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

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USAID FROM THE AMERICAN PEOPLE

IFDC

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Acronyms and Abbreviations

AAPI	Accelerating Agriculture Productivity Improvement
ACIAR	Australian Centre for International Agricultural Research
AFAP	African Fertilizer and Agribusiness Partnership
AFU	Agricultural and Forestry University
AgMIP	Agricultural Model Intercomparison and Improvement Project
AGRA	Alliance for a Green Revolution in Africa
AGRIFOP	Agribusiness-Focused Partnership Organization
AN	Ammonium Nitrate
ANOVA	Analysis of Variance
ASA	American Society of Agronomy
ASDS	Agricultural Sector Development Strategy 2010 -2020
ATT	Agriculture Technology Transfer
AWD	Alternate Wetting and Drying
B	Boron
BAU	Bangladesh Agricultural University
BDT	Bangladeshi Taka
BFS	Bureau for Food Security
BRRI	Bangladesh Rice Research Institute
CAGR	Compound Average Growth Rate
CAN	Calcium Ammonium Nitrate
CEO	Chief Executive Officer
CH_4	Methane
CIF	Cost, Insurance, and Freight
CO_2	Carbon Dioxide
CoCoFe	Code of Conduct for Fertilizer Management
COMESA	Common Market for Eastern and Southern Africa
CSA	Climate-Smart Agriculture
CSM	Cropping System Model
CSSA	Crop Science Society of America
Cu	Copper
DAP	Diammonium Phosphate
DRA	*Direction Regionale de l'Agriculture*
DSSAT	Decision Support System for Agrotechnology Transfer
EAC	East African Community
ECOWAS	Economic Community of West African States
ES	Elemental Sulfur
FAI	Fertilizer Association of India
FAO	Food and Agriculture Organization
FDP	Fertilizer Deep Placement
FDP MD	Scaling Up Fertilizer Deep Placement and Microdosing in Mali Project
FITC	Fluorescein Isothiocyanate
FMC	Field Moisture Capacity
FP	Farmers' Practice
FQA	Fertilizer Quality Assessment
FSI+	Fertilizer Sector Improvement (project)

FSP	Fertilizer Subsidy Program
FTF	Feed the Future
FY	Fiscal Year
GH¢	Ghana Cedis
GHG	Greenhouse Gas
GIS	Geographic Information Systems
GoG	Government of Ghana
HOI	Honduras Outreach Inc.
HYV	High yielding variety
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IER	*Institut d'Economie Rurale*
IFA	International Fertilizer Association
IFDC	International Fertilizer Development Center
IFEG	International Fertilizer Experts Group
IFPRI	International Food Policy Research Institute
INERA	*Institut de l'Environnement et de Recherche Agricole*
IRRI	International Rice Research Institute
ISFM	Integrated Soil Fertility Management
ISP	Input Subsidy Programs
ITRA	Togolese Institute for Agricultural Research
K	Potassium
KeFERT	Kenya Fertilizer Roundtable
LCA	Life Cycle Analysis
LCC	Leaf Color Chart
LCI	Life Cycle Inventory
LIFT	Livelihoods and Food Security Trust Fund
LIV	Local Improved Variety
LRP	Locally Recommended Fertilizer Management Practice
LUD	Land Use Department
M&E	Monitoring and Evaluation
MAAIF	Ministry of Agriculture, Animal Industry and Fisheries
MALFI	Ministry of Agriculture, Livestock, Fisheries, and Irrigation
MAP	Monoammonium Phosphate
MELS	Monitoring, Evaluation, Learning, and Sharing
METASIP	Medium-Term Agriculture Sector Investment Plan
Mg	Magnesium
Mn	Manganese
MoFA	Ministry of Food and Agriculture
MOP	Muriate of Potash
MSU	Michigan State University
N	Nitrogen
N_2O	Nitrous Oxide
NARES	National Agricultural Research Extension Systems
NCPB	National Cereals and Produce Board
NGO	Non-Governmental Organization
NH_3	Ammonia
NIFA	National Institute of Food and Agriculture

NML	New Markets Lab
NO	Nitric Oxide
NSF	National Science Foundation
OPV	Open-Pollinated Variety
P	Potassium
PEMEFA	Partnership for Enabling Market Environments for Fertilizer in Africa
PR	Phosphate Rock
PUDP	Prilled Urea Deep Placement
PVoC	Pre-Export Verification of Conformity
RADD	Rwanda Agro-Dealer Development
RCBD	Randomized Complete Block Design
REI	Regional Economic Integration
RH	Relative Humidity
RP	Recommended Practice
S	Sulfur
SARI	Savanna Agricultural Research Institute
SFT	Soil Fertility Technology
SIL	Soybean Innovation Lab
SIRS	Strickland Irrigation Research Station
SMaRT	Soil testing, Mapping, Recommendations development, and Technology transfer
SSA	Sub-Saharan Africa
SSSA	Soil Science Society of America
STV	Stress-Tolerant Variety
TAFAI	The African Fertilizer Access Index
TC	Trade Creation
TD	Trade Diversion
TFI	The Fertilizer Institute
TSP	Triple Superphosphate
UCF	University of Central Florida
UDP	Urea Deep Placement
UGA	University of Georgia
UN	United Nations
UNADA	Uganda National Agro-inputs Association
USAID	U.S. Agency for International Development
USDA	U.S. Department of Agriculture
UV	Ultraviolet
WorldVeg	World Vegetable Center
WSP	Water-Soluble Phosphorus
WFTO	World Fertilizer Trends and Outlook
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 designed to more directly support the Bureau for Food Security (BFS) objectives, particularly in relation 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. During the current reporting period, activities reflect greater integration between field-based work in FTF countries and scientific support and expertise from IFDC headquarters. Some of the activities reported here are a continuation of work initiated in FY2017. A summary description of the major activities is presented below.

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

Under Workstream 1, IFDC is developing and validating technologies, approaches and practices that address nutrient management issues and advance sustainable agricultural intensification. The following activities were conducted during the reporting period:

- Technologies refined and adapted for mitigating stress and improving nutrient use efficiency, particularly for crops grown in areas subject to drought, submergence, salinity, acidity, and other constraints. This included:
  - Field trials to evaluate soil fertility management technologies tailored for rice production in submergence-prone areas in northern Ghana.
  - Field trials to determine the best management options for stress-tolerant rice varieties in Bangladesh, Nepal, and Myanmar.
  - Field and greenhouse experiments on methods to improve nutrient use efficiency with subsurface application of fertilizer, particularly in sub-Saharan Africa.
  - Studies to evaluate plant response to micronutrient fertilization, particularly manganese, zinc, copper, and boron, and research to determine the effect of coatings, inhibitors, and micronutrients on nutrient use efficiency.
  - Experiment to determine the role of enhanced efficiency fertilizer products and practices in slowing carbon dioxide emission and improving carbon sequestration.
- Balanced plant nutrition research to improve fertilizer recommendations that increase crop yields, protect soil health, and improve farmer profitability. This included:
  - Updates to soil fertility maps in northern Ghana.
  - Soil sampling and analysis to evaluate the Soil-SMaRT concept in the rice, maize, and vegetable-growing areas of Buzi district, Mozambique.

  - A workshop on the "State of Soil Fertility in Northern Ghana, Fertilizer Recommendations, Utilization and Farm-level Access."
  - On-farm demonstrations to evaluate the role of legumes in rice-based farming systems for nutrition, soil health, and income generation.
  - Greenhouse trials and field evaluation of activated phosphate rock.
  - Field evaluation of the agronomic effectiveness of various sulfur products.
- Fertilizer quality assessments for East and Southern Africa and Myanmar. Progress included:
  - Fertilizer quality assessment for Uganda completed and presented to government and the fertilizer private sector.
  - Chemical analyses of fertilizer samples completed for a fertilizer quality assessment for Zambia.
  - Fertilizer quality assessment in Myanmar completed. Findings and recommendations were presented to the government, private sector, and donor community. Trainings about fertilizer quality for government officials were carried out.
  - Initial preparation of a manuscript on the achievements and lessons learned from fertilizer quality assessments in nine countries in West Africa, three countries in East Africa, and four regions of Myanmar.
- Efforts to improve the existing soil dynamics model in the DSSAT Cropping System Model using soil and agronomic data generated by IFDC over past years.

Workstream 2: Supporting Policy Reforms and Market Development

Under Workstream 2, evidence-based policy analyses were conducted 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:

- Documentation and support for the development and implementation of fertilizer- and soil-related policies and legal/regulatory reforms. Activities included:
  - Workshop to support the Kenya Fertilizer Roundtable.
  - Contribution to USAID BFS Agriculture Core Course on agricultural input policies.
  - Contribution to a joint World Fertilizer Trends and Outlook (WFTO) report issued by FAO and participation in a global consultation on FAO's Code of Conduct for Fertilizer Management.
  - Participation as a consortium member of the Partnership for Enabling Market Environments for Fertilizer in Africa.
  - Technical briefs on input subsidy programs in Ghana and on regional economic integration.

- Impact assessment studies on soil and fertilization technologies, policies, and government programs aimed at improving farmers' access to and use of fertilizer. The following activities were conducted:
  - Initiation of an impact assessment study on the Kenya fertilizer subsidy program.
  - Initiation of an impact assessment study on agro-dealer development programs in Rwanda.
- Economic studies to inform public and private decision-making and identify policy areas for interventions to streamline the flow of fertilizers at reduced prices for smallholder farmers. Activities included:
  - Support to Kenya, Uganda, and Myanmar governments for fertilizer quality policy development.
  - Development of a consolidated report on West African fertilizer supply cost buildup assessments.
  - Initiation of a graduate research study on life cycle analysis of greenhouse gas emissions under a rice-paddy system in Bangladesh.
  - Empirical and economic analysis of fertilization methods for rice paddy in Bangladesh.
  - Initial steps toward collaborative activities to improve fertilizer use, access, and market development in Honduras and Guatemala.

Cross-Cutting Issues Including University Partnerships and Knowledge Management

Under the awarded agreement, IFDC conducted a range of activities and interventions prioritized by the 2018 annual work plan, including greater partnership with U.S. universities. A summary of the various associated outreach activities and the methods of disseminating research outcomes and findings are reported in Annexes 1 and 2.

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

Since technology/methodology development and field evaluation generally take more than a year, some of the activities reported are a continuation of work from the previous year. Therefore, this report is transitional and covers the completion of previous commitments as well as the implementation of new research with greater focus on testing new and innovative technologies that can improve the productivity and profitability of smallholder farmers while providing more resilience to abiotic and biotic stresses. All reported activities are being conducted in FTF countries or are targeted for FTF countries, and the majority are field evaluations. The research activities carried out at IFDC headquarters support and complement field activities. Below is a summary of activities for this reporting period.

1.1 Technologies Developed, Refined, and Adapted for Mitigating Stress and Improving Nutrient Use Efficiency

Fertilizer management is a major challenge for crop production in stress-prone environments that are subject to drought, submergence, salinity, acidity, and other constraints. The research trials reported here were conducted under on-farm, greenhouse, and laboratory conditions to: (1) evaluate whether fertilizer best management practices can improve stress tolerance, (2) quantify the effect of subsurface fertilizer application on improved nutrient use efficiency, (3) determine the effects of coatings, inhibitors, and micronutrients on nutrient use efficiency, and (4) quantify the carbon dioxide (CO_2) mitigation role of enhanced efficiency fertilizers and practices.

1.1.1 Can Fertilizer Best Management Practices Improve Stress Tolerance?

1.1.1.1 Rice Production in Submergence-Prone Areas – Ghana

For the past two growing seasons, IFDC, in collaboration with AfricaRice and Savanna Agricultural Research Institute (SARI), has been working to develop appropriate soil fertility management technology tailored for rice production in submergence-prone areas in northern Ghana. We have evaluated the effectiveness of fertilizer deep placement (FDP) technology for increasing rice productivity in such areas, using submergence-tolerant rice varieties, NERICA L-19 and NERICA L-49, as test varieties. In each trial, the effectiveness of FDP technology was compared with microdosing technology and a modification of the locally recommended fertilizer management practice (LRP) whereby the granular fertilizers were incorporated into the soil rather than surface applied. To determine rice yields resulting from the additional N applied from each treatment, a check treatment in which only the basal NPK fertilizer was applied was included in the treatments.

There were no significant interactions between fertilizer technology x rice varieties, location x fertilizer technology, and location x rice varieties; there were also no significant three-way interactions among location x rice varieties x fertilizer technology. The NERICA L-49 variety consistently produced greater yields (approximately 5-11% more grain yield) than the NERICA L-19 variety. Therefore, we used the average yields of the higher yielding variety (i.e., our recommended variety to the farmers) for the economic analyses presented in Table 1 and Table 2.

The production budget (Table 1) indicates that by incorporating the supplemental urea into the subsoil, rather that surface broadcasting, production costs increased by only about 4%; however, the microdosing and the FDP technologies increased production costs over the traditional broadcasting of urea by 3% and 5%, respectively. Nevertheless, the combined results from the two seasons' field trials showed that, for every kilogram of top-dressing N applied, an additional revenue of about GH¢ 48 (48 Ghana cedis) was obtained when using FDP technology; GH¢ 39 from microdosing technology; GH¢ 31 from the incorporation of supplemental urea; and GH¢ 8 from the surface broadcast of urea (Table 2).

Gross margin analysis was used as a proxy for profits. The gross margin per hectare for FDP technology was 268%, 229% for modified LRP, 189% for microdosing, 68% for traditional LRP, and only 2% for basal NPK application (calculated from Table 1 and Table 2). Based on these results, we conclude that FDP and modified LRP could be an appropriate climate-resilient soil fertility management technology for rice production in submergence-prone areas of northern Ghana. One manuscript from this study is being prepared for submission for publication. AfricaRice is taking the lead in preparing a production guide to share the technology among key stakeholders.

Table 1. Average cost of rice production in northern Ghana with different nutrient management technologies

Treatment	Common Costs[a] (GH¢/ha)	Additional N Application (kg/ha)	Additional N Cost (GH¢/ha)	Urea Briquetting Cost (GH¢/ha)	Additional Labor for N Split (man-days/ha)	Additional Labor Cost (GH¢/ha)	Total Production Cost (GH¢/ha)	Additional Cost[b] over LRP (GH¢/ha)
T1: Basal NPK only	1,560	0	0.00	0.00	0	0.00	1,560	**-**
T2: LRP (with urea broadcast)	1,560	150	375.00	0.00	0.5	18.00	1,953	**-**
T3: Modified LRP (subsurface incorporation of urea)	1,560	150	375.00	0.00	2.4	86.40	2,021	**68.40**
T4: Microdosing	1,560	96	240.00	0.00	5.7	205.20	2,005	**52.20**
T5: FDP (fertilizer deep placement)	1,560	113	283.00	50.00	4.2	151.20	2,044	**91.20**

a. Cost of seeds, NPK fertilizer, land preparation, nursery, transplanting, basal NPK application, weeding, harvesting, and threshing.
b. Total production cost – Total production costs for T2

Table 2. Average revenue from rice production in northern Ghana with different nutrient management technologies

Treatment	Grain Yield (ton[a]/ha)	Farmgate Price of Rice (GH¢/bag[b])	Price of Rice (GH¢/ton)	Total Revenue (GH¢/ha)	Gross Profit[c] (GH¢/ha)	Additional Revenue for Applied N (GH¢/ha)	Additional Revenue/kg of Applied N (GH¢)
T1: Basal NPK only	1.07	125	1,844	1,592	32	**-**	**-**
T2: LRP (with urea broadcast)	2.12	125	1,844	3,155	1,202	**1,170**	**7.80**
T3: Modified LRP (subsurface incorporation of urea)	4.84	125	1,844	6,667	4,646	**4,614**	**30.76**
T4: Microdosing	3.89	125	1,844	5,789	3,784	**3,752**	**39.08**
T5: FDP (fertilizer deep placement)	5.26	125	1,844	7,515	5,471	**5,439**	**48.13**

a. 1 ton of rice = 1,000 kg
b. 1 bag of rice = 84 kg
c. Total Revenue – Total Production Cost

1.1.1.2 Developing Appropriate Soil Fertility Management Technologies for Stress-Tolerant Rice Cultivars – Bangladesh, Myanmar, and Nepal

Salinity Trials in Bangladesh

During the dry season (called *Boro* in Bangladesh) of 2018, four field trials were established at different locations in Shatkhira, Bangladesh. These experimental sites are prone to soil salinity. Six treatment combinations of N fertilizer management practices and rice varieties (Table 3) were tested in each trial to compare the performance of urea deep placement (UDP) of briquettes and prilled urea deep placement (PUDP) with farmers' practice (FP). At each site, the experiment was laid out in a split plot design (variety as a main plot and fertilizer practice as a sub-plot) with three replications. Deep placement of both urea briquettes and granular urea was done manually. All other fertilizers in UDP and PUDP treatments were applied following the government-recommended practice, while fertilizers were applied as per farmers' practice in FP treatment.

Table 3. Experimental treatments used for salinity trials in Bangladesh during Boro 2017-2018

Variety	Fertilizer	N Rates (kg/ha)
High-yielding variety (HYV) (BRRI dhan28)	Farmers' practice	99±9†
	Prilled urea deep placement	78
	Urea briquette deep placement (UDP)	78
Stress-tolerant variety (STV) (Binadhan-10)	Farmers' practice	99±9†
	Prilled urea deep placement	78
	Urea briquette deep placement	78

†N rates for farmers' practice varied with trials.

Figure 1. Transplanting rice seedlings (left) and granular urea deep placement under saline-prone conditions, Satkhira district, Bangladesh

Under salinity conditions, both urea briquettes and granular urea deep placement increased grain yields consistently over farmers' practice across both rice varieties (Table 4). Farmers used over 30% more N compared to deep placement, but they produced significantly lower yields. Therefore, the farmers' practice of fertilizer application is very inefficient and not economically viable (please see the economic analysis below). These results confirm that if prilled or granular urea is deep-placed properly, it can be as effective as urea briquettes. However, deep placement is very challenging; it requires draining the fields, manually opening the furrow, placing the fertilizer, and immediately closing the furrow to reduce fertilizer movement to the floodwater. Unlike urea briquettes, PUDP on a large scale is impossible without complete mechanization. If farmers have access to urea briquettes, using briquettes is a more viable option than granular urea deep placement, particularly for smallholder farmers. Production of briquettes at the central level and improved availability throughout the country may allow farmers to have a choice between different fertilizer products, depending on their economic status and labor availability.

Table 4. Comparison of plant height, number of panicles, and grain yields with farmers' practice (FP), PUDP, and UDP (briquette) under high-yielding varieties (HYV) and stress-tolerant varieties (STV) at saline prone areas in Bangladesh

Fertilizer	Plant Height, cm			Panicles per m2			Yield, kg/ha		
	HYV	STV	Average	HYV	STV	Average	HYV	STV	Average
Asashuni, Satkhira (Noikhati)									
FP	86b	92c		299	304	301b	4,254	4,417	4,336b
PUDP	90a	100a		304	309	307a	4,602	4,876	4,739a
UDP	90a	99b		302	315	308a	4,600	4,952	4,776a
ANOVA (p value)									
Var (V)	0.0080			0.1325			0.0046		
Fert (F)	0.0000			0.0154			0.0000		
VxF	0.0010			0.1104			0.1360		
Sadar, Satkhira (Brommorajpur)									
FP	90	94	92b	300b	323b		5,787	6,828	6,308b
PUDP	92	97	95a	322a	331a		5,975	7,257	6,616a
UDP	93	98	95a	323a	335a		5,960	7,326	6,643a
ANOVA (p value)									
Var (V)	0.0384			0.0247			0.0000		
Fert (F)	0.0001			0.0000			0.0006		
VxF	0.4412			0.0039			0.0517		
Sadar, Satkhira (Dhulihor)									
FP	89	96	92b	289	320	304b	5,357	6,898	6,127b
PUDP	93	99	96a	304	334	319a	6,189	7,663	6,926a
UDP	93	99	96a	305	331	318a	6,214	7,554	6,884a
ANOVA (p value)									
Var (V)	0.0027			0.0134			0.0043		
Fert (F)	0.0003			0.0010			0.0000		
VxF	0.0083			0.5834			0.4912		

Fertilizer	Plant Height, cm			Panicles per m2			Yield, kg/ha		
	HYV	STV	Average	HYV	STV	Average	HYV	STV	Average
Sadar, Satkhira (Mahmudpur)									
FP	89	93	91b	291	346	318b	5,480	6,562	6,021b
PUDP	92	96	94a	305	379	342a	6,031	7,078	6,554a
UDP	94	98	96a	308	378	343a	6,064	7,053	6,558a
ANOVA (p value)									
Var (V)	0.0472			0.0047			0.0045		
Fert (F)	0.0009			0.0022			0.0001		
VxF	0.9664			0.2355			0.7876		

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

Across all saline experiment sites, the salinity-tolerant variety produced significantly higher grain yields over the locally popular variety. Though there was no significant interaction between fertilizer management practice and variety, farmers could get higher grain yield by adopting a salinity-tolerant variety with UDP or PUDP.

Economic Analysis of Fertilizer Management Practices under Stress-Prone Environment

An economic analysis was performed on the salinity and drought trial data to determine the profitability associated with each fertilizer practice. While the detailed economic assessment will be published in a scientific journal, a summary of the assessment is presented below. The economic analysis was performed with three fertilizer treatments – FP, government-recommended practice (RP), and best management with urea briquette deep placement (UDP) for two rice varieties (local improved, LIV; stress tolerant, STV) across different stress environments. For the saline-prone environment, economic analysis was done for FP, PUDP, and UDP treatments. The analysis provides comprehensive guidance for farmers to transition from the conventional fertilizer management practice to the improved one. This will help increase rice yields and economic profits, especially in areas where the conventional fertilizer management practice is inappropriate due to different environmental stresses (drought, submergence, and salinity).

For each fertilizer practice, an analysis was done for technical efficiency, economic efficiency, and profitability indicators across two crop varieties. Moreover, a marginal analysis was performed based on a partial budget, i.e., cost that varies across treatments, to determine the fertilization practice that brings the highest economic return to farmers. An example of a drought-and saline-prone area is presented here. In this experiment, data were collected from four locations in Bangladesh where field trials were conducted (Table 5). This analysis determines the best combination of variety and fertilization practice to offer the highest economic returns to farmers.

Table 5. Technical, economic, and profitability indicators for three fertilization practices across two rice varieties in drought and saline-prone environments, Bangladesh

Indicators	Unit	Drought			Saline		
		FP	RP	UDP	FP	UDP	PUDP
Grain yield	MT/ha (x1000)	4.6	4.6	5.0	5.7	6.2	6.2
Grain revenue	BDT/ha (x1000)	97.5	98.5	107.1	125.3	136.7	136.6
Total production cost	BDT/ha (x1000)	79.9	73.9	73.8	110.1	104.5	104.6
Technical efficiency							
Grain productivity of fertilizer	kg grain/kg fertilizer	9.5	14.2	15.9	8.2	13.57	13.63
Grain productivity of labor	kg grain/labor unit	56.2	57.8	58.6	65.7	71.7	70.7
Economic efficiency							
Cost per kilogram of grain	BDT/kg	16.6	15.2	13.9	19.3	16.81	16.85
Labor cost per kg of grain	BDT/kg	10.8	10.4	9.7	7.7	7.0	7.1
Fertilizer cost per kg of grain	BDT/kg	2.4	1.3	1.2	2.7	1.7	1.5
Profitability							
Grain net income (profit)	BDT/ha (x1000)	17.6	24.7	33.3	15.2	32.3	32.0
Value-cost ratio (VCR)	BDT/BDT invest	1.4	1.5	1.6	1.1	1.3	1.3
Rate of return on cash investment	%/BDT invest	0.4	0.5	0.6	17	34	34

FP, farmers' practice; RP, recommended practice; UDP, deep placement of urea briquettes; PUDP, deep placement of prilled urea; BDT, Bangladesh Taka = U.S. $0.012

The assumption of the economic analysis is that farmers adopt new farming practices that meet the goal of food security, either by producing enough food or by selling enough produce to generate cash for familial needs. In either case, farmers are interested in the highest economic benefit for their farming activities, determined by the highest rate of return derived from the additional investment (if any) of transitioning from one farming practice (e.g., fertilizer practice) to another.

