Togo.

The two trial types necessary for validation and refinement of improved fertilizer formulations are discussed: best-bet trials and nutrient omission trials. Best-bet trials are used to generate the data necessary for fertilizer companies and/or subsidy programs to change to better fertilizer alternatives, and involve comparisons of best-bet alternatives for various crops and soil types with current recommendations. Nutrient omission trials are used to evaluate economic returns to individual nutrients and/or lime, to determine if their inclusion in formulations is justified. Important characteristics of these trials include (1) an initial nutrient/soil acidity mapping to determine the location of nutrient and acidity constraints that may be limiting yields; (2) use of nutrient rates to sustain yields for a given yield target without inducing deficiencies or toxicities or wastage due to over-application; (3) on-farm evaluation at many sites within an agro-ecological zone for each target crop; (4) equal management of all plots, including control; (5) both yield and economic return evaluation; (6) evaluation of fertilizers that are the same or very similar to what fertilizer companies are able to produce; (7) collaboration with fertilizer companies, and if evaluated against current subsidized fertilizers, collaboration with government entities charged with approval of new fertilizers into subsidy programs.

Wendt, J., and L.W. Mbuthia. 2017. "A Conceptual Framework for Delivering Improved Fertilizers to Smallholder Farmers in Africa," Presented at the Myanmar Soil Fertility and Fertilizer Management Conference, Nay Pyi Taw, Myanmar.

Most smallholder African farmers have access to only NP and NPK fertilizers. A host of secondary and micronutrient deficiencies have been identified throughout the continent, which when addressed, results in marked yield improvement. A challenge is to get balanced fertilizers (those that supplement available fertilizers with secondary and micronutrients) to these smallholders, who often can neither afford nor access quality soil analyses. We lay out a conceptual framework, which is being implemented to varying degrees in various African countries, to deliver improved fertilizers to smallholders. The SMaRT framework stands for Soil Testing, Mapping, Recommendations development, and technology transfer.

www.feedthefuture.gov