Among the different fertilization practices, UDP outperformed RP and FP across all indicators (technical, economic efficiency, and profitability). Under saline conditions, PUDP and UDP indicators (yield, revenue, efficiency, etc.) were similar (Table 5). UDP revenues were 9% (saline) to 10% (drought) higher than FP. Under drought-prone areas, UDP revenues were 9% higher than RP, while RP revenues were only about 1% higher than FP. On the other hand, the production cost with UDP was 5% (saline) to 8% (drought) lower than FP and similar to the production cost of RP. The higher performance of (P)UDP, in terms of all the economic indicators, was due to reduced production (fertilizer) costs and higher grain yields compared to FP and RP. The cost reduction from lower fertilizer use was evident when comparing UDP and PUDP with FP. This suggests that farmers' fertilizer use practice is very inefficient since they are using an excessively high amount of fertilizers, particularly urea. The lower cost and higher revenue result in higher (P)UDP net profits. UDP profit is about 90% (drought) to 112% (saline) higher than FP. In addition, under drought conditions, UDP profits were 35% higher than RP (drought) while RP profits were 40% higher than FP. This confirms that (P)UDP is more efficient in the use of resources, mainly fertilizer and labor (less weeds and less labor for weeding), despite using a higher number of labor units for the application of urea briquettes. The higher cost caused by a higher number of labor units is partially offset by the lower use, and therefore lower cost, of fertilizer, the low use of agro-chemicals, especially herbicides, and the need for less labor for manual weeding.

Marginal Analysis

In addition to the indicators above, a marginal analysis was performed to compare the changes in cost and the benefits associated with each fertilizer management practice. This analysis was based on a partial budget. The data presented in Table 6 are average gross benefits and costs across rice varieties and locations. Net benefits are estimated based on the gross benefits and the total costs that vary across the different fertilization practices. The estimated net benefit, based on the partial budget, is not the same as what is presented in Table 5 since the partial budget does not consider all costs, especially those that must be incurred and do not vary regardless of the production technology or fertilization practice (i.e., plowing, seeding, land rental, etc.).

Table 6. Partial budget (variable cost) and net benefits of three fertilization practices

Particulars	Unit	Drought			Saline		
		FP	RP	UDP	FP	UDP	PUDP
Yield	kg x 1000/ha	4,588	4,637	5,038	5,697	6,215	6,209
Gross benefits	BDT/ha	97,493	98,544	107,064	125,328	136,739	136,595
Cost that varies							
Fertilizer cost	BDT/ha	10,984	6,238	6,058	15,492	10,320	9,538
Agrochemical cost	BDT/ha	3,670	3,670	3,221	3,563	3,144	3,563
Labor cost	BDT/ha	49,327	48,335	48,795	43,762	43,762	44,212
Other cost†	BDT/ha	7,911	7,636	7,721	39,097	39,075	39,076
Total	BDT/ha	71,892	65,879	65,795	101,914	96,301	96,389
Net benefit	BDT/ha	25,601	32,665	41,269	23,414	40,438	40,206

†Other cost – land rental, plowing, seeding, etc.

Marginal analysis further confirms that (P)UDP is the more efficient fertilization practice, compared to the others, under both drought- and saline-prone conditions. (P)UDP results in higher benefits and lower costs than FP. FP has the highest production cost, but it has the lowest net benefits. Therefore, by using (P)UDP, farmers could achieve more economic benefits under both drought (BDT 16,000) and saline (BDT 17,000) prone conditions while lowering production cost by BDT 5,000-6,000 (Table 6). Although RP (evaluated only under drought condition) has similar production costs to UDP, it yields lower net benefits (BDT 7,000) compared to UDP. This clearly suggests that farmers are not using their financial resources properly while also, though unknowingly, contributing to negative environmental impacts (N pollution). Therefore, farmers (in the areas where urea briquettes are available) should be encouraged to move from FP to UDP or PUDP (areas where displacement of prilled/granular urea is possible), not only to increase yields and economic returns, but also to reduce the production cost and environmental impact associated with the overuse of N fertilizers.

Comparison Among Varieties

Further analysis was carried out to compare two rice varieties, BRRIdhan-56 and Guti Shorna, in combination with fertilization practices. Results show that the adoption of the drought-tolerant variety, BRRIdhan-56, outperforms the locally improved variety (Guti Shorna) in terms of yield, revenues, costs, and profits (Figure 2). Similar results were observed with the salinity-tolerant rice variety, BINAdhan-10, over BRRIdhan-28 in saline-prone areas.

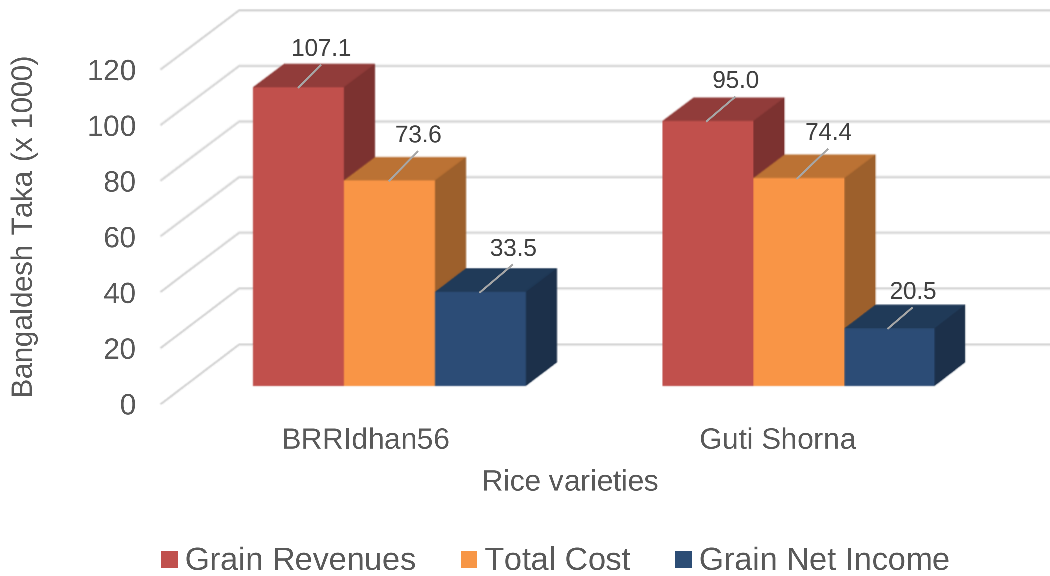


Figure 2. Revenues, Costs, and net income of two drought-tolerant rice varieties across three fertilization practices being evaluated in four locations in Bangladesh

The higher performance of BRRIdhan-56 is also reflected in the economic efficiency indicators, as presented in Figure 3. This shows that BRRIdhan-56 is more efficient in resource use (labor, fertilizer), requiring lower cost per unit of grain output compared to Guti Shorna. Furthermore, the farmers who are using the UDP practice along with the local improved variety can achieve greater net benefits by adopting the stress-tolerant varieties (BRRIdhan-56 for drought conditions and BINAdhan-10 for saline areas). Adopting stress-tolerant varieties can ensure higher yields, even under extended drought or increased salinity conditions.

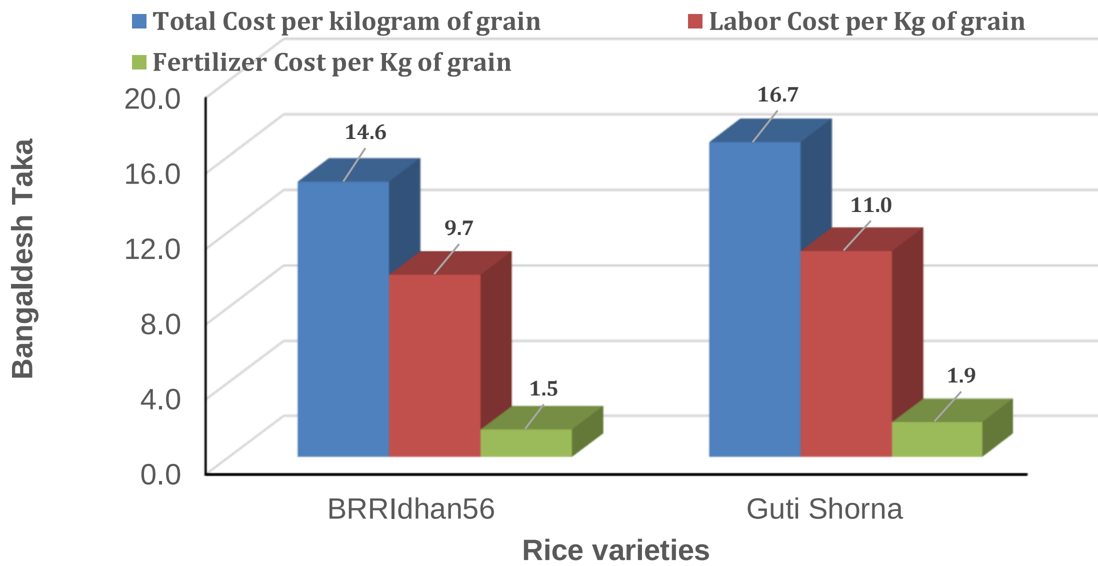


Figure 3. Economic efficiency indicators of two drought-tolerant rice varieties across three fertilization practices being evaluated in four locations in Bangladesh

Based on the technical and economic analyses of two (saline-prone areas) or three (drought-prone areas) fertilization practices across two rice varieties and four locations in Bangladesh, it is suggested that (P)UDP is the best fertilization practice among the three being evaluated. (P)UDP offers the highest marginal rate of return across all locations and rice varieties. Benefits could further be improved if farmers adopt stress-tolerant varieties instead of locally improved ones.

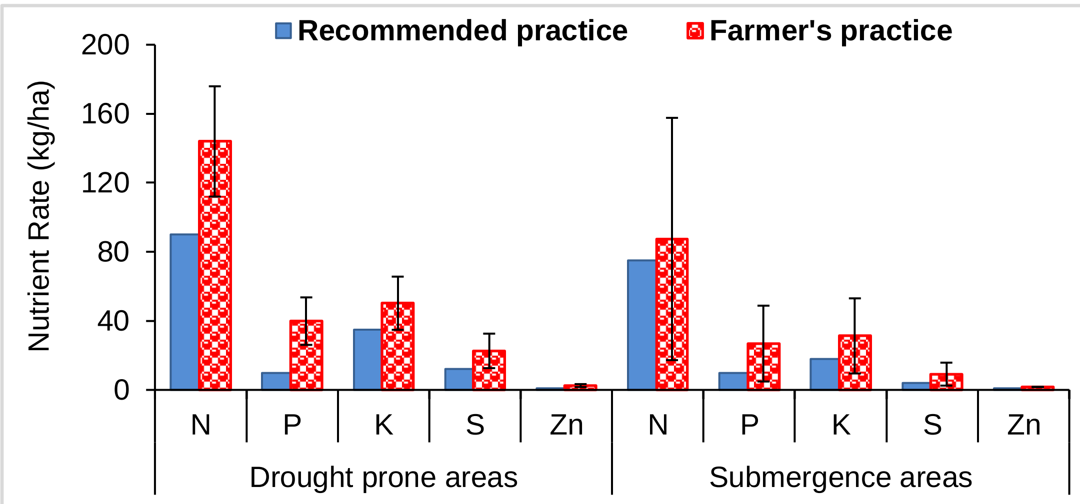
These analyses are also helpful for policymakers to revise current policies or to envision alternative policies with regard to the proper use of fertilizer, especially among smallholder farmers. Some of these policies may address issues related to technical assistance, credit for fertilizer, input/fertilizer supply chain, and input and output prices, among others.

Farmers' Knowledge Gap on Fertilizer Management Practices in Rice Cultivation under Stress-Prone Areas

Balanced plant nutrition through organic and mineral fertilization improves soil fertility and crop productivity. However, there is a wide knowledge gap between the recommended nutrient management practices and farmers' practices in developing countries, particularly under stress-prone areas. A survey was conducted under drought- and submergence-prone areas in Bangladesh and under drought-prone areas in Nepal to explore the knowledge gap between the recommended nutrient management practices and farmers' current practices and to develop appropriate strategies to increase the adoption of improved fertilizer management practices. Survey data shows that farmers in both countries are not adopting the recommended fertilizer practices. Although fertilizer use is imbalanced in both countries, the amount of fertilizer used is higher than recommended in Bangladesh and lower than recommended in Nepal.

In Bangladesh, every farmer surveyed used more than the recommended amount of fertilizer under both stress environments (Figure 4). The amounts of N, P, and K fertilizers were 60%, 298%, and

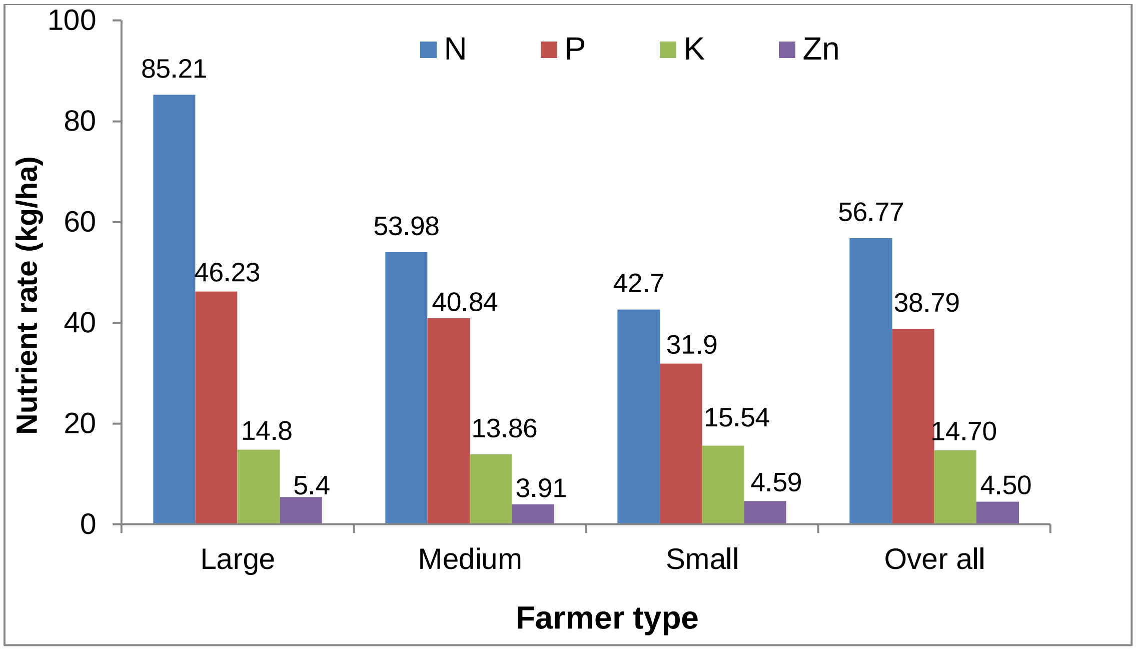
43% higher under drought-prone areas and 17%, 168%, and 74% higher under submergence-prone areas, respectively. Fertilizer use was guided by farmers' own experience or by copying neighboring farmers, but very few farmers adopt the advice of extension workers. While around 30-40% farmers had access to extension advice, they did not follow the recommended rates because of their perception that, since the recommended rates are lower, they are insufficient for higher yields. More data analyses to determine other factors associated with the adoption of fertilizer practices will be conducted in the next reporting period.



Source: Farmers' survey 2017.

Figure 4. Average fertilizer use rate (as nutrients) by farmers in drought- and submergence-prone areas in Bangladesh

In Nepal, most farmers have no access to extension advice regarding fertilizer use (amount and timing), and they use fertilizers based on their neighbors' farming practices and their own experiences. In general, they use less than the recommended amount of fertilizers (except phosphorus), and the use is imbalanced (Figure 5). The main influencer for fertilizer use is economic; rich farmers buy more fertilizers compared to poor farmers. The amount of fertilizer used is also affected by irrigation facilities, livestock population, type of varieties, etc. Though farmers use less fertilizer for local and improved varieties, they use relatively higher amounts for hybrid varieties. To increase the adoption of recommended nutrient management practices, innovative extension approaches, such as large plot on-farm demonstration, farmer training, and access to technology and information, should be considered. A paper entitled "Exploring farmers' knowledge gap on fertilizer management in a rice-based cropping system in a rainfed drought region of Nepal" has been drafted and is under team review.



Source: Farmers' survey 2017

Figure 5. Average fertilizers use rate (as nutrients) by farmers under drought-prone areas in Nepal (the government-recommended rate for rainfed rice is 60:30:30 kg NPK/ha)

Drought Trials in Nepal (Rice-Wheat System)

The experiment under drought-prone areas (rainfed conditions) in Nepal was conducted in partnership with the Agricultural and Forestry University (AFU). The objective of the experiments was to determine the optimum method of N fertilizer placement for the rice-wheat system. Five fertilizer treatments were tested in a split plot design, with rice varieties as main plots and fertilizers as sub-plots. The five fertilizer treatments were control (0 kg N ha_{-1}), urea broadcast (78 and 100 kg N ha_{-1}), and granular and urea briquette deep placement (78 kg N ha_{-1}). Both granular and briquette urea were deep-placed manually. UDP produced significantly higher grain and straw yields and agronomic nitrogen use efficiency (kg grain/kg N) across all varieties; these results were reported in the previous reporting period. The experiment was, however, continued for wheat to see the residual effects of N fertilizer treatments (all treatments except control received 75% of the recommended N rate), if any, on wheat grain yields. Although the UDP plot produced the highest yield (3.6 t/ha), it was not significantly different from other N fertilizer treatments (Figure 6).

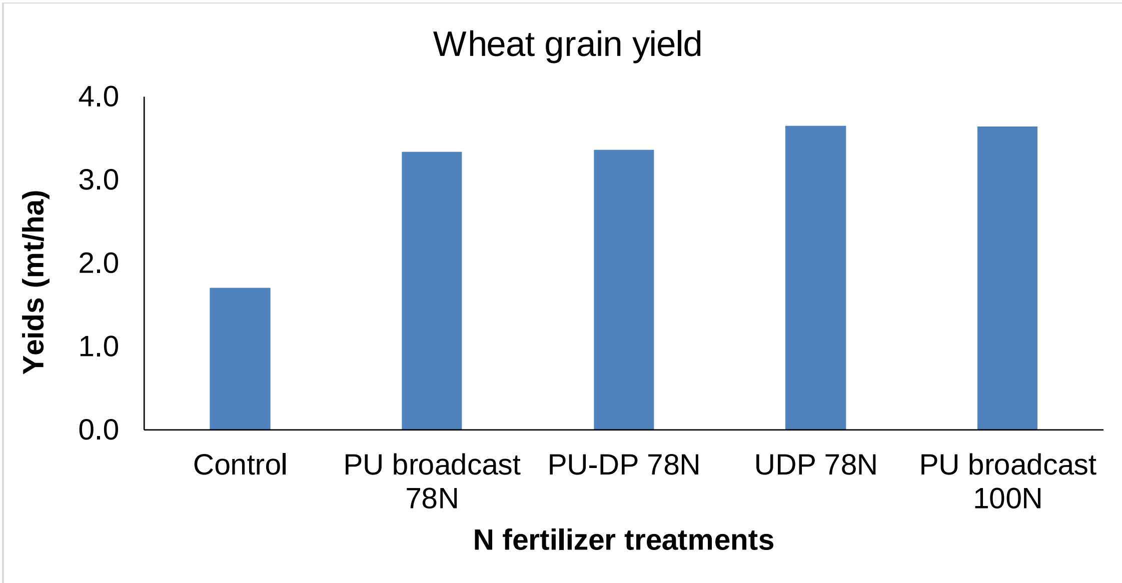


Figure 6. Wheat grain yields from N fertilizer treatments of drought-prone rice in Nepal (all fertilizer treatments except control received 75% of recommended N rate of wheat)

A separate experiment was conducted to compare the effects of UDP with different decision support tools for optimum N management. The amount and frequency of N were determined by an optical sensor (green seeker), a SPAD meter, a leaf color chart (LCC), recommended practice, and UDP. In rice, the use of the optical sensor reduced the amount of fertilizer used compared to other treatments. However, among all treatments, UDP produced the highest yields (Table 7). In wheat, the use of the optical sensor, SPAD, and LCC produced higher yields while reducing the N requirement by up to 50%, compared to conventional broadcast application. UDP was as effective as LCC, the optical sensor, and SPAD methods of N management in terms of grain yields, but N saving was only 22% compared to broadcast methods. These results suggest that farmers, based on the market availability of decision support tools and the farmers' level of skill, could select any tools or UDP to get higher yields.

The field trials for rice 2018 were established under drought-prone areas in Nepal (Figure 7). Fifteen treatment combinations from various fertilizer practices (five) and varieties (three) were tested to compare the performance of deep placement granular and briquette urea compared to broadcast urea. These trials are in progress and will be reported in the next semi-annual report.

Table 7. Comparison of grain yields among different decision support tools for N management in rice and wheat under drought-prone areas in Nepal

Fertilizer	Rice			Wheat	
	N Applied (kg/ha)	Panicle/ Hill	Grain Yield	N Applied (kg/ha)	Grain Yield
Control	0	7.2c	3.89d	0	1.20c
Optical sensor	50	9.2b	6.11a	50	2.70b
SPAD	50	9.8ab	5.82bc	50	2.92ab
LCC	67	10a	6.10	66.7	2.93ab
Optical sensor (25 kg N basal)	50	9.7ab	5.98ab	50	3.23a
SPAD (25 kg N basal)	58	8.5c	5.24c	50	2.93ab
LCC (25 kg N basal)	83	9.5b	6.36ab	66.7	3.42a
Urea broadcast	100	9.5b	6.07ab	100	3.24a
UDP	88	11.1a	6.67a	78	3.17a

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

Figure 7. Deep placement of granular urea and urea briquette in drought trial, Nepal

Salinity Trials in Myanmar

During the 2018 dry season, two field trials were conducted in saline-prone areas of Myanmar (Dedaye and Bogale). Four fertilizer treatments, namely farmers' practice at 100 kg N/ha; recommended practice at 75 kg N/ha; prilled urea deep placement (PUDP); and urea briquette deep placement (UDP) by hand, both at 66 kg N/ha, were tested in combination with a local (90-day variety) and saline-tolerant variety, Pyi Myanmar Sein.

Fertilizer treatments had no interaction effects with variety on grain yields. UDP increased grain yield significantly compared to FP and RP at both locations, and the effect of PUDP on grain yields was comparable with UDP (Table 8). These results confirm that deep placement is equally as effective under stress environments (saline soils) as in irrigated rice fields.

Table 8. Comparison of plant height, number of panicles, and grain yields with farmers' practice, recommended practice, prilled UDP, and UDP (briquette) under local improved varieties and stress-tolerant varieties in saline-prone areas of Myanmar

Fertilizer	Plant Height (cm)			Panicles per m^2			Yield (kg/ha)		
	LIV	STV	Average	LIV	STV	Average	LIV	STV	Average
Dedaye									
FP (100 kg N ha^{-1})	89.7	96.5	93.1	13.8	13.1	13.5	3.26	1.58	2.42
RP (75 kg N ha^{-1})	88.2	94.5	91.4	13.4	16.0	14.7	2.72	1.68	2.20
PUDP (66 kg N ha^{-1})	91.7	97.7	94.7	15.9	18.1	17.0	3.44	1.96	2.70
UDP (66 kg N ha^{-1})	88.9	99.2	94.0	13.9	18.1	16.0	3.45	2.49	2.97
ANOVA (p value)									
Variety	0.0416			0.2192			0.8083		
Fertilizer	0.8011			0.1341			0.4055		
Variety x Fertilizer	0.9317			0.4325			0.8362		
Bogale									
FP (100 kg N ha^{-1})	68.1a	83.4bc		10.9	18.9	14.9	1.64	2.56	2.10b
RP (75 kg N ha^{-1})	71.3a	79.5a		12.5	17.1	14.8	2.04	2.71	2.38a
PUDP (66 kg N ha^{-1})	72.0a	89.2c		14.5	20.2	17.4	2.52	2.84	2.68ab
UDP (66 kg N ha^{-1})	69.7a	86.5b		13.9	20.2	17.1	2.13	2.88	2.51a
ANOVA (p value)									
Variety	0.0018			0.0058			0.4093		
Fertilizer	0.0171			0.0912			0.0260		
Variety x Fertilizer	0.0405			0.5505			0.3525		

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

Field trials for the 2018 wet season under submergence-prone areas in Myanmar have been established. Two fertilizer treatments, farmers' practice at 75 kg N/ha and urea briquette deep placement at 50 kg N/ha, were tested in combination with the local improved variety and the submergence-tolerant variety, Swarna sub1. These trials are in progress and will be reported in the next semi-annual report.

Under each production environment, field trials were conducted for two seasons. Except for a drought trial in Nepal and a submergence trial in Myanmar, all trials were harvested. In addition, a farmers' knowledge gap analysis (Bangladesh and Nepal) and an economic analysis of each fertilizer practice under drought and submergence environments were conducted. All of this data has been analyzed, and a manuscript is being prepared for journal publication.

1.1.2 Improved Nutrient Use Efficiency with Subsurface Fertilizer Application

Subsurface fertilizer application improves nutrient use efficiency by improving the availability of nutrients for crop uptake and/or reducing nutrient losses.

1.1.2.1 Comparison of Agronomic and Economic Performance of FDP (NP, NPK, and Urea Briquettes) on Paddy Rice Under Irrigated and Lowland Cropping Systems in Mali

During FY18, in partnership with *Direction Regionale de l'Agriculture* (DRA) and non-governmental organizations (NGOs), field trials promoting the use of UDP in lowland and irrigated rice systems were conducted in select locations in Mali.

In UDP and FP treatments, the mean paddy yields in irrigated rice ecosystems were 6,457 kg/ha and 4,755 kg/ha, respectively, representing a 36% yield increase with the UDP treatment. In the lowland ecology, the mean paddy yield from the UDP plots was 1,992 kg/ha. This represented a 93% increase compared to the mean paddy yield of 1,032 kg/ha obtained with the FP treatment. The use of FDP resulted in a 31% reduction in production costs and a 61% increase in unit gross margin. In the lowland system, the reduction in production costs was 36% with a 140% increase in unit gross margin. These results confirm the profitability of integrating UDP in irrigated and lowland rice farming systems.

Table 9. Mean rice paddy yield with FDP compared with farmers' practice (FP) in irrigated and lowland rice systems

	Unit	Irrigated system			Lowland system		
		FP	FDP	Δ	FP	FDP	Δ
Average yield paddy	kg/ha	4,755	6,457	1,702	1,032	1,992	961
Average sales price	FCFA/kg	137	137	-	125	125	-
Average cost of production	FCFA/kg	50	34	-16	48	30.5	-17.5
Unit gross margin	FCFA/kg	87	103	16	77	94.5	17.5
Gross margin per ha	FCFA/ha	415,197	663,476	248,279	78,444	108,022	29,578
Gross margin per ha ($1=528 FCA)	**$/ha**	**786**	**1,256**	**470**	**148**	**204**	**56**

1.1.2.2 Adapting Balanced FDP (NP and NPK Briquettes) to Intensive Rice Cropping Systems (SRI) in West Africa (Mali, Togo, and Burkina Faso)

The proposed activities were intended to be a collaboration with the Cornell SRI initiative, but they eventually involved only the national agricultural research extension systems (NARES) of the selected countries because Cornell had no budget to support such collaborative research. A contract was drafted between IFDC and *Institut d'Economie Rurale* (IER) in Mali and between IFDC and *Institut de l'Environnement et de Recherche Agricole* (INERA) in Burkina Faso. The Togolese Institute for Agricultural Research (ITRA) could not provide the timely feedback and preparation needed to start the activities during FY18; therefore, Togo could not participate in the FDP SRI activities. The major research activities planned were:

1. Adapting UDP to SRI under flooding or alternate wetting and drying (AWD) water management systems in a split-plot design with four replicates in three agroecological zones.
2. Interactive effects of UDP and organic matter in an SRI system in a split-plot design with four replicates in three agroecological zones.
3. Testing of multi-nutrient briquettes in irrigated and lowland rice systems in a randomized complete block design (RCBD) with four replicates.

In Mali, the trials were established at Niono, Selingué, and San for irrigated rice and at Sikasso for lowland rice. The AWD UDP trial will be initiated during the off-season when rains recede. Trial-related activities are in progress.

In Burkina Faso, INERA failed to start the normal winter season activities on time.

1.1.2.3 Agronomic and Economic Evaluation of Deep Placement on Maize and Winter and Off-Season Vegetables in Mali and Ghana

Vegetable Trials in Mali

FY18 on-station trials are being conducted in partnership with the World Vegetable Center (WorldVeg) through the Scaling Up Fertilizer Deep Placement and Microdosing Technologies (FDP MD) project to improve fertilizer use on vegetables in Mali. The activity is quantifying vegetable crop yield and quality as affected by the rate and placement of NPK fertilizer briquettes.

For the off-season crops, eggplant, onion, and tomato were grown at three locations. For each crop species, the field layout was a split plot design with four replicates. The main plot was placement of fertilizer at three depths (surface, 5-cm deep, and 10-cm deep) and four subplots for the rate of fertilizer application: no fertilizer (T1), recommended practice (RP) – broadcast incorporated (T2), two-thirds of the RP rate as briquettes (T3), and one-half of the RP rate as briquettes (T4).

Data collection is in progress, and data include crop yield, fruit number and mean weight per treatment, quality of fruits as measured by size, fiber, and nutrient content. In addition, data for economic assessment of treatments are being collected. Yield data of the off-season vegetable trials are summarized by crops for the major sites.

Tomato

Tomato yields varied between sites with higher yields at Bougouni and lower yields at Samanko, most likely as a result of differences in indigenous fertility of the soils at the sites. The control without fertilizer application (T1) did not differ from plots receiving the recommended NPK fertilizer rates (surface application -T2). One explanation could be that there has been some soil fertility build up at the site, probably due to continual fertilizer applications during previous experiments.

Reducing the recommended fertilizer rate and applying the reduced fertilizer rate as briquettes resulted in an overall higher tomato yield. Even with reduction of the recommended rate (T4) by half, the yield difference was substantial (Figure 8).

An analysis of briquette placement showed that placing the briquettes 5-10 cm deep also improved crop response to the applied briquettes, compared to surface application (1 cm deep covered with soil).

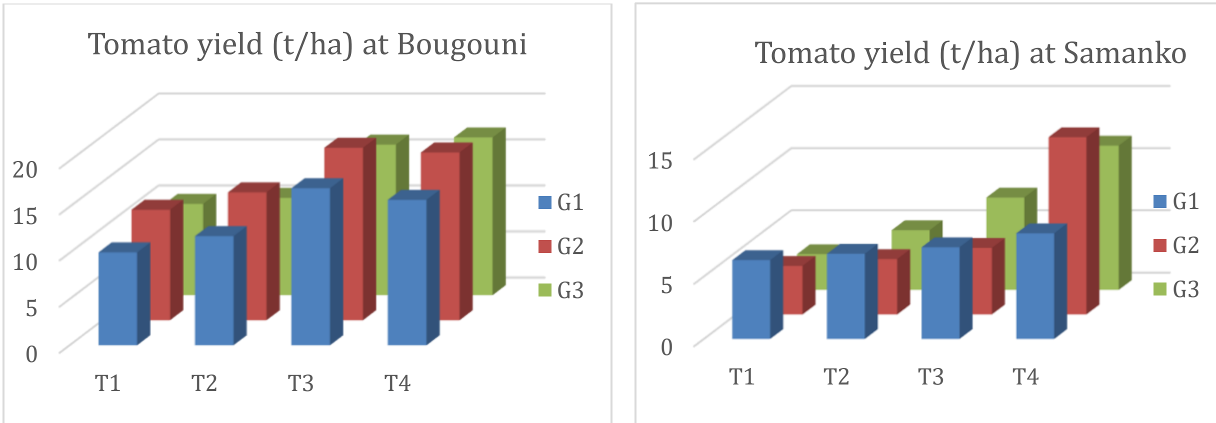


Figure 8. Tomato yield as affected by rate of fertilizer and placement of NPK briquettes.

Eggplant and Onion

The trend observed with tomato plants was repeated with eggplants and onion with no significant difference between the absolute control (T1) and the recommended surface application of NPK fertilizers (T2). The briquette treatments, despite the reduced fertilizer application rate, exhibited relatively higher crop yields (Figure 9). This is most likely a result of improved nutrient use efficiency by the crops. This improvement was more apparent with T4, which received half of the recommended NPK as briquettes. Furthermore, deep briquette placement worked better than sub-surface placement. While G2 (placement at 5 cm deep) and G3 (placement at 10 cm deep) were comparable at Bougouni, results at Samanko showed that deeper briquette placement (G3) improved crop yield (Figure 9). Deep placement in coarser textured soil at Samanko may have resulted in reduced volatilization losses.

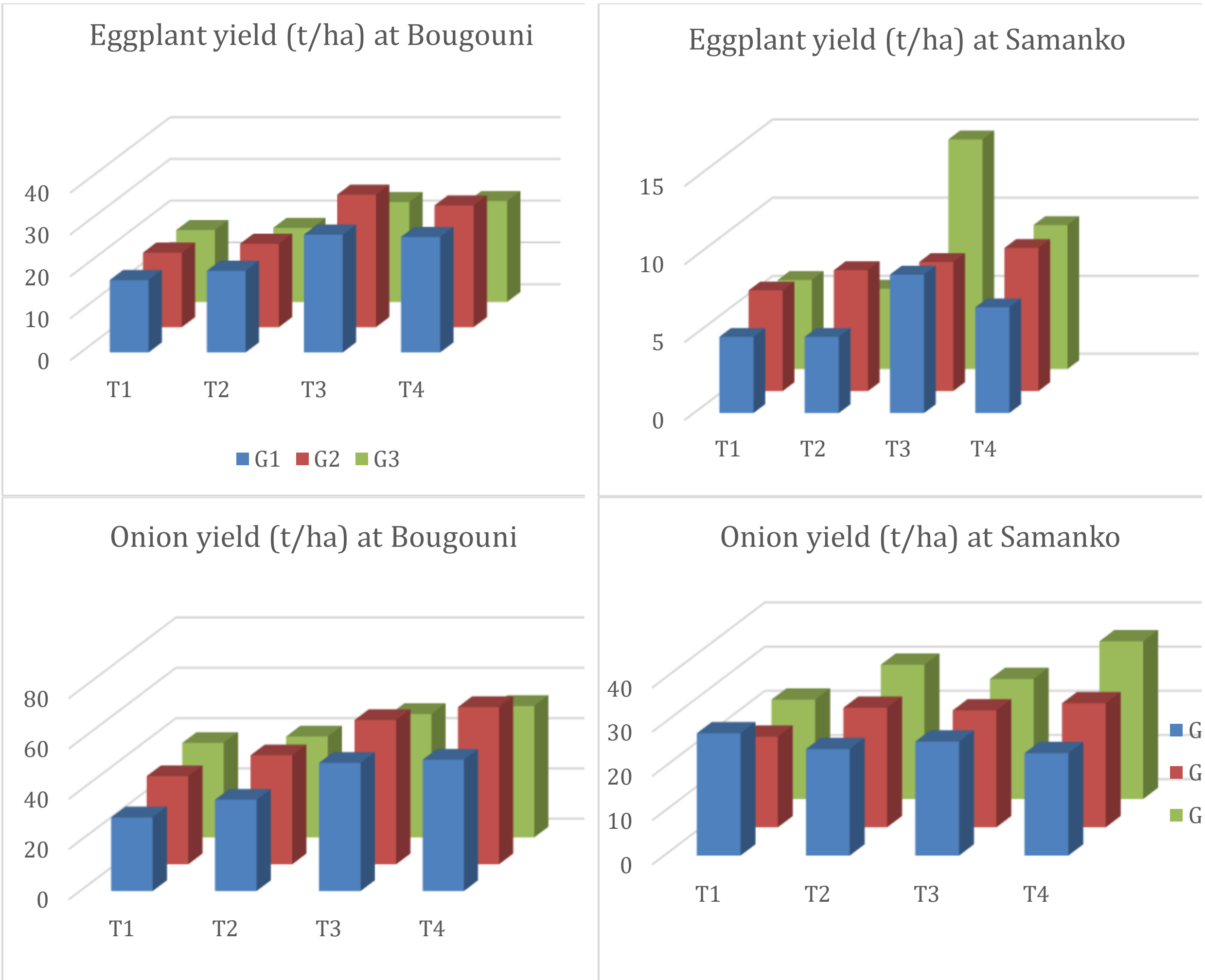


Figure 9. Eggplant (top) and onion (bottom) yields as affected by rate of fertilizer and placement of NPK briquettes

Winter 2018 Vegetable Trials

Within the framework of a collaborative agreement between IFDC and WorldVeg, tomato, eggplant, okra, and onion plots were installed at three sites in July 2018. Those sites were: Samanko, Bougouni, and Koutiala. The okra plots suffered excess rainfall at Samanko. Onion and tomato had to be re-sown at Bougouni due to irregular seed germination at the nursery stage. Tomato had to be re-sown at Koutiala for the same reason.

Maize Trials in Ghana

Several studies have shown that maize yields could be increased if applied fertilizer is incorporated into the subsoil, rather than surface broadcast. However, most smallholder farmers in SSA, and especially in northern Ghana, are reluctant to adopt the practice. Farmers find subsoil application cumbersome and labor intensive, as it requires measuring the needed fertilizer for each plant, applying it to a hole dug near the plant, and covering the hole after application. An innovative approach to overcome this obstacle could be *a priori* briquetting of the quantity of fertilizer required by the plant and applying the briquettes to the plants, thereby eliminating the measuring of the granular fertilizer before applying it to the plant. During the third quarter of FY17, 15 sites were selected in the three northern regions of Ghana (six in the Northern region, four in the Upper East region, and five in the Upper West region) to conduct adaptive trials to evaluate the effectiveness of using the urea briquette technology in improving productivity of upland maize production, using climate-resilient maize varieties as the test crop.

The experiments were laid in an RCBD with an individual plot size of 10 meters (m) x 10m. The treatments were four fertilizer application methods: (i) Farmer practice, where supplemental granular urea was surface applied; (ii) subsurface placement of granular urea; (iii) subsurface placement of urea briquettes; and (iv) microdosing fertilizer technology. For all treatments, basal NPK (23-15-10) fertilizer was applied at a recommended rate of 250 kg/ha (two 50-kg bags/acre) at planting. Also, all plots received equal amounts of sulfur (S), zinc (Zn), and boron (B) at a blanket application of 20 kg S, 5 kg Zn, and 2.5 kg B per hectare. During the first quarter of FY18, the trials were harvested at anthesis and at maturity to determine N content and grain yield, respectively. The total above-ground N uptake and nutrient use efficiency were then determined.

Results obtained from the 15 locations were consistent throughout with no significant yield variation among locations (no significant treatment x location interaction). Therefore, the results were pooled to compare treatment means. The greatest yields were obtained from the FDP treatment with an average grain yield of 7 tons/ha, followed by the subsurface-applied granular urea treatment with an average yield of 6.7 ton/ha (Figure 10). Despite the statistical similarity in grain yield between these two treatments (FDP and subsurface placement of granular urea), 25% less supplemental N fertilizer was used for the FDP treatment (Table 10) to obtain that yield. In addition, the subsurface application of granular urea required more labor (1.5 man-days more per ha) than the FDP treatment (Table 10). With the subsurface granular urea placement, farmers needed to measure the quantity of fertilizer to apply to each plant, whereas this step was eliminated from the FDP treatment. The differences in yield between the two treatments could be attributed to the significantly higher N uptake (less N losses) from the FDP treatment than the subsurface application of granular urea (Figure 11). The microdosing treatment required significantly less supplemental N fertilizer, but the labor requirement to apply that fertilizer was high (1.5 man-days more than the FDP treatment) (Table 10), and the less-than-average grain yield emanating from that treatment was about 4.5 tons/ha (Figure 10). Although N uptake at anthesis was greatest for the microdosing treatment (Figure 11), the fact that small supplemental N fertilizer was used (30% less than the recommended supplemental N rate) (Table 10) accounted for the low maize yields.

Gross margin analysis was used as proxy for profits to calculate net profit due to the implicit nature of some cost items. The results from Table 11 suggest that farmers could benefit more (profit) by adopting the FDP technology for upland maize production. The gross margin per hectare for the FDP treatment was 246%, 220% for the subsurface placement of granular urea, 122% for the microdosing technology, and 49% for the traditional farmer practice (calculated from Table 10 and Table 11). Thus, from the combined agronomic and economic analysis data, it can be concluded that FDP technology could be an alternative soil fertility management technology for upland maize production, particularly among smallholder farmers. One manuscript from this study is being prepared for journal publication. Also, a production guide is being prepared for dissemination to key stakeholders to upscale the technology among smallholder farmers.

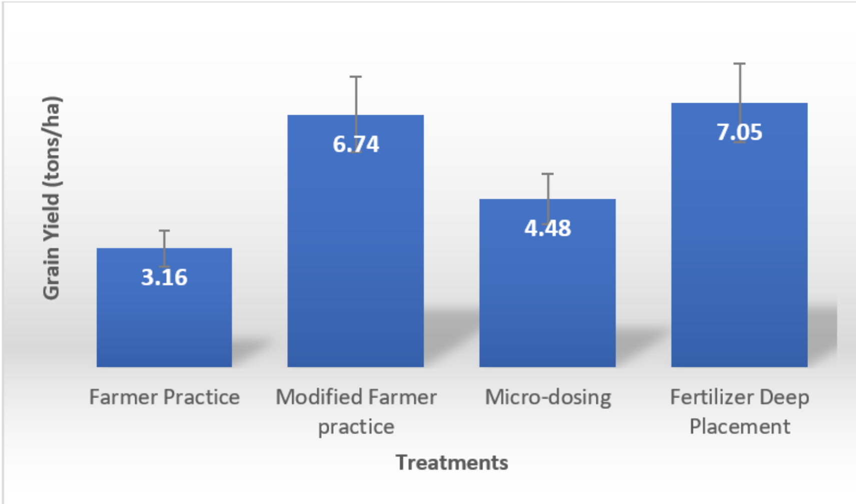


Figure 10. Average grain yield (mt/ha) of maize at 15 locations in the three northern regions of Ghana under four treatments. Bars represent average of 15 locations X 4 replicates; error bars represent standard error

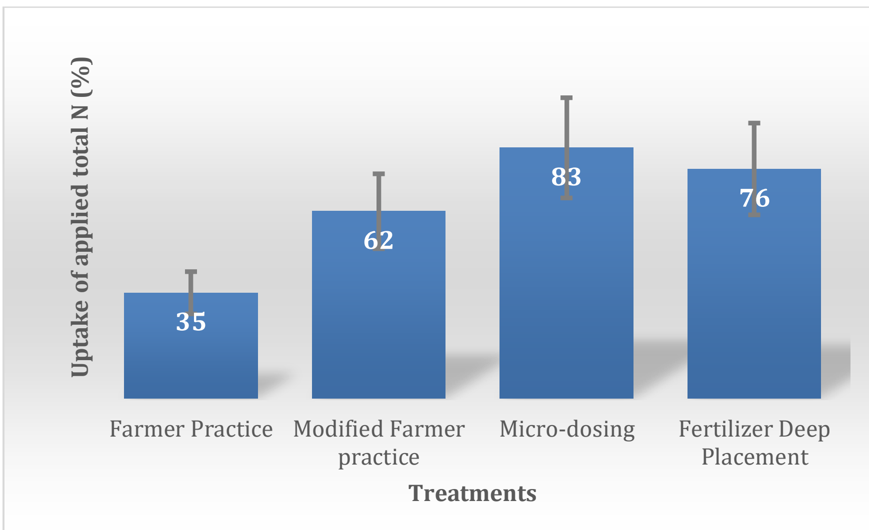


Figure 11. Average nitrogen uptake as percent of N applied to maize grown at 15 locations in the three northern regions of Ghana under four treatments. N uptake was measured at anthesis. Bars represent average of 15 locations X 4 replicates; error bars represent standard error

Table 10. Average cost of upland maize production in northern Ghana with different nutrient management technologies

Treatment	Common Costs[c] (GH¢/ha)	N Split-Applied (kg/ha)	Additional N Cost (GH¢/ha)	Urea Briquetting (GH¢/ha)	Additional Labor for N Split (man-days/ha)	Additional Labor Cost for Split N Application (GH¢/ha)	Additional Labor for Weed Control (man-days/ha)	Additional Labor Cost (GH¢/ha)	Total Production Cost (GH¢/ha)
T1: Farmer practice[a]	2,320	125	312.50	0.00	0.5	18.00	4	144.00	2,924
T2: Modified farmer practice[b]	2,320	125	312.50	0.00	4	144.00	0	0	2,906
T3: Microdosing	2,320	90	225.00	0.00	4	144.00	0	0	2,783
T4: Fertilizer deep placement	2,320	100	250.00	50.00	2.5	90.00	0	0	2,813

a. Supplemental urea applied through surface broadcast.
b. Supplemental urea applied through subsurface incorporation by dibbling.
c. Costs of seeds, NPK fertilizer, land preparation, nursery, transplanting, basal NPK application, initial weed control, harvesting, and threshing.

Table 11. Average revenue from upland maize production in northern Ghana with different nutrient management technologies

Treatment	Average Grain Yield[a] (ton/ha)	Farmgate Price of Maize (GH¢/bag[b])	Total Revenue (GH¢/ha)	Gross Profit[c] (GH¢/ha)	Additional Revenue over Farmer Practice (GH¢/ha)
T1: Farmer practice	3.16	138	4,361	1,437	-
T2: Modified farmer practice	6.74	138	9,301	6,395	4,958
T3: Microdosing	4.48	138	6,182	3,399	1,962
T4: Fertilizer deep placement	7.05	138	9,729	6,916	5,479

a. An average of 15 trials.
b. Bag of maize = 100 kg.
c. Gross profit = total revenue – total production cost (Table 10).

Upland Vegetable Production in Ghana

This trial was 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 and make the enterprise more attractive. Yield increases resulting from the FDP technology (urea and NPK briquettes) have been reported in Burkina Faso on tomato (26% increase), cucumber (22%), and yard-long bean (9%), compared to the conventional fertilizer application practice.

During the last quarter of FY 17, nine sites were selected in the three northern regions of Ghana (three in each region) to evaluate the effect of the FDP technology on yield and nutrient use efficiency of vegetable crops (tomato, pepper, eggplant, onion, and okra). The study also evaluated the synergetic effects of the FDP technology and organic fertilizers on the growth, development, and production of vegetables. The experiments were laid in a split plot design with an individual plot size of 10m × 10 m. The first factor, soil organic matter treatment, was applied on the main plots, but the second factor, the four fertilization treatments stated below, were randomized on the subplots. The NPK (prilled urea for N, diammonium phosphate [DAP] for N and P, and muriate of potash [MOP] for K) briquette, urea briquette, and straight fertilizer (prilled urea, TSP and MOP) were used to provide different nutrient combinations. The four treatments were designed to evaluate crops' response to the subsurface incorporation of granular N, P, and K fertilizers, deep placement of urea briquettes, NPK briquettes, and farmers' practice. The application rates were based on fertilizer recommendations from the local agricultural extension services department as follows:

i. T_1: Granular urea (100% extension recommendation; subsurface incorporation)
ii. T_2: Urea briquette (10% less N; deep-placed)
iii. T_3: NPK briquette (10% less NPK; applied one-time)
iv. T_4: Farmers' practice (100% extension recommendation; surface application)

For the main plots receiving organic materials, a pre-determined quantity (2.5 tons/ha) of either well-decomposed cow dung, poultry litter, or compost, etc., was applied at the time of final harrowing, incorporated into the soil, and thoroughly mixed with the soil. Phosphorus- and potash-containing fertilizers were used for basal application for all treatments except treatment 3 (T_3). After 10 days of transplanting, NPK briquettes (for T_3) and urea briquettes (for T_2) were applied in a ring method. Urea briquettes and NPK briquettes were applied 9-10 cm apart from the base of the plant and 7-8 cm deep into the soil. Subsequently, fertilizers were completely covered by soils. In treatment T_1, one-half of the N was basal applied, and the remaining N was applied 30 days after transplanting. All plots received equal amounts of S-, Zn-, and B-containing fertilizers. All required management practices were adhered to and followed accordingly for each vegetable, and the crops were harvested at maturity. All vegetables (except onion) were harvested twice weekly for a period of four to six weeks, depending on the vegetable and environmental conditions. Onion was harvested by uprooting the bulbs at maturity.

Results showed that across all locations and fertilizer application technologies, incorporating organic materials into the soil prior to planting/transplanting the vegetables significantly increased the yields of individual vegetables, compared to yields obtained from plots without organic material application (Figure 13 through Figure 16), despite applying 25% less mineral fertilizer. This observation is consistent with numerous studies that have shown that a combination of mineral fertilizers and organic materials (integrated soil fertility management [ISFM]-based practices) results in significant benefits for productivity, profitability, resilience, and/or reduced nutrient losses as targeted in Climate-Smart Agriculture (CSA). Vanlauwe et al. (2005) showed that when mineral fertilizers and organic inputs were combined, maize grain yields were between 0.26 and 2.4 ton/ha greater than when the same inputs were applied separately. These results prove that practicing ISFM generates sustainable increases of crop productivity and input use efficiency, which ultimately benefits the livelihood of farmers.

Regardless of organic material treatment, the farmer practice consistently produced the lowest yields for all vegetables at equivalent quantities of fertilizer application rates. Studies have shown that surface broadcast of fertilizers enhances N losses by volatilization, denitrification, and erosion, compared with subsurface incorporation into the soil, thus reducing fertilizer use efficiency. Subsurface incorporation of the fertilizer products increased yields of the individual vegetables grown with and without organic material soil amendment. Consistently, across all locations, the greatest yields observed for all vegetables (Figure 12 through Figure 16), regardless of organic material treatment, occurred in the urea briquette and the NPK briquette treatments, despite applying 10% less respective fertilizer products compared to the extension-recommended application rates. No significant differences in yields were observed for the urea briquette and the one-time NPK briquette application treatments. This implies that the one-time NPK treatment could be a cost-effective nutrient management strategy for vegetable production in terms of reduced labor cost for fertilizer application and relatively less fertilizer application without sacrificing yield.

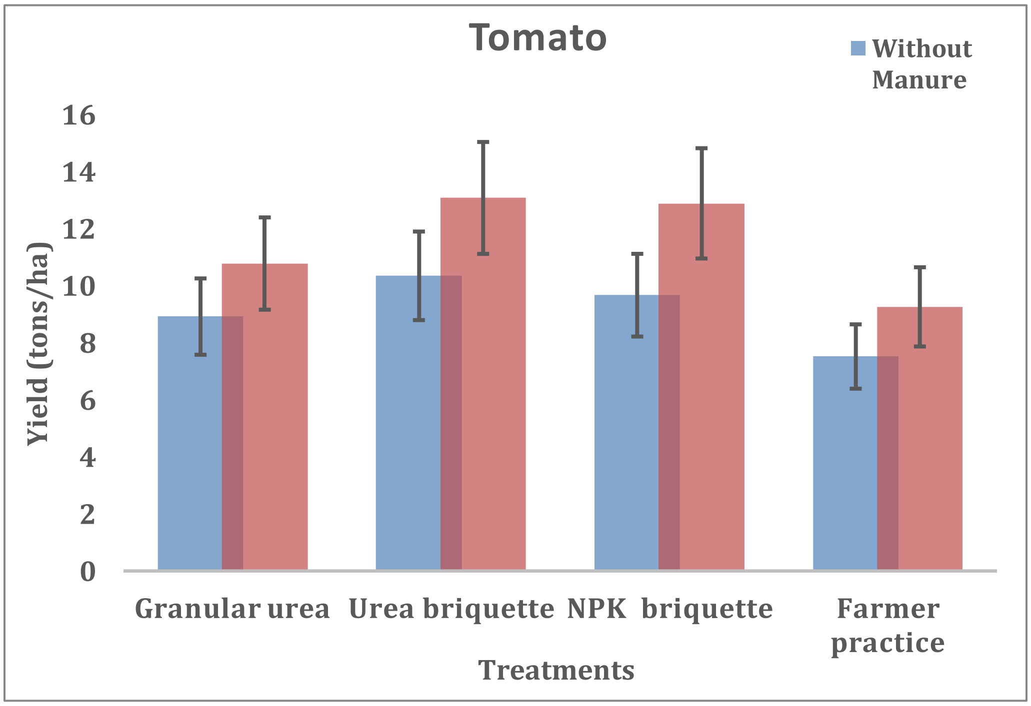


Figure 12. Average yields of tomato in response to different fertilizer management technologies

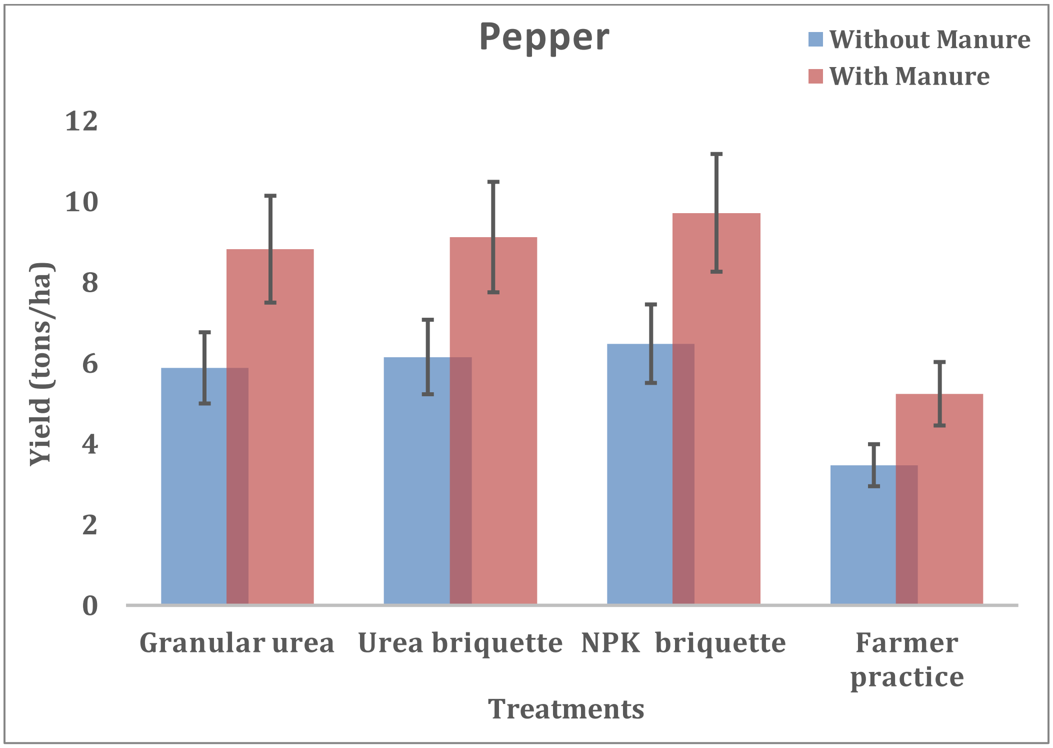


Figure 13. Average yield of pepper in response to different fertilizer management technologies

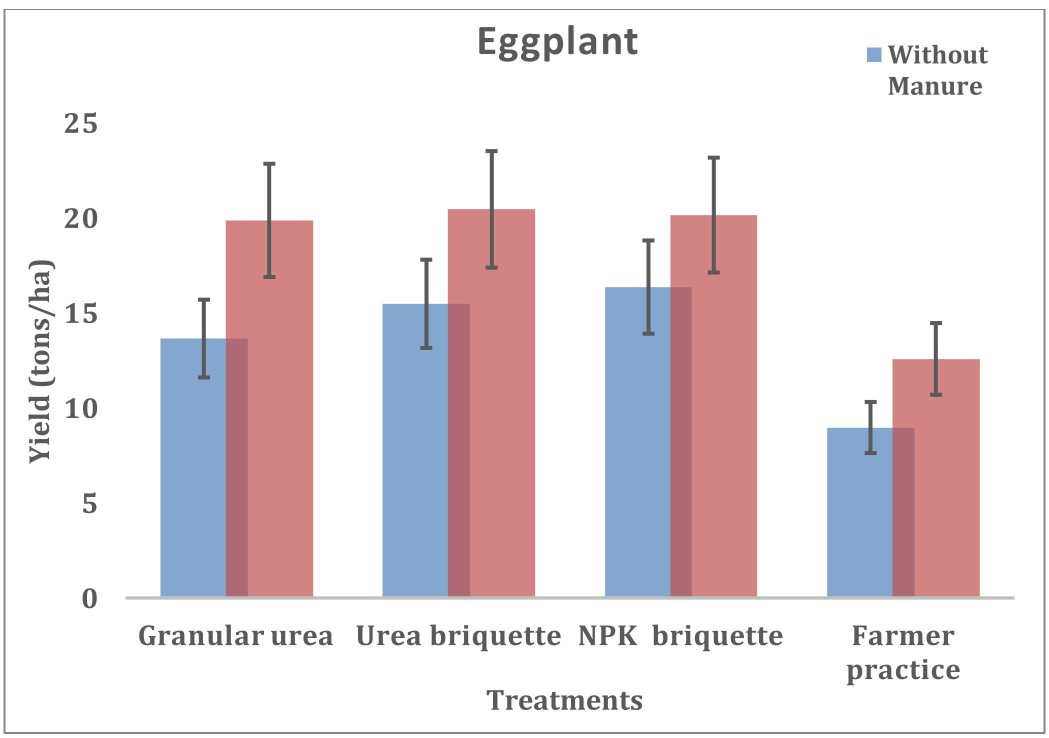


Figure 14. Average yield of eggplant in response to different fertilizer management technologies

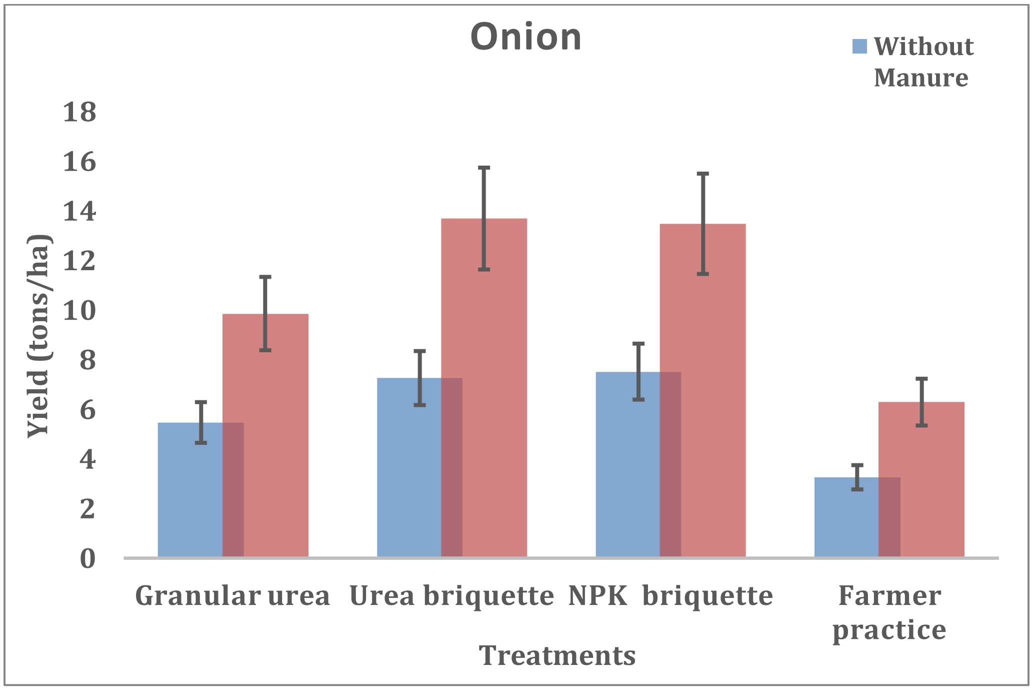


Figure 15. Average yield of onion in response to different fertilizer management technologies

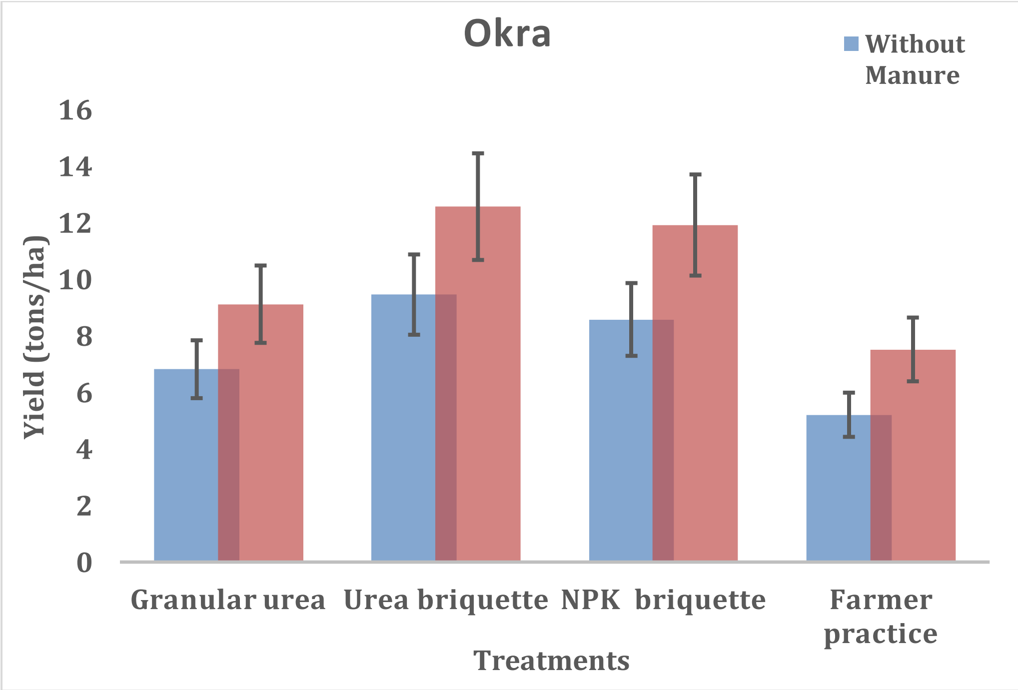


Figure 16. Average yield of okra in response to different fertilizer management technologies

Gross margin analysis (difference between gross revenue and total variable cost) was employed to help analyze the profitability of the different fertilizer technologies for the production of the five upland vegetables in northern Ghana. Because the vegetables were not harvested at once, different quantities were sold at different prices across the season. Therefore, for this study, the weighted average price of vegetables was used in place of the farmgate price (except onion) for the gross margin analysis. For onion, farmgate price was used for the gross margin analysis. The total variable cost of cultivating a hectare of the vegetables was computed from the quantity of the various inputs used and the respective prices at which they were purchased. These included, but were not limited to, cost of land rental, land preparation, seed, nursery practices, mineral fertilizer, organic material and its transportation, agrochemicals, labor, and other farm management costs. A summary of the gross margins resulting from the different fertilization strategies for the respective vegetables is provided in Table 12.

The results from Table 12 suggest that farmers could reach higher profits by adopting ISFM practices, combining organic materials with mineral fertilizers for vegetable production. Despite transportation and spreading costs associated with incorporating organic materials into the soil prior to planting/transplanting, farmers could still make gross margins of 26% to 72% more per hectare (depending on the crop and fertilizer management technology), compared to not using organic material. Without organic amendments, the gross margin percentage of the total variable cost of tomato, for example, was calculated to be 26% using the farmers' practice; 37% for granular urea incorporation; 54% for urea briquette deep placement; and 58% for NPK briquette deep placement. This implies that for every Ghana cedi (GH¢) invested, gross margins of GH¢ 0.26, 0.37, 0.54, and 0.58 was accrued by using farmer practice, granular urea incorporation, urea briquette deep placement, and NPK briquette technologies, respectively. Across all vegetables, locations, and organic amendments, the gross margin percentage for the various fertilizer management technologies followed the order NPK briquette ≥ urea briquette ≥ granular urea deep placement > farmer practice. Thus, the gross margin results indicate that combining either NPK or urea briquettes with organic materials for vegetable production is the most profitable technique, followed by a combination of granular urea incorporated with organics. Manuscripts from this study are being prepared for submission for publication. Also, a production guide will be prepared for dissemination to key stakeholders to upscale the technology among smallholder farmers.

Table 12. Average gross margin[a] per hectare (in Ghana Cedis) resulting from different nutrient management strategies for vegetable production in Northern Ghana

Treatments	Okra		Pepper		Eggplant		Tomato		Onion	
	Without Organic Material	With Organic Material	Without Organic Material	With Organic Material	Without Organic Material	With Organic Material	Without Organic Material	With Organic Material	Without Organic Material	With Organic Material
Granular urea[b]	11,830[c]	14,823	15,203	20,905	15,674	21,031	7,675	8,875	19,162	30,698
Urea briquette	16,411	20,454	15,901	21,661	17,775	22,055	8,905	10,666	25,432	36,326
NPK briquette	14,884	19,230	15,755	23,038	18,786	22,050	8,320	10,398	26,343	37,002
Farmers' practice	9,038	12,043	8,972	12,404	10,300	13,409	6,470	7,593	11,420	14,381

a. Gross margin = Total Revenue – Total variable cost (in Ghana cedis)

b. Supplemental urea applied through subsurface incorporation by dibbling.

c. An average gross margin of nine locations.

1.1.2.4 Greenhouse Quantification of Subsurface Urea Application

The results from the subsurface application (deep placement) of urea briquettes and prilled urea study have been submitted for publication and have also been utilized in ongoing modifications to deep placement applicators. Overall, the results showed that prilled urea can be effectively subsurface applied; however, it performed as well as urea briquettes when soils were saturated with little or no standing water, and it performed better with manual deep placement. Subsurface granular urea deep placement requires development of more reliable deep placement applicators.

1.1.2.5 Quantifying Greenhouse Gas (GHG) Emissions and N Losses

Trials quantifying greenhouse gas (GHG) emissions and N losses under varying water regimes, N application methods and sources, and cropping systems were conducted under field and greenhouse conditions in Bangladesh and IFDC, Muscle Shoals, respectively. Bangladesh trials were conducted at BRRI and BAU. The results from field studies have been published as "Nitrous oxide and nitric oxide emissions from lowland rice cultivation with urea deep placement and alternate wetting and drying irrigation" by Islam et al, and “Efficient Fertilizer and Water Management in Rice Cultivation for Food Security and Mitigating Greenhouse Gas Emissions” by Gaihre et al. Three manuscripts based on greenhouse studies have been submitted for publication.

As part of the capacity-building effort, IFDC is continuously providing technical support to develop climate-smart fertilizer and water management technologies in rice-rice and rice-upland cropping systems in Bangladesh with support of the Krishi Gobeshona Foundation, a government funding agency. In addition, IFDC is collaborating with the International Rice Research Institute (IRRI) to quantify methane emissions mitigation potential from an alternate water management practice. Increased capacity on quantification of GHG fluxes would ultimately help the Bangladeshi government in designing mitigation strategies, calculating carbon credits, and claiming carbon credits. IFDC is also collaborating with Tuskegee University to expand its GHG research under the “1890 Institution Teaching, Research and Extension Capacity Building Grants (CBG) Program.”

1.1.2.6 Mechanization of Subsurface Fertilizer Application

Subsurface granular urea application approaches the efficiency of deep placement briquettes and can be combined with NPKs to further improve efficiency. Designing tools, including mechanization for subsurface application of fertilizer briquettes or granular fertilizer, would resolve labor constraints and could have a major impact on adoption. During FY18, two prototype mechanized applicators were developed in partnership with National Agro Machinery Industries, Ludhiana, and Khedut Agro-Engineering Pvt. Ltd, Gujarat (Figure 17). The latter is being evaluated in partnership with the USAID Fertilizer Sector Improvement (FSI+) project in Myanmar. Further evaluation during FY19 will take place in Myanmar, Nepal, and Cambodia.

A University Partnership Grant has been awarded to Mississippi State University to modify a commercial rice transplanter to perform both deep placement and rice transplanting in a single operation. A prototype for field evaluation will be available during FY19.

Figure 17. Mechanized applicator for subsurface fertilizer application and seeder

1.1.3 Improving Nitrogen Use Efficiency of Organic and Inorganic Fertilizers

The ongoing activities are conducted in partnership with fertilizer industry clients, University of Central Florida (UCF), the Tropical Research and Education Center of the University of Florida, and on a three-year (plus one-year no-cost extension) grant funded by the U.S. Department of Agriculture (USDA) National Institute of Food and Agriculture (NIFA). The activities are executed in collaboration with The Connecticut Agricultural Experiment Station (as the lead) and The University of Texas in El Paso. In addition, a research grant submitted to the National Science Foundation (NSF) in collaboration with North Dakota State University Fargo is currently pending and is expected to contribute to the proposed activity if it is funded.

1.1.3.1 Role of Micronutrient Fertilization in Crop Yield and Nutrient Utilization

Conceived in the context of balanced crop nutrition, this continuing project has the broad objective of evaluating micronutrient effects on agricultural crop productivity and nutrient utilization under different production conditions. Evaluating micronutrients such as Zn, manganese (Mn), copper (Cu), and B allows for a better understanding of how micronutrient fertilization influences crops' use of N, P, and K and the cognate micronutrient. For the FY18 studies described in this report, Zn and Mn were evaluated in wheat. Zn was evaluated as ZnO nanopowder or Zn-sulfate (salt); and Mn was evaluated as MnO nanopowder, bulk MnO powder, or Mn-chloride (salt). The Zn rate was 6 mg/kg soil (in an 8-kg pot), and the Mn rate was 10 mg/kg soil. NPK rates were 200, 75, and 200 mg/kg soil, respectively. In the Zn study, the experiment was conducted using fresh and used soils (previously treated with the same Zn types and amount and cropped with sorghum) to demonstrate whether Zn as nanopowder or salts (ions) has any residual value as fertilizer for subsequent crops, compared to fresh Zn applications. The soil used in the studies was a sandy loam with a near-neutral pH of 6.87, which suggests the pH was nearing the upper border line for optimum soil Zn and Mn bioavailability. For Zn, the initial level of 0.1 mg/kg was below the critical level of 0.5 to 1.0 mg/kg; for Mn, the level of 6.4 mg/kg in the soil was just above the critical level of 1-5 mg Mn/kg indicated in the literature for wheat. The major findings from these studies, which have now been published, are summarized below.

Zinc Studies

Residual and fresh Zn significantly ($p < 0.05$) increased grain yield by 15% and 29%, depending on soil Zn aging rather than Zn type (Figure 18). Decreased post-harvest soil pH and a loss of ZnO nanoparticle spectral peak indicated transformation to ions as the mechanism of ZnO nanoparticle bioactivity. Zn was significantly bioaccumulated from both Zn types (Figure 18), but root-to-shoot accumulation efficiency was low (lower with Zn salt than ZnO nanoparticles). Grain Zn content significantly increased between 186% and 300% (Figure 18), with high translocation efficiency that changed depending on Zn type and aging in the soil. Zincon assay indicated that grain Zn does not exist in the ionic state. These findings have relevance for Zn biofortification efforts in grains for human nutrition. Taken together, it is hoped that the findings on Zn effects on grain yield and nutritional quality provide useful information pertinent to the frequency and utility of Zn exposure, especially in used soils. In addition, information on differences that were observed between Zn types could be important in recommending specific Zn types to achieve specific targets, such as yield increase or grain fortification. Further details of this study with appropriate statistics on yield and nutrient acquisition and distribution among the plant organs and in soil (mass balance), and the effect of Zn aging and type on these outcomes, are published in Dimkpa et al. (2018).

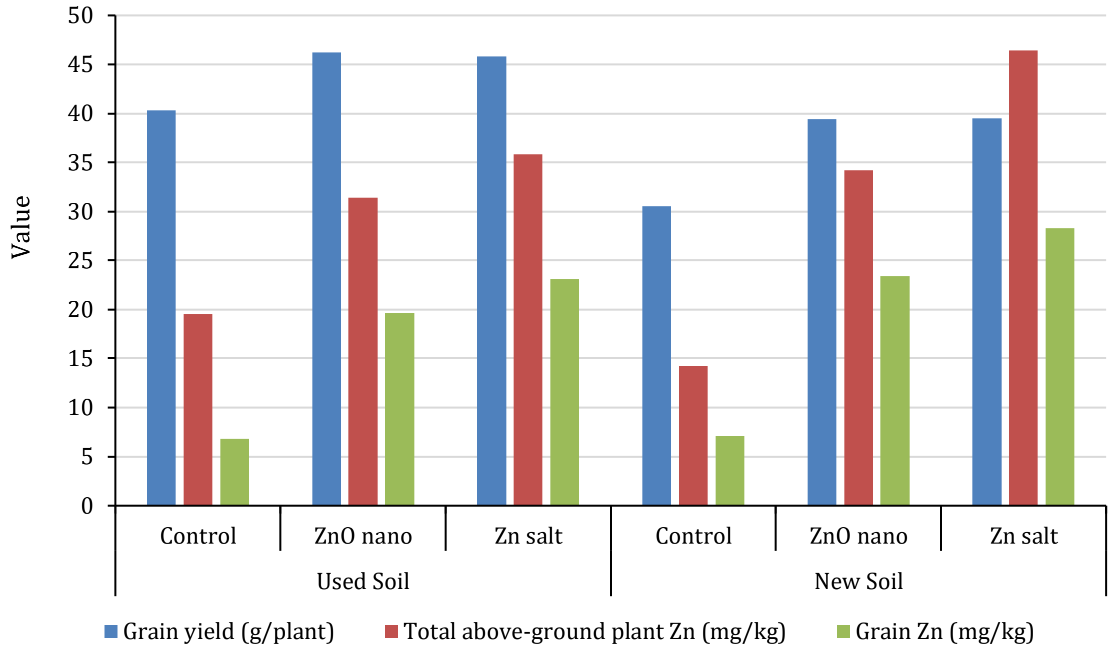


Figure 18. Yield, nutrient accumulation, and grain Zn responses of wheat to ZnO nanopowder and Zn salt in fresh and used soils.

Manganese Studies

Compared to the control (i.e., NPK only), Mn treatment in soil as salt (ionic), bulk particle, or nanoparticle increased grain yield by 9%, 13%, and 16%, respectively. In addition, the Mn nanopowder as a foliar treatment increased grain yield by 22%. Thus, nano-Mn was more effective in promoting grain yield in wheat than other Mn forms, resulting in 6% more grain yield when applied as a foliar treatment, compared to soil application. However, due to high variability among the treatment replicates, these effects were statistically not significant. In addition to its potential to increase crop yield, the Mn plant treatment significantly ($p < 0.05$) reduced shoot N by 9-18%, compared to the control treatment. However, nano-Mn in soil exhibited other subtle effects on nutrient acquisition that were different from ionic or bulk Mn, including reductions in shoot Mn (25%), P (33%), and K (7%) contents. Despite lowering shoot Mn, nano-Mn resulted in a higher grain Mn translocation efficiency (22%), as compared to salt-Mn (20%), bulk-Mn (21%), and control (16%). When compared to soil, foliar exposure to nano-Mn exhibited significant differences: greater shoot (37%) and grain (12%) Mn contents and more shoot (43%) P. The combined effect of exposure to Mn types on total (shoot + grain) plant acquisition of Mn, N, P, and K is summarized in Figure 19. Put in perspective, nutrients in the form of nanomaterials, including Mn, are increasingly being deployed in agriculture as fertilizers (nanofertilizers) and pesticides, due to supposed heightened efficiency arising from size and surface area properties that are different from conventional nutrient types. The main implication of the findings reported in this study is that, although nano-scale Mn tended to increase grain yield more than other Mn types, exposure of agricultural plants to nano-scale Mn in soil could affect plants in subtle ways that are different than bulk or ionic-Mn. This suggests caution in its use in agriculture. Nevertheless, applying nano-Mn as a foliar treatment could enable greater control on plant responses. A detailed report on this study can be found in Dimkpa et al. 2018.

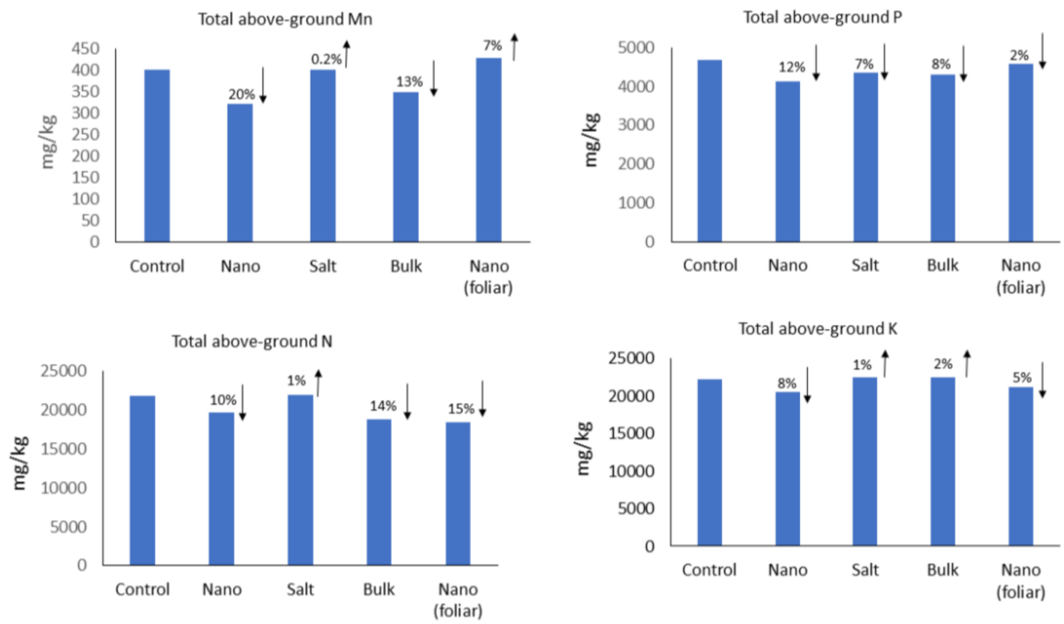


Figure 19. The effects of the Mn type (nano, salt, and bulk) and exposure route (soil v. foliar) of nano-Mn on total (shoot and grain) Mn, N, P, and K concentrations in wheat. The values on the bars are percentage decrease (downward arrow) or increase (upward arrow) in nutrient levels, compared to the control.

Two other studies, one nearing completion and the other recently initiated, are ongoing under the broad objective described in 1.1.3: (i) A micronutrient omission trial using a combination of Zn, Cu, and B in nano and bulk forms. This trial is to assess which of these micronutrients is critical for soybean productivity and utilization of macronutrients and to evaluate whether differences exist depending on the types of Zn, Cu, or B. (ii) An evaluation of Zn effects on sorghum yield and nutrient use under limited water conditions. Sorghum is a drought-tolerant crop, and Zn is reported to be involved in water relations in plants. However, little is known as to what roles Zn might play in sorghum production under water-limiting conditions. Hence, a range of Zn doses is being evaluated in sorghum under water-limited conditions. Updates on these studies will be provided in a future report.

1.1.3.2 Effect of Coatings, Inhibitors, and Micronutrients on N Efficiency

Biodegradable coatings, inhibitors, and nano-materials are becoming affordable to use for improving nutrient use efficiency, and they are no longer restricted to fertilizers for high-value crops or developed country markets. Multiple sub-activities are underway for this activity.

Facile Urea Coating System with Micronutrients for Improved N Use Efficiency

An in-house preliminary activity based on a facile coating system is being conducted in which composites of N (urea granules) and micronutrients in nano forms have been developed using a facile system involving inexpensive and readily available “coating” materials. So far, three types of micronutrient-coated N-fertilizers have been developed: Urea-ZnO, urea-CuO, and urea-B_2O_3. Preliminary work indicated that commercial food-grade vegetable oil is suitable to achieve a perfectly uniform coating of the micronutrients onto urea. To this end, urea was coated separately with ZnO, CuO, and B_2O_3 at different weight ratios, dependent on their specific crop requirements (in this case between 0.5 to 2% wt/wt). Food-grade vegetable oil (0.5% v:w) was used for coating. In addition, food-grade coloring (0.2 v/w urea) was used to distinguish the different composites, since ZnO and B_2O_3, like urea, are white and lack contrast. Moreover, this also helped to avoid cross contamination. Coloring was not necessary for the urea-CuO composite, as CuO is color-contrasting with urea; however, the coloring agent was included for process uniformity and to avoid treatment variability. A second system used urea briquettes with larger particle sizes than urea granules. These products are presented in Figure 20. This facile coating system will continue to be optimized with the different micronutrients, and the final products demonstrating better shelf-life will subsequently be evaluated in crops and compared to non-coated fertilizer combinations.

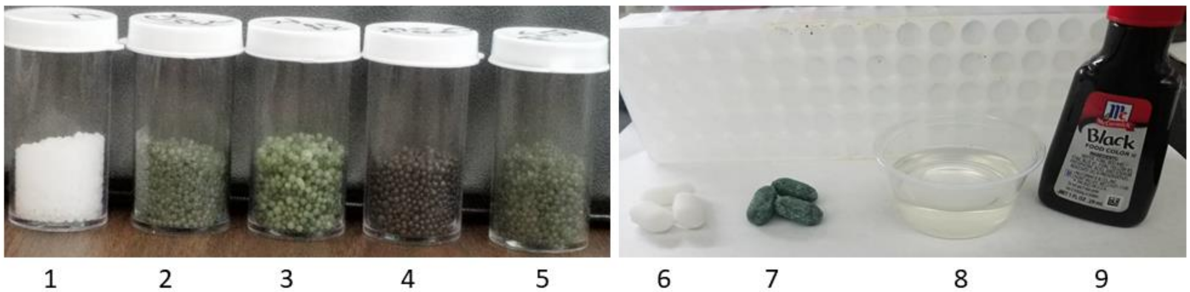


Figure 20. "Nano-enabled" urea developed by coating with oxide nanoparticles of micronutrients: (1) urea with vegetable oil (VO); (2) urea with VO and food colorant (FC); (3) urea with ZnO NP + VO + FC; (4) urea with CuO NP + VO+FC; (5) urea with B_2O_3 NP + VO + FC; (6) urea briquette with VO; (7) urea briquette with VO and FC; (8) VO; (9) FC.

Fine-Tuning Urea Coating with Nano Zn for Improved Plant Delivery of Zn

This project is being pursued in partnership with UCF. The objectives are to: (i) synthesize and characterize fertilizer-grade ultra-small size nano-ZnO; (ii) spray-coat granular urea with the nano-ZnO formulation; and (iii) study the root uptake and systemic movement of Zn from the formulation. A tabletop seed coater (Figure 21a) (USC LLC, Kansas, U.S.) was used to coat urea with ZnO. In order to optimize the coating process, a commercial slow-release fertilizer mix (Miracle Gro Shake 'n Feed All-Purpose Plant Food, which included granular urea) was coated with a fluorescein isothiocyanate (FITC)/ethanol solution (Figure 22). The isothiocyanate group reacted with the primary amine of the urea molecule, forming a stable thiourea linkage. Fifty grams (50-g) of fertilizer were loaded in the drum (Figure 21b), and 20 ml of FITC solution (0.5mg/mL) were sprayed for 6 minutes under rotation. Then, the coated fertilizer was air dried using compressed air for the same period of time. The sample was unloaded and observed under a hand-held black light source.

Figure 21. Tabletop seed coater (a); and loaded drum (b).

Figure 22. FITC solution and fertilizer mix under natural light (left); and UV-light (right).

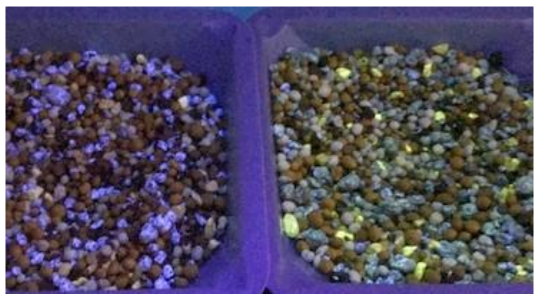


Figure 23. Fertilizer mix under UV-light before (left) and after (right) coating with FITC solution

As expected, the urea portion of the fertilizer mix showed fluorescence under the UV light (Figure 23, right, green-yellow color). Urea granules were uniformly coated. Other granular fertilizer particles were coated, but the FITC green-yellow emission color was not prominent, possibly due to the fluorescence being quenched by other metals present in the fertilizer mix. FITC is a good fluorescent marker to confirm uniform coating of granular urea. We have also observed that ethanol is a good solvent to coat the urea surface. Next, granular urea will be coated with the proposed nano-Zn micronutrient. We will also prepare a batch of nano-Zn coated urea with fluorescent markers for characterization purposes. These formulations will be evaluated on crops in the near future and will be reported in subsequent updates.

Urea Coating Research: Increase N Efficiency and Nutrient Delivery

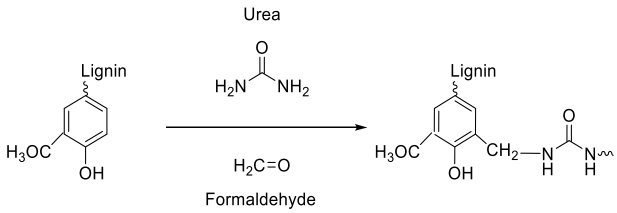
Since urea is the main fertilizer used worldwide, IFDC is conducting a series of coating tests to improve nitrogen use efficiency through control or slow release fertilizers and by adding other elements that will benefit plant uptake. Several products, including secondary nutrients and micronutrients have been used in the initial trials to verify the feasibility of different products to coat urea granules with/without the addition of any “binders.” Different methods included dry and wet blending, different concentrations of binders and coating agents, temperatures, particle sizes, and application methods.

Over 150 small batch trials were performed at lab-scale. The coatings of the products shown in Figure 24 include graphene, biopolymers, phosphate rock, wax, and micronutrients. A few of the products generated from the coating tests will be selected to advance to the next stage of testing. This next stage will involve a quick 21-day incubation test to evaluate N transformation. The most promising products will be chosen based on the quality of their coatings and will be tested in conjunction with some commercially-available fertilizers that are known to exhibit slow-release qualities. The ultimate goal of this research is to advance some of these products further to greenhouse testing and pilot plant testing, which can then be scaled up for field trials and commercial production.

Figure 24. Coated urea fertilizers

Along with in-house testing, IFDC and the University of Florida are involved in a partnership to develop smart fertilizers. This joint research aims to develop and test new fertilizers/soil amendments which will protect the environment, improve crop production, and increase farmer profits. The partnership will also develop teaching materials on new fertilizers and soil amendments for farmers, fertilizer professionals, undergraduates, and graduate students.

New chemicals, materials, and test instruments have already been evaluated for the upcoming research. The preliminary experiment on grafting urea on lignin through the Mannich reaction to form a strong absorbent for nitrate was done by briefly adding urea into alkaline lignin at 50°C with a pH level of 11. Then, the temperature was increased to 90°C for 4 hours. After the mixture was cooled to ambient temperature, 1M HCl was added until precipitates were formed. Precipitates were filtered by filter paper and washed with distilled water until the pH level reached neutral. Modified lignin powder was obtained after residues were dried overnight at 65°C under vacuum and grinded to powder. The chemical reaction is shown below:



This type of grafted lignin had strong nitrate ion precipitation capability, which could significantly benefit the soil-water ecosystem by reducing nitrate leaching from soils and improve nitrate availability to plants as a slow-release fertilizer. As a follow up to this research, different methods to modify lignin and other biomasses, such as castor oil to form new coating materials for controlled release fertilizers, will be developed and evaluated.

Further coating research collaborations for the next 2-3 years will be:

1. Chelating micronutrients: Lignin (organic wastes from pulping and bioenergy processes) will be modified chemically to produce a bio-based chelator for micronutrients, such as ion and zinc. The functional groups will be chemically grafted on lignin to make a bio-based EDTA, like polymer, which can act as a chelating agent to hold micronutrients through the coordinate bindings.
2. Biochar fertilizers: (a) Engineered biochars with high cation and anion exchange capacities will be developed to hold nutrients and release them slowly; (b) engineered biochar with special pore structure and large surface area will be developed to host beneficial microbes as a novel bio-fertilizer; and (c) biochar-based composite will be evaluated as an organic fertilizer.
3. Nano fertilizers: Nano-coated balanced fertilizers (plus micronutrients) will use extremely thin layers to coat fertilizers. Nano foliar fertilizers will penetrate leaves easily. This activity also includes a partnership with UCF.
4. Bio-fertilizers: Phosphorus/iron solubilizing microorganisms will be cultured and deployed to make soil residual P available to plants.

1.1.4 CO_2 Mitigation Role of Enhanced Efficiency Fertilizers and Practices

Urea application, independent of the method of application, results in CO_2 emission during urea hydrolysis. In broadcast-applied urea, all CO_2 emissions (0.73 kg/kg urea) to the atmosphere occur within five to seven days of application, contributing to the GHG pool. Although CO_2 emissions have a negative impact as a GHG, it also increases dry matter and grain yield, particularly in C3 plants such as rice, wheat, and legumes, due to its positive effect on photosynthesis. However, to have the latter effect, CO_2 emissions must occur over a prolonged period, much like controlled-release fertilizers.

Results presented in Figure 25 show a net increase in CO_2 emissions from all fertilizer treatments within the different soils and moisture contents. The three soils used were: Hiwassee (pH 5.5), Greenville (pH 6.2), and Brownfield (pH 6.9). These soils provided a wide range of pH, texture, nitrogen, and organic matter content that are known to affect soil respiration. The fertilizer treatments were surface application of granular urea, ESN (polymer-coated urea), Agrotain (urease inhibitor), ammonia nitrate (AN), urea briquette deep placement, and check (no N). The application of AN takes into account the effect of N fertilization on microbial activity; however, unlike urea-based products (UDP, Agrotain, ESN), there is no direct CO_2 emission from AN. Enhanced efficiency fertilizer, such as ESN, control the release of urea-N, hence urea hydrolysis. UDP, ESN, and Agrotain are known to reduce ammonia (NH_3) emissions.

The moisture conditions chosen for this research were 50% field moisture capacity (FMC), 75% FMC, and flooded conditions. These conditions were used to test the CO_2 emission from the fertilizer x soil x moisture interactions with the purpose of simulating low, medium (ideal), and high moisture contents and studying the behavior of urea hydrolysis, microbial activity, and aerobic and anaerobic conditions. Statistical analyses showed that any combination between fertilizer, soil, moisture, and time and their interactions were highly significant.

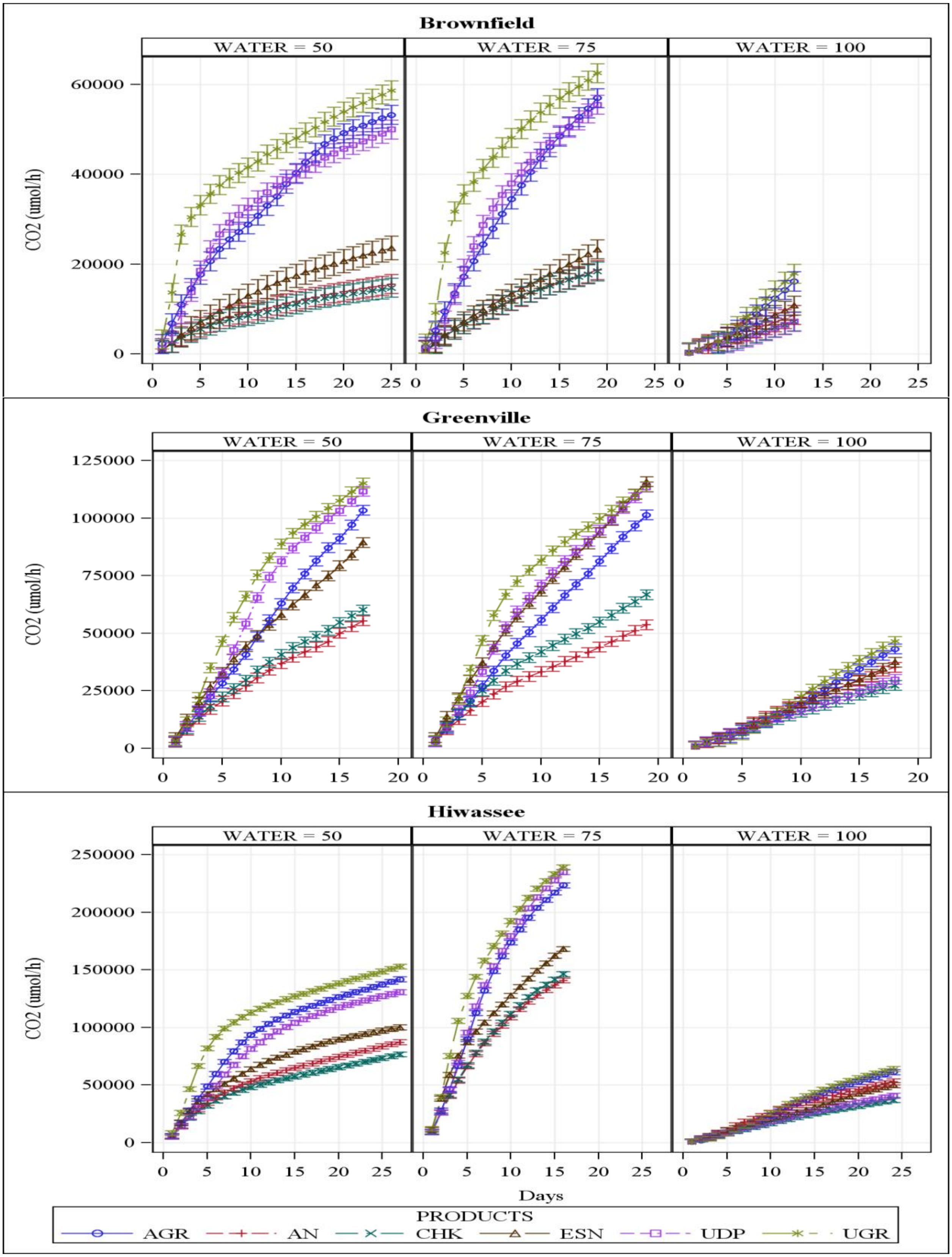


Figure 25. Cumulative CO_2 emissions per soil per moisture for different fertilizer treatments

For the initial conclusions, urea granular showed higher and faster cumulative emissions than other fertilizers in most conditions (Figure 25). Although UDP and Agrotain, showed similar results in terms of cumulative CO_2 emissions as urea, overall, they had slower emission rates within the first five to seven days. Such reduction in CO_2 emission rates may improve the opportunity for CO_2 to be captured by plants and soil microflora.

Table 13. CO_2 emission as influenced by fertilizer type, soil, and moisture regime

Treatment Description		Total CO_2 (g pot^{-1})			Corrected Total CO_2 (g pot^{-1})			CO_2 Emission Factor (% of C applied)		
Soil	N Fertilizers	M50	M75	M100	M50	M75	M100	M50	M75	M100
Brownville	AN	0.71bAB	0.87bA	0.44aB	-	-	-	-	-	-
	Check	0.67bAB	0.85cA	0.36aB	-0.04bA	-0.02bA	-0.08bA	-	-	-
	Agrotain	2.39aA	2.62aA	0.79aB	1.68aA	1.75aA	0.35aB	60.00a	62.63a	12.35ab
	ESN	1.00bA	1.08bA	0.53aB	0.29bA	0.22bA	0.09abA	10.31b	7.71b	3.07ab
	UDP	2.26aA	2.55aA	0.36aB	1.54aA	1.68aA	-0.08bB	55.14a	60. 05a	-2.85b
	Urea granular	2.63aA	2.84aA	0.83aB	1.92aA	1.97aA	0.40aB	68.67a	70. 31a	14.11a
Greenville	AN	2.58cA	2.49cA	1.61abcB	-	-	-	-	-	-
	Check	2.79cA	3.10cA	1.25cB	0.21cAB	0.61cA	-0.35cB	-		-
	Agrotain	4.88aA	4.69bA	1.99abB	2.30aA	2.20bA	0.38aB	82.12a	78.58b	13.68a
	ESN	4.24bB	5.37aA	1.74abcC	1.67bB	2.88aA	0.13abC	59.54b	102.92a	4.50ab
	UDP	5.14aA	5.23abA	1.37bcB	2.56aA	2.74aA	-0.23bcB	91.45a	97.88a	-8.33b
	Urea granular	5.26aA	5.18abA	2.14aB	2.69aA	2.69aA	0.53aB	96.02a	96.09a	18.85a
Hiwassee	AN	3.89cdB	6.42dA	2.85aC	-	-	-	-	-	-
	Check	3.42dB	6.66dA	1.67bC	-0.47eB	0.24dA	-1.18cC	-	-	-
	Agrotain	6.30abB	10.17bA	2.74aC	2.41bB	3.75bA	-0.11aC	86.19b	133.82b	-3.92a
	ESN	4.46cB	7.77cA	2.24abC	0.57dB	1.35cA	-0.61bC	20.23d	48.43c	-21.70b
	UDP	5.80bB	10.70abA	1.83bC	1.91cB	4.28aA	-1.03cC	68.13c	152.85a	-36.63
	Urea granular	6.79aB	10.83aA	2.86aC	2.90aB	4.41aA	0.01aC	103.63a	157.36a	0.22a

Among soils, Hiwassee, which represented a lower pH and higher organic matter content soil, released higher CO_2 compared to Brownfield and Greenville. On the other hand, Brownfield loamy sand with near neutral soil acidity, Ca content, and low organic matter presented a lower CO_2 emission. The high CO_2 emission factor under Hiwassee, at 75% FMC (Table 13), can be explained by the priming effect on microbial activity under ideal moisture and high carbon content. The AN treatment showed that microbial activity due to the nitrogen fertilizer application was minimal, supporting claims from Brumme et al. (1992) in which a non-CO_2 nitrogen fertilizer showed lower CO_2 emission than control plots.

The higher CO_2 emission in the 75% FMC compared to 50% FMC could be explained by the effects of moisture on the rate of urea hydrolysis and microbial activities. Overall, the lower emissions were from flooded fields, demonstrating the effects of a low redox potential environment for soils where most of the CO_2 is used or reduced to methane (CH_4).

1.2 Balanced Plant Nutrition Through Improved Fertilizer Product Recommendations (Cross-Cutting with Workstream 2.3)

For sustainable crop intensification and protection of natural resources, balanced nutrient management/fertilization is critical. Balanced fertilization is also important in the efficient use of fertilizers, soil health, and crop resilience. In addition to N, P, and K, many soils in SSA are now deficient in S, magnesium (Mg), Zn, and other secondary and micronutrients.

In Asia and SSA, several blends of fertilizers are available, and more will come into the supply chain. Assuming the fertilizer product has not been adulterated, such fertilizers generally have a positive impact on crop productivity. However, the availability of a given nutrient within a granule of fertilizer is strongly affected by the presence of other nutrients and the interactions of various nutrients within the granule or as the granule dissolves when applied. With synergistic combination of macro- and micronutrients in a granule, the plant availability and efficiency of fertilizer use can be increased. Conversely, antagonistic effects can result in reduced plant availability of critical nutrients and lower use efficiency. The progress of IFDC's ongoing work on balanced plant nutrition through improved fertilizer product recommendations is presented below.

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

Updates to Soil Fertility Maps

To increase agricultural productivity, spatial soil fertility variability must be considered in order to design soil fertility recommendations to achieve sustainable growth in productivity, particularly in SSA. During FY17, we collected soil and plant tissue samples across the three northern regions of Ghana (FTF zone of influence in Ghana) and analyzed them for their elemental (nutrient) concentrations. Using geostatistical tools, we began the process of developing soil fertility maps for the region. These maps have been continuously updated as and when new data become available. During the first quarter of FY18, the remaining soil and plant tissue samples collected were analyzed to update the soil maps. The updated maps include maps for pH, organic matter, nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, zinc, and boron (Figure 26 through Figure 35). These soil fertility maps will provide the basis for soil- and crop-specific fertilizer recommendations, evaluation of the Soil testing, Mapping, Recommendations development, and Technology transfer (SMaRT) approach and refinement of the GSSAT software (geographic information systems crop model application).

The updated maps did not deviate from the results of the previous maps. As stated in the FY17 report, across all three northern regions, 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. In addition, large portions of the total land area have soils deficient in P (<10 mg/kg), S (<6 mg/kg), Zn (<1 mg/kg), and B (<1 mg/kg). Thus, to increase productivity in such soils and realize the full benefits of fertilizer investments, efforts must be made to supply farmers with fertilizers containing these essential plant nutrients and make farmers aware of these nutrients for healthy crops. However, the quantities of the nutrients to supply will depend on the results of the nutrient omission trials.

The results of this activity were presented at a soil fertility workshop held in Accra, Ghana. A paper entitled, "Do Blanket Fertilizer Recommendations Still Work? A Case Study of Maize Production in Northern Ghana," will also be presented during the Soil Science Society of America meetings in San Diego, California.

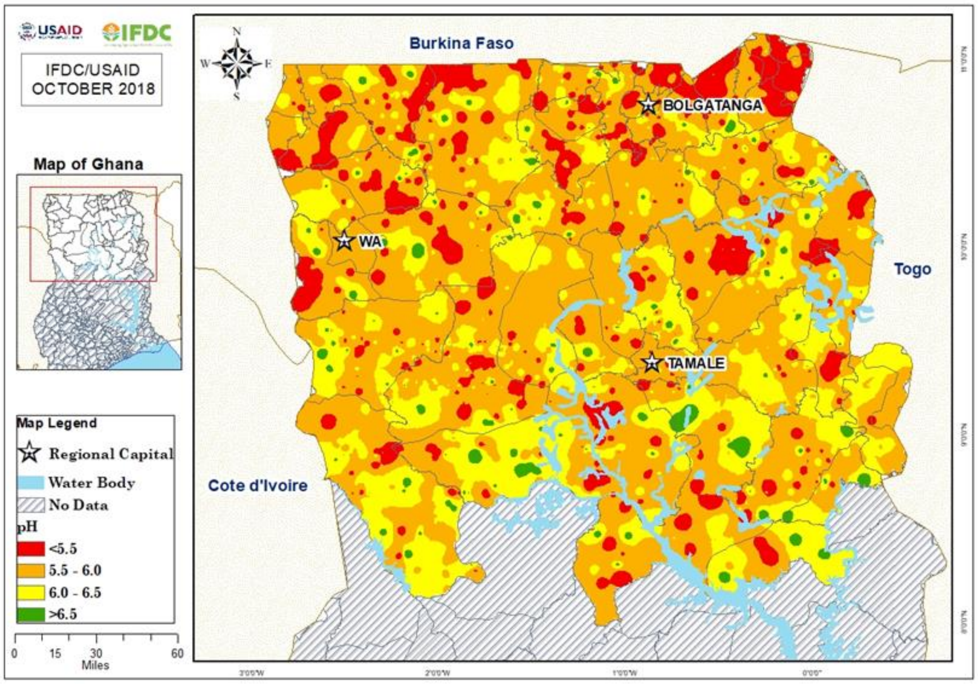


Figure 26. Updated map showing spatial distribution of soil pH in northern Ghana

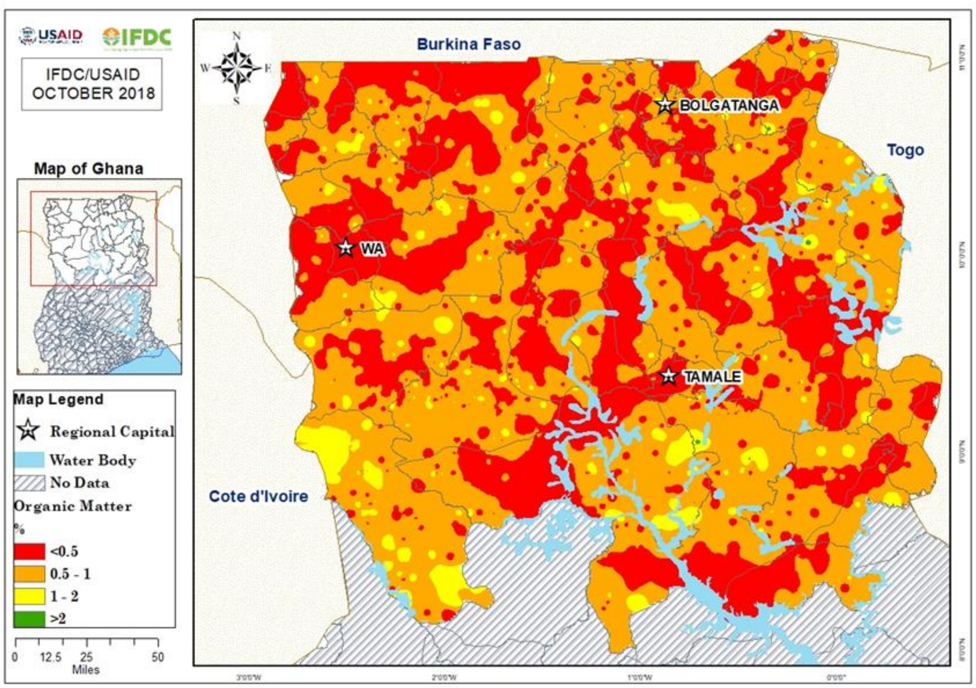


Figure 27. Updated map showing spatial distribution of soil organic matter content in northern Ghana

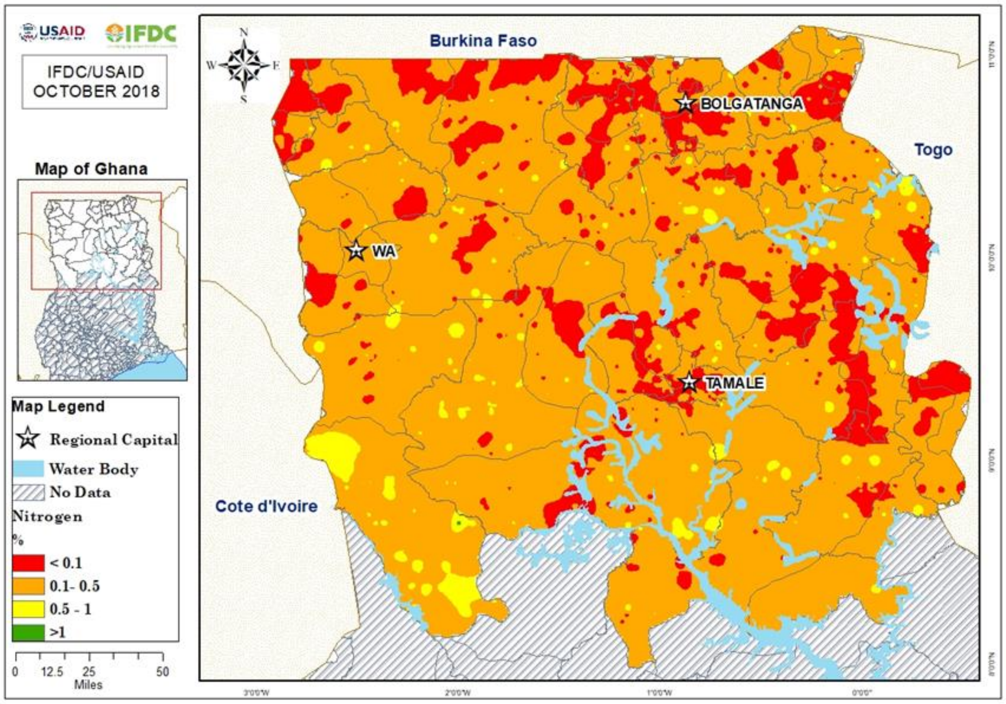


Figure 28. Updated map showing spatial distribution of soil nitrogen concentration in northern Ghana

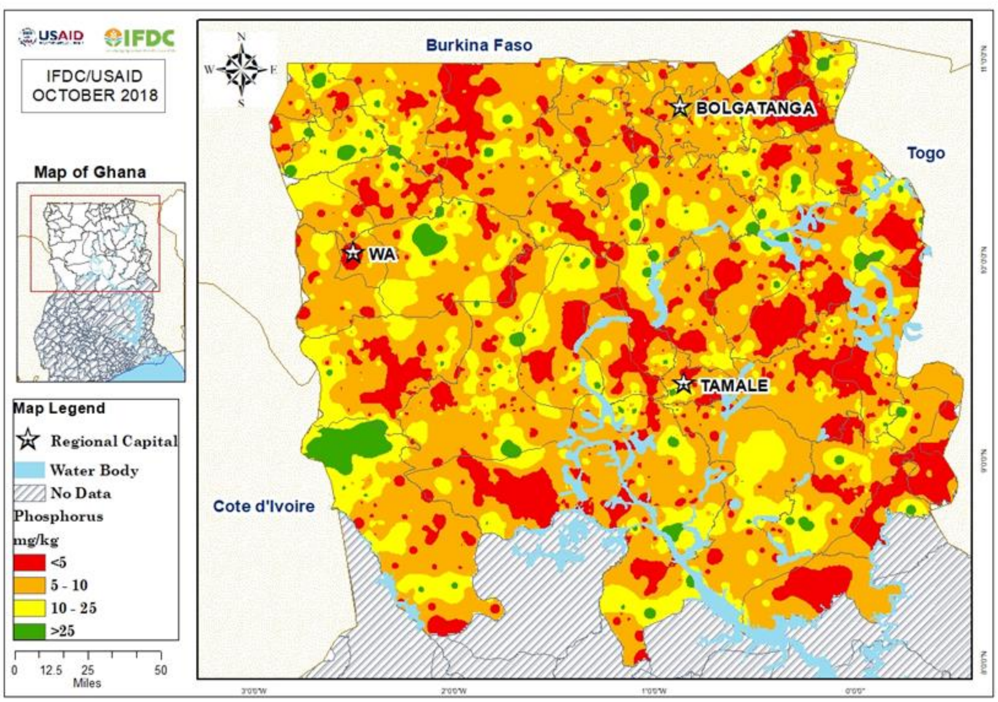


Figure 29. Updated map showing spatial distribution of soil phosphorus concentration in northern Ghana

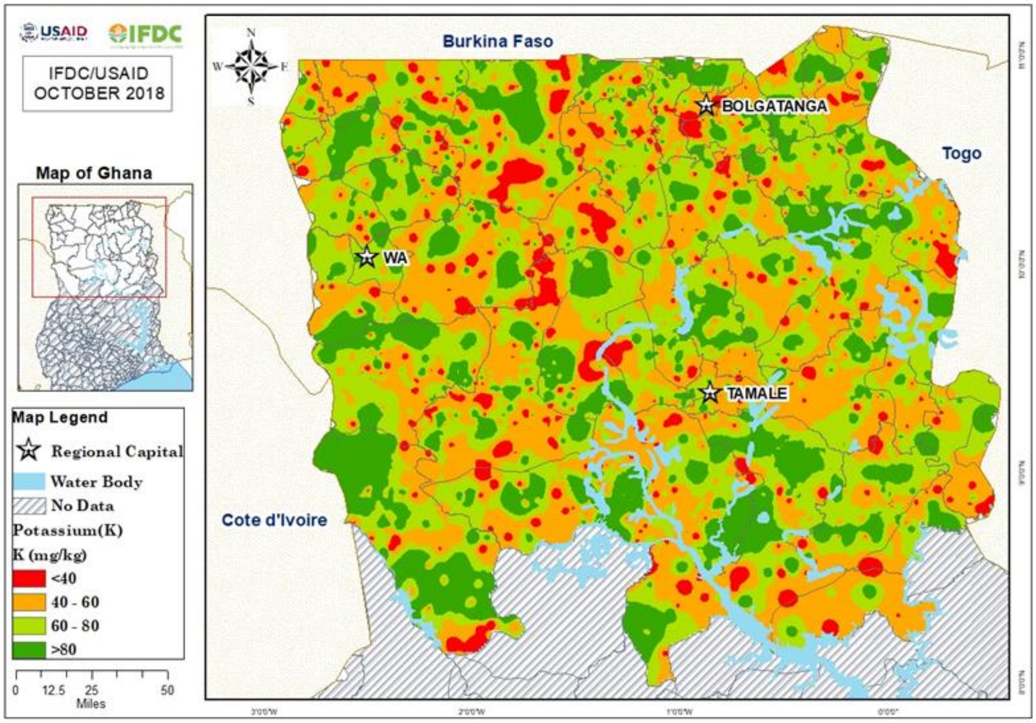


Figure 30. Updated map showing spatial distribution of soil potassium concentration in northern Ghana

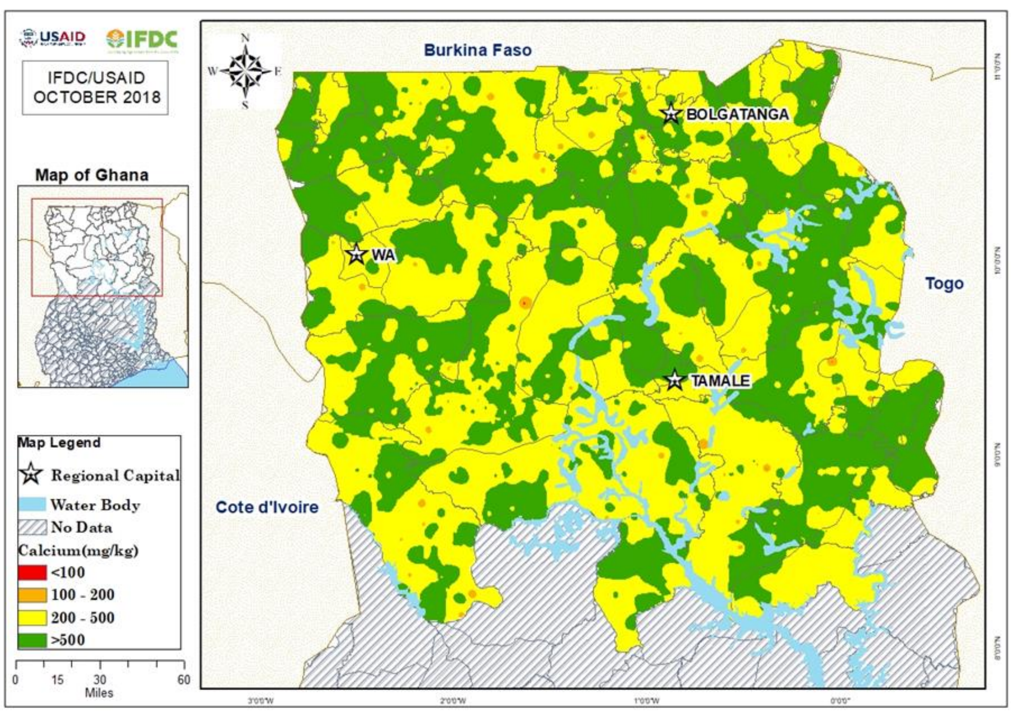


Figure 31. Updated map showing spatial distribution of soil calcium concentration in northern Ghana

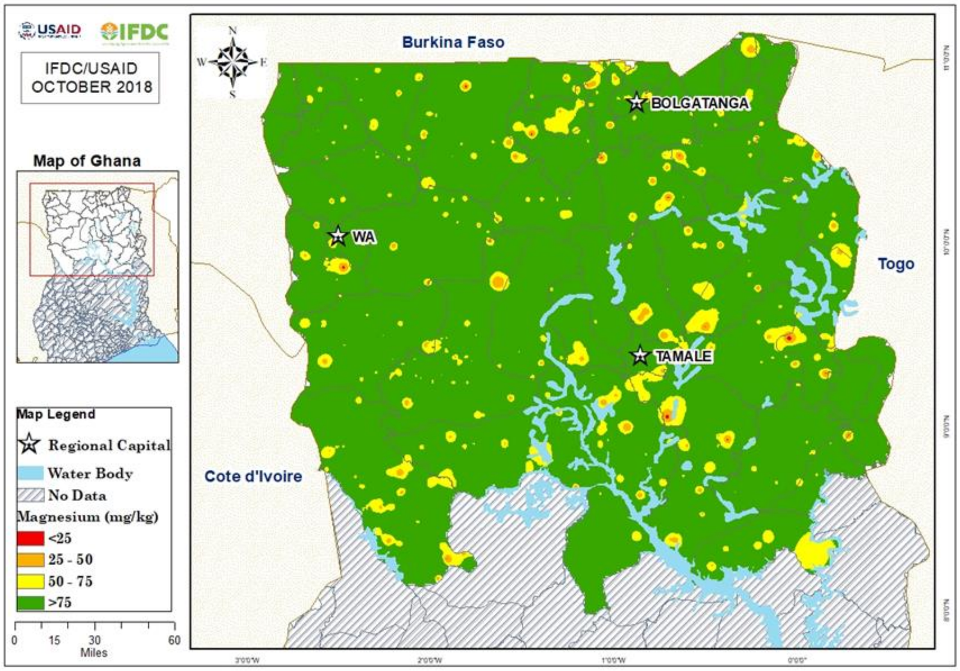


Figure 32. Updated map showing spatial distribution of soil magnesium concentration in northern Ghana

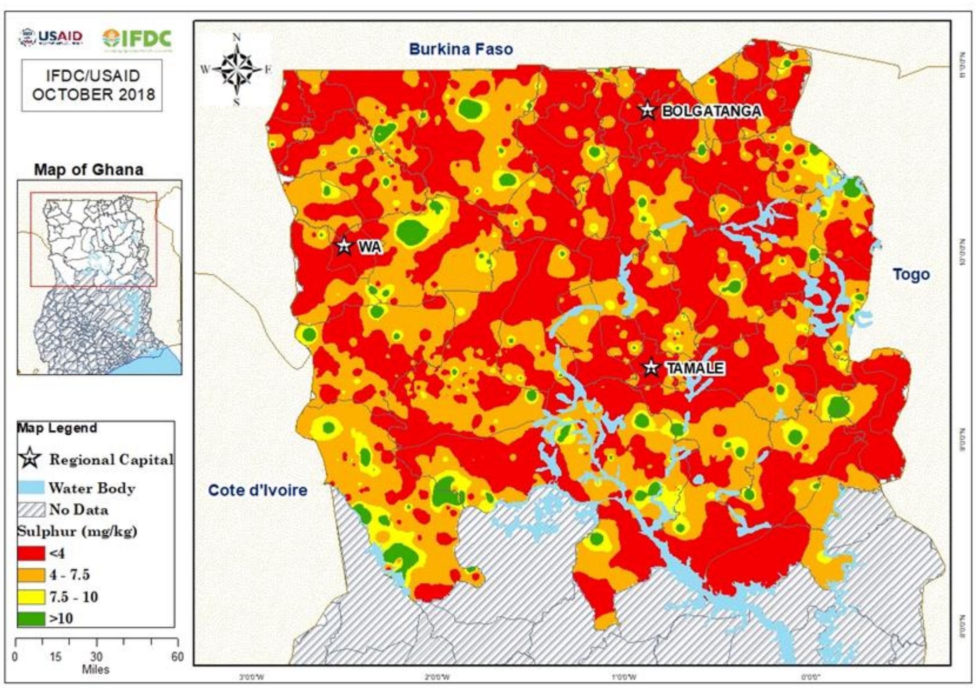


Figure 33. Updated map showing spatial distribution of soil sulfur concentration in northern Ghana

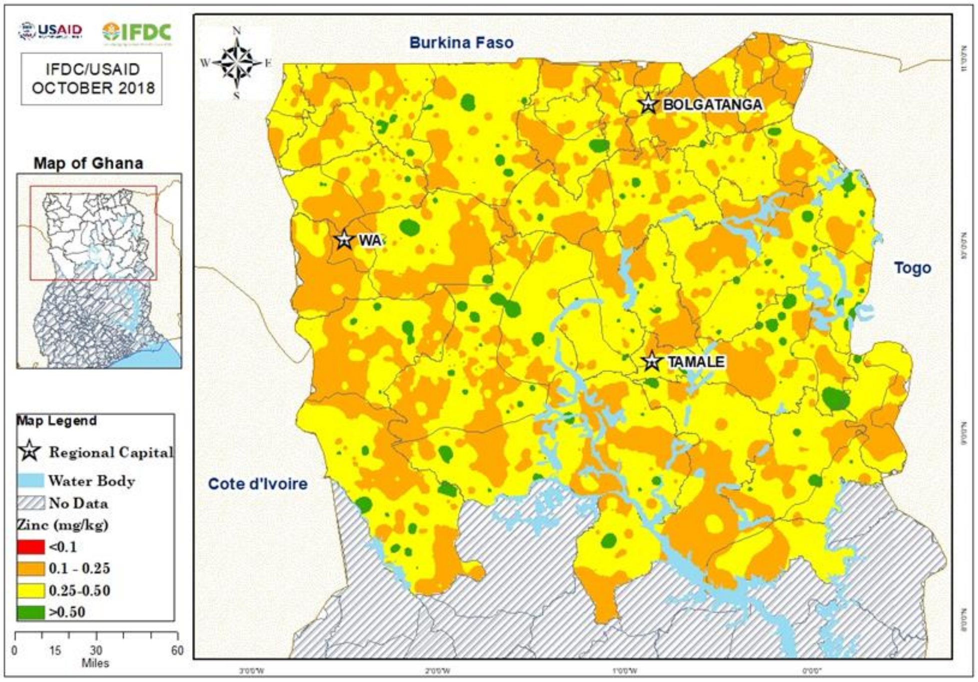


Figure 34. Updated map showing spatial distribution of soil zinc concentration in northern Ghana

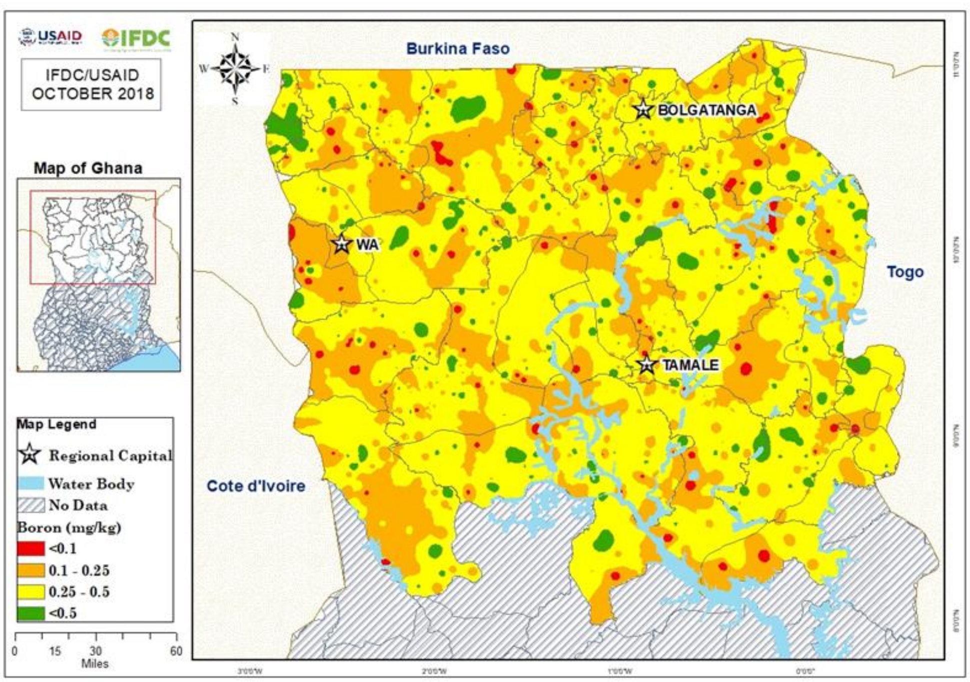


Figure 35. Updated map showing spatial distribution of soil boron concentration in northern Ghana

Nutrient Omission Trials

Despite the advancement in geographic information systems (GIS) mapping, remote sensing, and soil testing technology useful for approximating soil fertility requirements at specific sites, northern Ghana continues to use blanket fertilizer recommendations based on soil tests and experiments that are several decades old. Through extensive geo-referenced soil samplings and analyses, IFDC has developed soil fertility maps for the three northern regions of Ghana (11 districts in the Upper West region, 13 districts in the Upper East region, and 26 districts in the Northern region) to aid site- and crop-specific fertilizer recommendations. Several essential plant nutrients, including N, P, K, Zn, S, and B, were identified as potential limiting nutrients in many communities across the three northern regions.

We are in the process of using the SMaRT concept to develop fertilizer recommendations for the northern regions of Ghana. First, soil samples were collected and analyzed, and by using geo-statistical GIS techniques, soil fertility maps were developed. Based on the maps, 176 nutrient omission trials were established during FY18. This was in collaboration with the Feed the Future Agriculture Technology Transfer (ATT) Project, Soybean Innovation Lab (SIL), Ministry of Food and Agriculture (MoFA), and the University for Development Studies. Of the 176 trials, IFDC established 96 trials, as follows:

a. 51 multi-nutrient omission trials: 24 in the Northern region, 16 in the Upper East region, and 11 in the Upper West region.
b. 18 sulfur omission trials: 5 in the Northern region, 8 in the Upper East region, and 5 in the Upper West region.
c. 12 boron omission trials: 4 in each region.
d. 15 zinc omission trials: 5 in each region.

For all the omission trials conducted by all partners, except SIL, maize was used as the test crop (SIL is using soybean as the test crop). All trials were established at the beginning of the raining season in northern Ghana (late June to mid-July), and all treatments were applied. The trials are expected to be harvested during the first quarter of FY19 (late October through November 2018).

Statistical Methodologies for Spatial Variability Analysis

A manuscript entitled, "Use of spatial variability to estimate experimental error in multifield non-replicated experiments," which is based on soil sample analysis from Burundi, has been submitted to the *Agronomy Journal*.

Evaluate SMaRT Concept

A total of 232 soil samples from rice, maize, and vegetable growing areas of Buzi district, Mozambique were collected as first steps toward the evaluation of the SMaRT concept (Figure 36). This is a collaborative effort with government extension officers, Yara Fertilizer Company, and the African Fertilizer and Agribusiness Partnership (AFAP). Samples have been sent to SGS Laboratory in South Africa for a full soil analysis. The results from the soil analyses – expected to be available in the coming weeks – will be used to develop soil fertility maps that will show the spatial distribution of limiting nutrients, soil acidity, and other constraints. These results will also be used to develop improved fertilizer blends to be tested under farmers' conditions in the 2018/19 growing season starting in November-December in Buzi district.

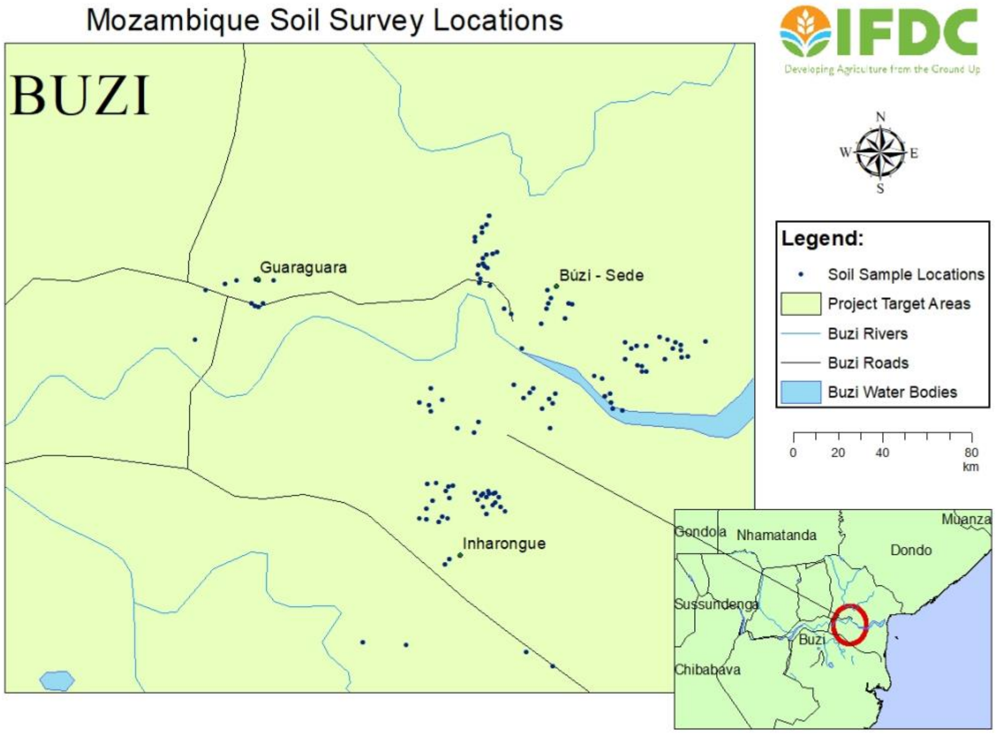


Figure 36. Soil Sample Locations in Mozambique

1.2.2 Workshop on the State of Soil Fertility in Northern Ghana, Fertilizer Recommendations, Utilization, and Farm-Level Access

A major characteristic of farming systems in SSA is their low productivity caused by degraded soil fertility and limited use of agricultural inputs, especially fertilizers. Most of the fertilizers recommended for various crops in SSA, particularly Ghana, are outdated because of their blanket pan-territorial application, which fails to account for the dynamics of soil fertility and the related productivity constraints. Use of inappropriate fertilizer products relative to crop and soil needs results in low profitability, hence low incentives for farmers to use fertilizers. There is growing interest in updating fertilizer formulations for crops in Ghana, especially in northern Ghana, that will provide tailored fertilizer recommendations for smallholder farmers. However, before these new formulations are promoted and recommended for widespread use, there is the need for an actionable dialogue among stakeholders.

A workshop was held during the week of April 9th at the Mövenpick Ambassador Hotel, Accra, Ghana, to discuss the "State of Soil Fertility in northern Ghana, Fertilizer Recommendations, Utilization and Farm-level Access." The workshop was funded by USAID with support from the Alliance for a Green Revolution in Africa (AGRA), ATT project, and AFAP. Approximately 70 (Figure 37) delegates, consisting of government officials and public policymakers, international fertilizer manufacturers, traders, importers, blenders, distributors, research institutions, development partners, agricultural producer organizations, and farmer groups, attended the event. The main objective of the forum was to bring together the agricultural community, government policymakers, and industry leaders for an actionable dialogue on the status of soils in northern Ghana. The discussion was focused on the latest scientific analyses, review of existing fertilizer recommendations considering this latest information, and exploration of effective mechanisms for increasing smallholder farmers' access to appropriate fertilizers. Other key objectives were to: (i) provide the current status of soils in the three regions of northern Ghana; (ii) discuss the impacts of micronutrient supply on target crop productivity; (iii) present current fertilizer recommendations for major staple crops in northern Ghana and the fertilizers commonly available at local input markets; (iv) deliberate on smallholder farmer fertilizer utilization and access issues; and (v) review Ghana's National Fertilizer Policy and its effects on appropriate fertilizer availability and utilization in northern Ghana. The workshop was very successful and presented a platform for sharing ideas and sparking insightful and meaningful discussions on enhancing agricultural productivity, farmer profitability, and food security. It also gave delegates the opportunity to network, make business contacts, garner information from policymakers, and articulate their challenges and frustrations on issues within the agriculture value chain. The participants expressed their hopes that the recommendations made would be transformed into implementable action plans to improve and preserve soil fertility and sustain long term crop productivity through strengthened partnerships that will drive the Green Revolution agenda.

Figure 37. Participants of the workshop

1.2.3 Improved Nutrient Delivery from Multi-Nutrient Fertilizer Granules for Improved Yield, Quality, and Nutrition

The availability and accessibility of multi-nutrient fertilizers to smallholder farmers will go a long way toward overcoming imbalanced fertilizer application. The activities involving university partnerships are expected to commence in FY19. The field work in Ghana, Nepal, and Mozambique will begin at the onset of the rainy season.

1.2.3.1 Quantify the Improvement in Grain/Product Quality from Field and Greenhouse Studies

The activity, under university partnership with Tennessee State University, was not initiated during FY18 and will be conducted during FY19.

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

The smallholder farming systems in the larger area of Buzi district are dominated by staple and cash crop rice, and by women farmers. Vegetables are mainly cultivated during the off-set of rainy seasons, and the cultivation is limited to larger farmers with resources to invest in irrigation equipment. More than 50% of the farmers in the target areas have no access to water to make vegetable cultivation during the off-season an option. We are exploring chickpea cultivation as an alternative crop to be grown in sequences with rice in Buzi district. Since chickpea is a relatively new crop (not cultivated yet) in Mozambique, IFDC imported seed from International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)-Nairobi, and a total of 18 on-farm demos were established in collaboration with farmers and government extension officers in Buzi district. The nodulation analysis showed that no nodules were formed, indicating that seed inoculation is required. In addition to information on the soil nutrient status, we collected plant samples for tissue analysis. These analyses, in combination with grain analysis (nutritional aspect), will be conducted at IFDC's Headquarters laboratory.

During the growing season, the unusually excessive rains (136.3 mm, of which 111.4 mm were received in three consecutive days) damaged more than 50% of the established fields. However, observations on remaining fields, through monitoring and participatory evaluation with farmers, showed promising results in terms of adaptability and potential yields. We expect to harvest the chickpea by November 2018.

This activity will partially complement the ongoing IFDC project, "Food security through climate Adaptation and Resilience in Mozambique-FAR," aimed at tackling food security in the face of climate change. FAR is designed to address the lack of capacity and ability of smallholder farmers to manage the risks and shocks associated with climate change.

Figure 38. Explaining to Farmers the Lack of Nodulation on Chickpea in Buzi

Figure 39. Farmers Sharing Ideas on Chickpea – This is the First Time that Farmers Are Seeing Chickpea

Figure 40. Chickpea Field Completely Flooded

Figure 41. Explaining to Farmers the Benefits of Chickpea as a Nutritional Crop

Figure 42. Farmers Observing Chickpea during a Field Day

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

Due to commitments that developed in the early part of 2018, the training will likely be held in May 2019 in Ghana.

1.2.5 Improved Efficiency and Accessibility of Phosphatic Fertilizers

Phosphorus is one of the most limiting nutrients in weathered soils found in SSA. As with other fertilizers, the lack of a well-developed domestic P fertilizer industry and limited foreign exchange for fertilizer imports constrains P fertilizer use in SSA. Many of the phosphate rock (PR) deposits in SSA have not been developed because the deposits are too small to warrant the investment needed for mining and processing, while impurities in some PRs prevent the production of water-soluble phosphorus (WSP) fertilizers using conventional industrial processing technology. However, many of these constraints do not apply to direct application of reactive PRs or PR compacted with WSP fertilizers, such as DAP. One innovative and practical approach to enhancing PR agronomic efficiency is dry compaction of PRs with minimal WSP (~20%) fertilizers. The compacted/activated PR is a more cost-effective product of the wet granulation process and holds considerable promise in SSA countries and other regions that have deposits of low- to medium-reactivity PR.

1.2.5.1 Production of Activated Phosphate Rock for Field and Greenhouse Studies

A commonly available PR from SSA, Togo PR, was used to make 100 kg each of Togo PR:DAP and Togo PR:DAP:urea. The activated products supplied 80% P from Togo PR and the remaining 20% from DAP. The products have been shipped to Kenya and Ghana for field trials. Small quantities of activated PR products were made using Cabinda PR from Angola for greenhouse studies, with P supply from PR ranging from 50% to 75% and the remaining P supplied by monoammonium phosphate (MAP).

1.2.5.2 Greenhouse Evaluation of Activated Phosphate Rock on Acid and Alkaline Soils

In recent greenhouse studies, a modest amount of DAP was compacted with a non-reactive PR (Idaho PR) at a ratio 20% DAP to 80% PR (4:1 PR/WSP ratio). It was then evaluated on two soils of extreme acidity/alkalinity (pH) levels: (i) an alkaline soil (Sumter soil; pH 7.78) and (ii) an acidic soil (Hartsells soil; pH 4.73). During the spring/summer season, the agronomic effectiveness of activated PR was evaluated using the Sumter soil with rice as the test crop, and in the winter season, wheat was grown on the acidic soil. In both experiments, 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 in a randomized complete block design with four replications for each treatment, and the crops were grown to maturity to determine yields. At anthesis, plant samples were taken to quantify P uptake.

Regardless of the soil pH, the crop, and season of crop production, the significant effect of the agronomic effectiveness of the activated PR was observed, suggesting that a combination of a modest amount of DAP with PR could be a cost-effective means of enhancing P availability in PRs without the usual soil pH constraint on the agronomic effectiveness of PRs. In the alkaline soil, applying the activated Idaho PR as the sole P source increased total rice yields by nine-fold

(900%), compared to using Idaho PR, and was 95% as efficient as DAP (Figure 43; Table 14). This could be the result of an enhancement of P uptake through the activation process. Applying Idaho PR alone resulted in a P uptake of < 1% of the applied P. However, activation with the modest amount of DAP increased P uptake to ~25% of the applied P (100 mg/kg), comparing favorably to P uptake of 31% with DAP application (Table 14).

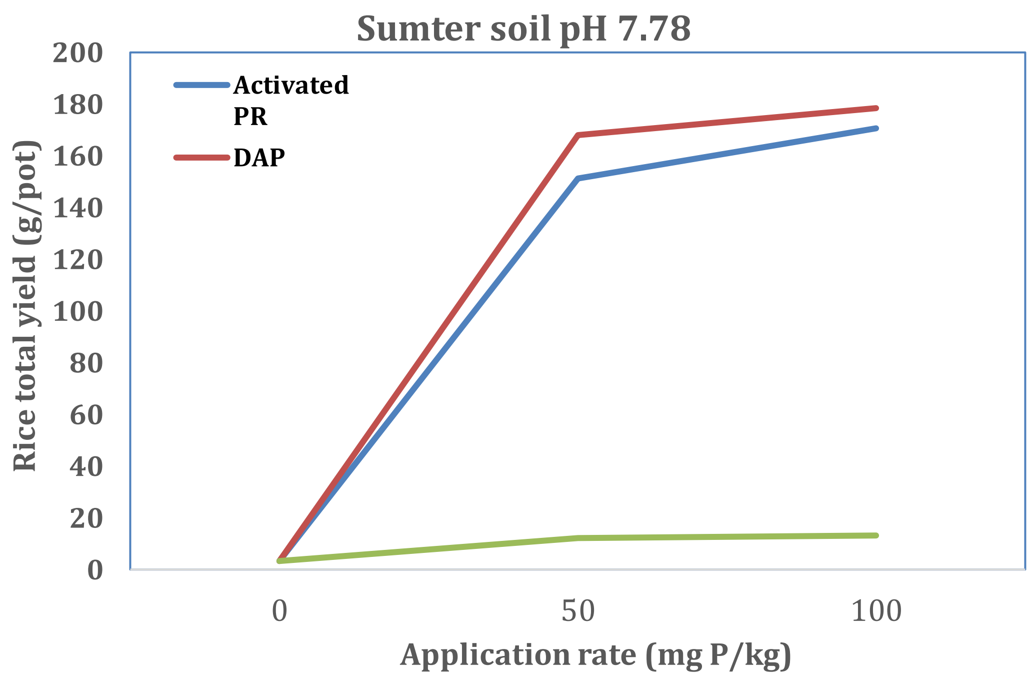


Figure 43. Effects of phosphate sources on total yields of rice grown in an alkaline soil (Sumter soil pH =7.78)

Table 14. Relative agronomic efficiency and P uptake as influenced by activated P compared with DAP and untreated Idaho PR for rice grown in an alkaline soil (Sumter soil pH =7.78)

Treatment	P Rate (mg/kg)	RAE %	P Uptake %
Idaho PR	50	6.8	0.78
“Activated” PR	50	84.7	35.43
DAP	50	94.2	44.59
Idaho PR	100	7.1	0.27
“Activated” PR	100	95.6	24.70
DAP	100	100	31.38

Results obtained from the acidic soil was more dramatic, with the treatment of the activated Idaho PR out-yielding the treatment of DAP by nearly two-folds (Figure 44). In addition to supplying P, the dissolution of the PR released Ca^{2+} in the soil solution, which helped to condition the soil acidity effects, thus providing a conducive soil environment for proper growth and development of the wheat crop.

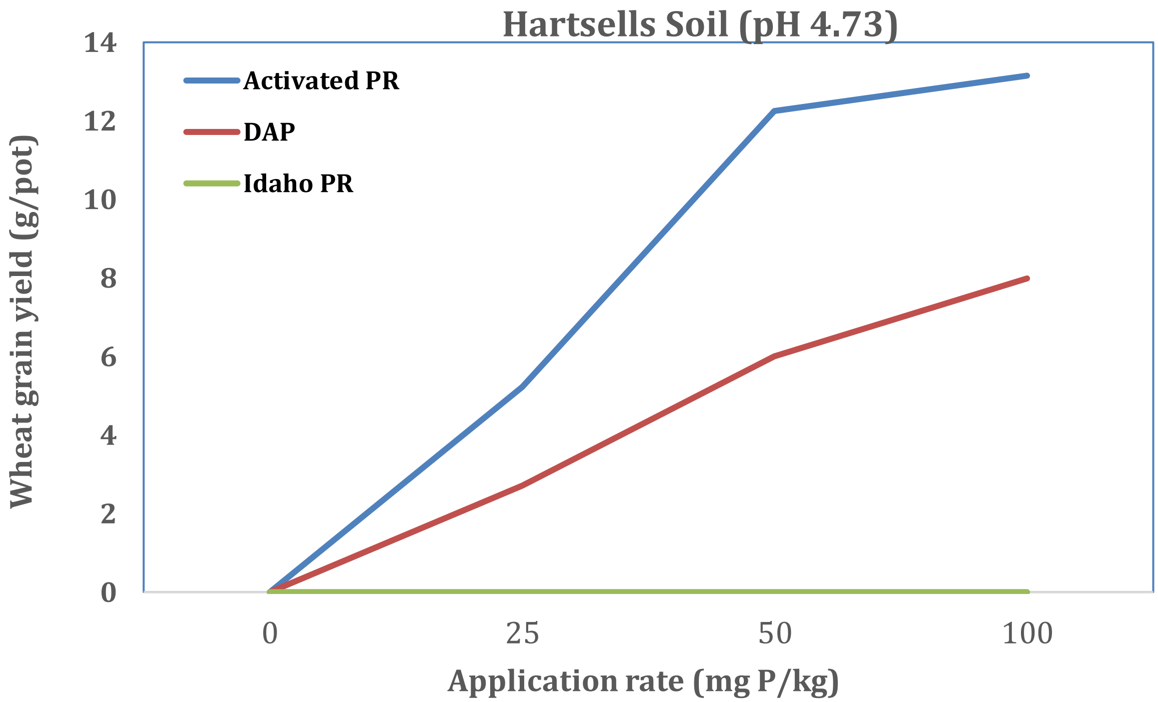


Figure 44. Effects of phosphate sources on grain yields of wheat grown in an acid soil (Hartsells soil pH =4.73)

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. This process is an energy efficient and environmentally desirable alternative to the current WSP fertilizer production technology and could improve P utilization for smallholder farmers to increase productivity and household incomes. Further studies are evaluating the effectiveness of the "activated" PRs under field conditions.

1.2.5.3 Field Evaluation of Activated Phosphate Rock for Upland Crop Production in Ghana

Several studies have shown that a combination of finely ground PR and triple superphosphate (TSP) at 1:1 PR/TSP ratio was agronomically as effective as TSP applied alone (Menon and Chien, 1996; Begum et al., 2004). The dissolution action of the monocalcium phosphate component of TSP on PR, and the stimulation of early growth and root development, likely increased the effectiveness of PR in the presence of TSP.

In recent greenhouse studies, two major changes were made: first, instead of TSP, we used DAP, a more commonly available P fertilizer than TSP in most countries. DAP also has an acidification effect on PR dissolution. Second, a modest amount of DAP at a ratio of 20% DAP to 80% PR was used.

During the FY18 farming season in northern Ghana, 17 on-farm trials were established (seven in the Northern region; four in the Upper West region, and six in the Upper East region) to evaluate the effectiveness of the “activated” PRs under field conditions. These on-farm trials served to validate the greenhouse results with the following specific objectives: (1) to quantify P uptake as influenced by “activated P” fertilizer application and (2) to quantify the effect of “activated P” application on grain and biomass yield. Treatments in this experiment were:

1. Water Soluble P (DAP) at recommended P rate.
2. Activated Togo PR (1) (4 PR:1 DAP) at recommended P rate.
3. Activated Togo PR (2) (4 PR:1DAP + urea) at recommended P rate.
4. Untreated Togo PR.
5. Check with all other nutrients except P.
6. Farmer practice.

For each treatment, adequate quantities of all essential limiting nutrients were provided such that P was the only limiting nutrient. The six treatments with four replications (blocks) (24 plots) were laid out in a randomized complete block design. Each plot was 5 m x 5 m in size. Drought-tolerant early/medium-maturing maize hybrids (or OPVs) were planted (based on the location) with six rows per plot. The recommendation and practice followed by farmers calls for basal application (at planting) of all (P, K, and micronutrients) fertilizers except nitrogen fertilizer sources that are split-applied. Therefore, N fertilizer was applied in two splits, one basal application at planting, and the second split was applied at the V6 stage of crop growth. Some of the plants will be harvested at anthesis to determine P uptake, and the remaining plants will be harvested at physiological maturity to measure grain yield and P uptake. Results from this field evaluation will be presented in the next semi-annual report.

1.2.5.4 Field Evaluation of Activated Phosphate Rock in Kenya and Ghana

Trials to evaluate the efficacy of activated PR relative to DAP were established at four sites in Kenya. The first trial was established in May 2018 at a medium pH site in Narok county and at a low pH site in Uasin Gishu county; wheat was used as the test crop for this trial. The second trial was established in late August 2018 at a low pH site in Bungoma county and a higher pH site in Kisumu county; maize was used as the test crop. Sites were chosen to evaluate the activated PR over a range of soil pH values but on soils that tested low in phosphorus. The soil analyses are shown in Table 15.

Table 15. Soil analyses from sites used in wheat and maize activated phosphate rock trials, Kenya

GPS Coordinates		Crop	pH	EC	P	K	Ca	Mg	S	B	Zn	Cu	Fe	Mn	CEC	Total N	Organic Matter	C/N
Latitude	Longitude		H_2O	uS/cm	Mehlich-3, ppm										cmol/kg	%	%	Ratio
-1.04103	36.14283	Wheat	6.6	132	10.5	893	4,270	311	<0.5	1.08	7.8	0.71	187	52.2	10.5	0.3	7.43	17
0.30686	35.38061	Wheat	6.1	47.9	7.17	1,120	1,870	436	<0.5	0.39	4.4	1.32	133	294	7.17	0.2	4.12	13
-0.07539	34.65815	Maize	6.7	53.7	2.45	301	5,420	947	2.11	0.62	1.1	1.97	82.5	148	2.45	0.1	4.74	21
0.78812	34.70831	Maize	5.3	23.3	7.07	44.4	610	96.8	6.63	0.069	0.6	1.8	77.9	77	7.07	0.1	1.81	9.6

Wheat trials were well-established, and the maize at trial sites is just emerging. So far, the only problem that has been encountered is damage by moles at one wheat site. Observations in wheat are that PR, activated PR, activated PR granulated with urea, and DAP are all out-performing the no-P treatment. However, there is little visual distinction between these three treatments, which is somewhat surprising since we anticipated wheat to be less responsive to the low-activity P source (Togo PR).

1.2.6 Improved Efficiency and Accessibility of Sulfur Fertilizers

Traditionally, farmers have been using sulfate (SO_4-S) fertilizers as the main source of S for plant nutrition, since elemental sulfur (ES) is observed to have extremely low reactivity. However, with advances in micro- and nano-sized elemental S, and other technological advances, ES is no longer "inert or very slow-release S" that could not meet plants' S demand. From greenhouse and field trials Thiogro-urea (micronized ES+ urea; 13% S), a new S fertilizer product, was observed to be an effective S source with reduced SO_4-S leaching loss.

1.2.6.1 Field Evaluation of Urea with Micronized Elemental S for Maize Production

Field evaluation for the agronomic effectiveness of different sulfur (S) fertilizer products was conducted to: (1) quantify N and S uptake as influenced by different S fertilizer sources; (2) quantify the effect of S fertilizers on grain and biomass yield; and (3) quantify the fate of elemental sulfur (ES) at the end of harvest through a sulfate-S analysis of the soil. The trial was conducted in the summer of 2017 on S-deficient Lexington silt loam soil (fine-silty, mixed, active, thermic Ultic Hapludalfs) under conventional tillage at the Ames Plantation near Grand Junction, Tennessee. The experiment consisted of 10 treatments (Table 16) with four replications. S was applied at 30 kg/ha in all treatments (except Check), and the other nutrients (N, P, K, etc.) were applied at the optimum rates. The study was conducted in partnership with Shell Canada.

Table 16. S Fertilizer Treatments and Description

Treatment	Description	S (%)	S Form	N (%)
1	Tiger 90CR (low reactivity ES)	88	ES	0.25
2	Thiogro-ES13	13.14	ES	38.9
3	ES Rotoform	14.2	ES	39.8
4	ES fluid bed (UFT)	13.9	ES	40.0
5	Special-S	73.1	ES	
6	Micronized ES	100	ES	0
7	Thiogro-ESS13	13	SO_4-S, ES	36.5
8	Ammonium Sulfate	22.9	SO_4-S	21
9	MES10 (Mosaic)	10	SO_4-S, ES	12
10	Check	0	-	0

As shown in Table 17, maize yields were very high, on average more than 13 t/ha, regardless of treatment because of the favorable weather conditions. Although topsoil at 0-30 cm is deficient in S (< 4.7 mg/kg – MCP method), the high SO_4-S content at 30-cm (38.8 mg/kg) was more than adequate for plants to overcome S deficiency. Without any S fertilization, 12.4 t/ha grain yield and 19.7 t/ha total biomass was produced. Thiogro-ES 13% (drum granulation) and micronized ES produced significantly higher grain yields than Check (no S application). Grain S concentration and grain S uptake were also significantly higher on application of these products than Check and Tiger 90CR. Significantly higher total S uptake, compared to Check and Tiger 90CR, was obtained when micronized ES, Special S, and Thiogro ESS 13% were applied. These products, together with other Thiogro ES products, generally had higher soil SO_4-S content at 0-15 and 15-30 cm depths at anthesis stage of the maize crop.

Overall, despite the very high native soil S content at lower depths, significant differences in grain yield, grain S concentration and uptake, total S uptake, and soil SO_4-S content were obtained with selected Thiogro ES and ESS products. The Thiogro products with higher ES oxidation rates were able to meet the S-requirement of maize, a high S-demanding crop. These products also have the added advantage of reducing SO_4-S leaching loss in coarse-textured soils and high rainfall environments.

Table 17. Effects of S Products on Plant Biomass, Grain Yield, and Grain and Straw S and N

Treatment Description	Biomass (t/ha)	Yield (t/ha)	Grain S (ppm)	Grain S Uptake (kg/ha)	Grain N (%)	Grain N Uptake (kg/ha)	Straw S Uptake (kg/ha)	Straw N Uptake (kg/ha)	Total S Uptake (kg/ha)	Total N Uptake (kg/ha)
Tiger 90CR	20.5cd†	13.10bc	896e	11.7de	1.10d	145d	3.69cd	31.1bcd	15.4de	176c
Thiogro-ES13	20.2cd	13.82a	965bc	13.3ab	1.21a	166a	3.26d	25.9d	16.6cde	193abc
ES Rotoform	20.3cd	13.08bc	1042a	13.6a	1.18abc	155bc	3.43d	26.7cd	17.1bcd	181c
ES fluidbed	23.5a	13.08bc	969bc	12.7bc	1.13bcd	148cd	5.47abc	43.7ab	18.2abc	192abc
Special-S	25.8a	12.90cd	910de	11.7de	1.12cd	145d	6.96a	53.9a	18.7ab	199ab
Micronized ES	22.9abc	13.67ab	1031a	14.1a	1.197ab	163a	5.16abcd	41.1abc	19.2a	205a
Thiogro-ESS13	23.8ab	13.28abc	1012ab	13.4ab	1.20a	160ab	5.81ab	46.5a	19.3a	206a
Amm. Sulfate	21.9bc	12.66cd	955cd	12.1cd	1.14bcd	145d	4.89bcd	40.8abc	17.0bcd	185bc
MicroES10	22.7bc	12.63cd	941cde	11.9cde	1.19abc	150cd	5.03bcd	42.3ab	16.9bcd	192abc
Check	19.7d	12.40d	901de	11.2e	1.18abc	146d	3.68cd	30.7bcd	14.9e	176c

† Means in a column followed by the same letter are not significantly different at P = 0 0.05, according to the Fisher's protected LSD.

1.2.6.2 Field Evaluation of Urea with Micronized Elemental S for Upland Crop Production

During the FY18 farming season in northern Ghana (June-July 2018), 12 on-farm trials (four in each region) were established to evaluate the new S fertilizer product. The main purpose of the trials was, therefore, to evaluate the agronomic effectiveness of the new S fertilizer product under field conditions on yield, growth, and plant N and S uptake with respect to locally available commercial S fertilizer products and the locally recommended farmer practice in terms of fertilizer applications. Each plot consisted of six rows of corn, planted to a length of 5 m. Six treatments with four replications (blocks) (24 plots) were laid out in randomized complete block design, with individual plot sizes of 5 m x 5 m. The treatments tested were: (i) Thiogro ES at a recommended S rate of 50 kg/ha; (ii) Thiogro ES at 25 kg S/ha; (iii) Thiogro ES at 75 kg S/ha; (iv) locally available sulfate fertilizer at the recommended S rate (50 kg S/ha); (v) S check (0 S); and (vi) farmer practice. Each treatment was randomly assigned to a plot within each block. Adequate quantities of all essential limiting nutrients were provided such that S was the only limiting nutrient.

Drought-tolerant early/medium-maturing maize hybrids (or OPVs) were planted (depending on the location) with six rows, 5 m long, per plot. All basal fertilizers (initial N, P, K, and micronutrients) were applied as blanket (uniform) rates, following the local extension recommendation for all treatments. Pre-determined rates of S fertilizer products (based on different treatments) were applied basally at planting. The recommendation and practice followed by farmers called for basal application (at planting) of all (P, K, and micronutrients) fertilizers, except nitrogen fertilizer sources which are split-applied. The nitrogen fertilizer was applied in two splits, one basal application at planting and the second at the V6 stage of crop growth. Thus, except for the N, all remaining fertilizers were applied basally at planting for all treatments except the "Farmer Practice" Treatment (Trt 6). Some plants will be harvested at anthesis to determine S uptake, and the remaining plants will be harvested at physiological maturity to measure grain yields and S uptake. Results from this study will be provided in the next semi-annual report.

1.3 Fertilizer Quality Assessments: Support Policy Efforts to Harmonize Fertilizer Regulations (Cross-Cutting with Workstream 2.3)

IFDC has conducted a series of fertilizer quality assessments (FQAs) in East and Southern Africa with the purpose of making country fertilizer quality diagnostics and identifying factors, either directly associated with fertilizer properties or with characteristics of the distribution chain, that help explain the quality problems. The FQAs also propose solutions to address these factors. Information collected from these studies at the country level is being used by the Common Market for Eastern and Southern Africa (COMESA) to develop and implement a harmonized fertilizer quality regulatory system for its Member States. The current progress of the major activities is presented below.

1.3.1 Complete Ongoing Assessments for Stakeholder Consultations and Dissemination

1.3.1.1 Uganda Fertilizer Quality Assessment Report

The fertilizer quality activities during the 2018 fiscal year had two main objectives:

1. Produce the final report from the FQA conducted in fertilizer markets of Uganda in April 2017.
2. Conduct activities toward the development of a policy that will improve the fertilizer quality of fertilizers traded in Uganda. These included:
    - Presentation of the Uganda FQA report to the government and the fertilizer private sector in a workshop.
    - Discuss the FQA report and improvements of the fertilizer quality regulatory system of Uganda with representatives of the fertilizer private sector and the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) in two separate meetings.

Methodology

The key elements of the FQA methodology were:

- Random collection of fertilizer samples in two steps. First, to collect a sample of dealers from each of the country's regions: Central, Northern, Eastern, and Western. The second step is to collect random fertilizer samples from each of the members of the dealer samples.

- Data about market characteristics (size, urban or rural location, fixed or itinerant location) and characteristics of dealers (status of the business: importer, wholesaler, retailer, level of fertilizer knowledge, level of training, etc.) collected from each fertilizer crop/warehouse inspected.
- Nutrient content, cadmium content, physical properties, fertilizer bag weight, and storage conditions were quantified in each fertilizer sample to identify and quantify factors of direct effect on fertilizer quality.
- Statistical analysis consisting of probability distributions development from each fertilizer characteristic to quantify the frequency and severity of out of compliance nutrient content, cadmium, and bag weight.
- The reference points used to declare out of compliance nutrient and cadmium content as well as bag weight were the tolerance limits for these characteristics from the Kenya Fertilizer Quality Regulatory System because Uganda does not have tolerance limits in the legal documents related to fertilizer quality.
- Identifying relationships between fertilizer quality problems and physical properties, conditions of storage, or factors of indirect effect on quality was done using categorical logistic models.

Results

The fertilizer samples were classified as “large trade” or “low trade.” The large trade fertilizer group included DAP, urea, NPK 17-17-17, calcium ammonium nitrate (CAN), NPKS 15-5-5+5S, and ammonium sulfate. The low trade fertilizer group included numerous products with nutrient contents in a wide range of grades and in the form of granulated, liquid, crystal, and powder fertilizers.

The liquid fertilizers had significantly higher frequencies and severities of nutrient shortages out of compliance than the granulated fertilizers; among the granulated products, the set of fertilizers with low commercialization presented higher frequencies and severities of nutrient content shortages out of compliance than the set of fertilizers with high commercialization. This difference suggests that the importance of the products in the market has some type of effect on the quality, meaning that products with high commercialization show evidence of being manufactured with more care than products with low commercialization, and/or products of high commercialization are less affected by quality-damaging changes along the distribution chain.

Ten percent of the fertilizer bags used for weight verifications presented weight shortages beyond the 0.5-kg tolerance limits. Since Uganda has negligible re-bagging, the weight shortages must originate in the manufacturing plants or in the in-country bagging of fertilizers imported in bulk. Furthermore, most storage areas used by wholesalers and retailers do not reduce the temperature and relative humidity (RH) to the level required for the preservation of the physical and chemical properties of fertilizers, but thanks to appropriate granulation and the good quality of the bags used, cases of moist fertilizers, caking, and granular degradation in the fertilizers found in Ugandan markets were identified with low frequency. For these reasons, the nutrient content shortages found can hardly be attributed to degradation of physical properties.

No evidence of fertilizer adulteration was found in the Ugandan fertilizer markets. If adulteration takes place as fertilizers move down the value chain, it is through the dilution of nutrient contents and the addition of inert filling materials. No filling materials used to dilute nutrient content were identified during the fertilizer sampling in April 2017. An additional sampling, designed for the detection of adulteration in small fertilizer packs (≤ 10 kg) destined to be purchased by small-holder farmers, was conducted in June 2018 in fertilizer markets of the Central and Eastern regions by MAAIF inspectors trained by IFDC. Seventy-nine samples of fertilizers comprising NPKs, DAP, CAN, and urea were collected. None of the samples contained foreign materials used to adulterate the fertilizers through nutrient dilution. Results from these two samplings indicate that fertilizer adulteration is rare and not the main type of fertilizer quality problem in the country.

Recommendations

It was determined that the degradation of physical properties and adulteration were not the main sources of nutrient shortages in Uganda's traded fertilizers; therefore, the most plausible explanation for out of compliance fertilizers, both of high and low trade, is nutrient deficiencies that originated during manufacturing. As a result, it is important to establish a system that ensures pre-export verification of conformity (PVoC) is carried out by reputable and internationally accredited companies at source. This should be followed by confirmatory inspections at the destination port (or once entering into Uganda), especially for products that have a history of poor quality.

The Ugandan government needs to update the Agricultural Chemical (Control) Act of 2007 and the National Fertilizer Policy to establish the legal and administrative tools needed to conduct effective fertilizer quality assurance in the markets.

1.3.1.2 Zambia FQA Report

Chemical analyses of the fertilizer samples were completed in June 2018. Conducting statistical analyses and writing the report about the Fertilizer Quality Assessment in Zambia will be one of the first activities during FY19.

1.3.1.3 Myanmar Fertilizer Quality and Fertilizer Value Chain Analysis

Although much progress has been made in fertilizer market development in Myanmar, challenges remain that could hinder fertilizer market development and result in adverse consequences for agriculture productivity improvement and rural income growth.

The objectives of this assessment were to appraise the functional performance of the Myanmar fertilizer value chain with particular attention to (a) assessing the quality of fertilizers being sold to farmers; (b) evaluating the efficacy of the public and private sector fertilizer quality risk mitigation systems; and (c) providing recommendations to mitigate quality risks.

Methodology

The assessment approach comprised three elements: (a) *secondary data review* and analysis based upon available documents and prior assessments of the Myanmar fertilizer market; (b) *assessment of value chain characteristics*, including fertilizer product storage and handling practices, bag and container markings and labeling, and physical properties of fertilizers; and (c) *sampling of fertilizer products within the value chain and chemical analyses of the samples to appraise quality*.

The study targeted three geographic areas: Ayeyarwady and Mandalay Regions and northern Shan State of Myanmar. The targeted areas are primary agriculture production areas with active fertilizer trade and use.

The survey methodology involved the selection of a sample of the population of fertilizer dealers (manufacturers, wholesalers, and retailers of different sizes) selected from each township from the list of registered dealers provided by the Department of Agriculture. Two steam granulation NPK plants were also part of the sample.

Fertilizer samples were collected at the randomly selected dealer locations for laboratory testing of chemical properties. The samples were tested chemically for nutrient content and heavy metals in IFDC's laboratories, and a few samples were tested for quantification of growth hormone content in a laboratory at Auburn University (United States). At each of the randomly selected dealer shops, "on-site" observations were made of product handling and storage practices, bag/container labeling, and physical properties of the fertilizers. Particular attention was given to investigating indicators of adulteration. On-site interviews were conducted to collect value chain information. A digital system operated with smartphones and written questionnaires was employed. Once data was entered and complemented with lab results, statistical analyses were performed to assess the different aspects of fertilizer quality and identify the "weak situations/factors" along the value chains.

In the fertilizer quality assessment, both physical and chemical properties were examined. Visual inspections supported the physical property assessment and value chain member compliance with Fertilizer Law guidelines on bag/container labeling. It also provided insight into possible adulteration. Bag weights were checked, fertilizer granule segregation and integrity were evaluated, and the characteristics of "dry and free flowing" were considered. Chemical analyses were performed on fertilizer samples collected in Myanmar to assess nutrient content, presence of heavy metals, and other properties that affect quality. Laboratory tests were also performed to quantify the presence of the DA-6 growth hormone that is mixed with nitrogen in some fertilizers. The concept of "truth-in-labeling" was applied as an important factor in determining fertilizer quality.

Results

Fertilizer Quality

The quality of fertilizers in Myanmar varied. Key problem areas were identified in the following: (a) fertilizers with nutrient deficiencies, (b) underweight bags, (c) presence of a growth hormone at rates harmful to rice crops, and (d) presence of heavy metals in some products.

Regulatory

Myanmar has an established and functional regulatory system under provisions of the Fertilizer Law (2015). The law establishes the basic framework for the fertilizer market, although it lacks in completeness and clarity on many specific issues.

The proposed strategies and measures to mitigate regulatory-related risks include: (a) improving and completing the legal environment to an international standard; (b) reorganizing and/or strengthening the capacities of regulatory and advisory bodies and manpower; (c) upgrading and accrediting the designated analytical laboratories; (d) putting in place appropriate mechanisms to sustainably generate and use necessary funds to maintain the system; and (e) disseminating the laws and regulations, including the national manuals, for inspection, sampling, and analysis and sensitizing all stakeholders in the value chain. Training for all officials involved in regulatory system in their respective areas is also necessary.

Value Chain

The fertilizer value chain is essentially composed of 100% private sector participation at the import and domestic marketing (fertilizer processing, wholesale/distributor, and retail) levels. The government owns five small-scale ammonia/urea factories; three are in operating status, supplying up to 200,000 mt of urea. Sales of government-supplied urea are either direct to government bodies or via auction to private sector firms. However, data on the fertilizer market in Myanmar is extremely limited.

The fertilizer market is developing rapidly in terms of (a) fertilizer demand, (b) extension of retailer networks, and (c) product mix to include commodity-type fertilizers (e.g., urea, triple superphosphate, potassium chloride), numerous specialty-type grades (many containing secondary [sulfur and calcium] and micronutrients), organic products, and biological growth enhancement products. Fertilizer retailers have significantly higher chances of selling fertilizers with nutrient shortages than wholesalers. In addition, fertilizer dealers whose only customers are small-scale farmers are also selling fertilizers with nutrient shortages at a significantly higher frequency than dealers that sell to combinations of small-scale farmers and commercial farmers and fertilizer retailers. The routine inspection of dealers by the regulator and the training of dealers and small-scale farmers are solutions to this problem.

Fertilizer bulk blending is a rapidly advancing technology in Myanmar, and a number of fertilizer companies are engaged in fertilizer research programs (trials) and technology demonstrations as well as in dealer education to strengthen farmer advisory capacity. It is recommended that such practices be encouraged and extended with increased linkages with the Ministry of Agriculture, Livestock, and Irrigation and Yezin University research and extension staff.

The private sector has rapidly increased its presence at all levels to stimulate and meet farmer demand. Based upon Land Use Department (LUD) records, there are currently 628 registered fertilizer importers and 5,600 registered retailers in the country. Registration is not required for retailers that sell less than 5 mt of fertilizers per year. It is recommended that all retail points of sale engaged in the sale of fertilizer be registered either directly with LUD or as an authorized dealer of a registered value chain member.

Recommendations

A manuscript containing the achievements and lessons learned from the conduction of fertilizer quality assessments in nine countries in West Africa, three countries in East Africa, and in four regions of Myanmar is in preparation. Based on the existing draft, an oral presentation titled "Fertilizer Quality Problems in Markets of Developing Countries: An Obstacle for Economic Growth and Food Security" will be made at the American Society of Agronomy-Crop Science Society of America (ASA-CSSA) 2018 International Meeting. A manuscript will be submitted to a scientific journal.

1.3.2 Training Program on Improving Fertilizer Quality for Highly Productive Agriculture and Balanced Nutrition

The training program scheduled for May 7-11, 2018, in Arusha, Tanzania was cancelled because we were unable to attract enough participants.

1.4 Agronomic and Socioeconomic Database Management and Decision Support Systems – Cross-Cutting with Workstream 2

1.4.1 Improving the DSSAT Cropping System Model for Soil Sustainability Processes

Since there are large amounts and types of biophysical and socioeconomic data, IFDC plans to use the database platform developed for the global Agricultural Model Intercomparison and Improvement Project (AgMIP). The use and refinement of AgMIP's database for implementation by IFDC will be conducted in partnership with the University of Florida, which has been the developer of the AgMIP database from the beginning. The partnership with the University of Florida will also be used to improve the existing soil dynamics model in the DSSAT Cropping System Model (CSM) using the soils and agronomic data generated by IFDC in the past. The status of the ongoing research with the University of Florida is summarized in Table 18. Recent findings from the ongoing research will be presented at the International Rice Congress, October 15-17, 2018, and AgMIP Rice Modeling Workshop, October 18-20, 2018, in Singapore.

Table 18. Status of Deliverables – September 30, 2019

Task	Activity	Deliverable	Status on 9/30/2018
A. Model improvements			
A.1*	Soil C balance component	A version of DSSAT-CSM which produces a soil C balance report for the Ceres-based soil organic matter module, including seasonal and optional daily Soil C balance output.	Seasonal soil C balance report is now generated by CSM, but it still needs work to achieve a balance for some crops.
A.2*	N_2O emissions model components for Ceres-based soil organic matter module	A version of DSSAT-CSM in which the Ceres-based soil organic matter module is linked to the N_2O emissions module to produce predictions of daily and seasonal N_2 and N_2O emissions.	N_2O emissions estimates, based on the DayCent model, are now linked to the Century-based soil organic matter module in DSSAT. Additional work is required to link to the Ceres-based module.
A.3**	Generic fertilizer module to allow modeling of custom blends and slow release fertilizers (partial)	An input file format defined for slow release fertilizer types.	Upendra Singh provided Cheryl Porter with a list of fertilizer types to be read by the model. Some discussion occurred regarding how to characterize slow release fertilizers generically.
		Input parameters listed for at least three slow release fertilizers in the input file.	
A.4**	Improvements to rice plant growth and development model	Priority improvements to rice plant growth and development model identified.	No action this reporting period
		A version of DSSAT-CMS with at least one of the priority rice model improvements implemented.	No action this reporting period
A.5**	Methane emissions module	Methodology for methane emissions module identified based on literature and available existing models, as appropriate.	Cheryl Porter has obtained the MERES source code, which linked Ceres-Rice with a methane estimation routine developed by Robin Matthews in 1998. This will be the basis of the new routine in CSM v4.7.
B. Data acquisition for modeling			
B.1*	Data for model testing: LTAR data with N_2O emissions and soil C and N dynamics	Preparation of at least one dataset from LTAR and/or IFDC which includes measured N_2O emissions measurements for DSSAT formats (if available).	No action this reporting period
		DSSAT-CSM N_2O emissions model tested with at least one data set collected at LTAR sites and /or IFDC (if available).	No action this reporting period
B.2**	IFDC data from SSA, Asia, and U.S. for N_2O and methane emissions modeling	IFDC datasets appropriate for testing methane emissions model identified.	No action this reporting period
B.3**	Other IFDC datasets	Other IFDC datasets for use with model development and testing identified.	No action this reporting period

* Complete deliverables due by June 2019: A.1, A.2, B.1, C.1, D.1, D.2.
** Partial deliverables due by June 2019: A.3, A.4, A.5, B.2, B.3, C.2, D.3.

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

Under Workstream 2, IFDC conducts research and analysis for evidence-based policy recommendations and to support reform initiatives for market development focusing on accelerating agricultural growth using improved fertilizer technologies and complementary inputs. Most activities under this workstream are implemented through partnerships with different stakeholders with similar interests to promote policies and reforms aimed at improving fertilizer access and use among smallholders in the FTF countries.

The costs associated with BFS to fund Workstream 2 activities are shared either directly or on an in-kind basis from the partnering institutions to achieve the maximum outreach and impact in three broad categories related to soil technologies and fertilization management. These categories include:

a. Support the development and implementation of fertilizer- and/or soil-related policies and legal and regulatory reforms.

b. Assess the impact of new soil and fertilization technologies, policies, and government programs aimed at improving farmers' access to and use of fertilizer.

c. Conducting studies to show the economic and financial feasibility of soil and/or fertilizer technologies, fertilizer access, and market systems (including studies on fertilizer demand, supply, and its associated cost buildup).

Activities from Workstream 2, together with other IFDC field-based operations, contribute to IFDC's knowledge base and provide useful data and information for lessons learned to identify gaps for further research and actions. This knowledge base also provides a strong foundation for IFDC to take a key role in partnerships with other research and policy institutions in areas of mutual interest, including research for policy dialogue with stakeholders in the supply value chain and policy decision-makers across various countries in SSA, Asia, and Latin America.

2.1 Documenting Policy Reforms and Market Development

The work under policy reforms and market development focuses on taking advantage of the impetus for change to catalyze reforms to existing policies and to create a better regulatory environment conducive to larger private sector participation in the agro-input market, through investments that will result in increased access to inputs by smallholder farmers. With BFS support, IFDC worked with organizations and stakeholders at various levels in countries that showed high potential and interest for policy changes: (i) to support reforms by means of research to provide evidence-based recommendations and (ii) to build the capacity of stakeholders for an effective dialogue and implementation of reforms. Details are provided below.

2.1.1 Support for Kenya Fertilizer Roundtable (KeFERT)

The President of Kenya has established the government's socio-economic development agenda based on the "Big Four" pillars, which include the following priorities: a) 100% food security, b) affordable housing, c) manufacturing, and d) affordable healthcare. Kenya's Vision 2030 identifies the agricultural sector as one of the key sectors to deliver the 10% annual growth rate envisaged under the 100% food security pillar. The Agricultural Sector Development Strategy (ASDS 2010-2020) focuses on the challenges of food security, poverty reduction, employment creation, and transforming agriculture from subsistence to farming as a business.

Despite increased fertilizer use trends in Kenya, smallholder farmer yields remain stagnant and well below that obtained by many commercial farmers, some of which are achieving 10-15 mt/ha of maize. Overall cereal yield averages have stagnated at 1.7 mt/ha, indicating low smallholder yields in spite of a 25% increase in fertilizer use from 2014 to 2016. While crop management plays a key role into this yield gap, non-use or low rates of fertilizer use by smallholders are keeping yields stagnant. Soil acidity, due to inherent soil factors, fertilizer acidification, and lack of corrective liming further suppresses yields in many parts of Kenya. Smallholders use primarily NP fertilizers on maize (DAP or 23:23:0, CAN, and urea), yet deficiencies of other nutrients, including potassium, sulfur, calcium, magnesium, and micronutrients (particularly zinc and boron), are constraining yields. While some Kenyan and international fertilizer companies are producing balanced multi-nutrient fertilizer, no national soil mapping with nutrient deficiency exists to assist companies to better develop and target fertilizers according to varying agroecology and crop requirements. Providers of balanced fertilizer face competition from subsidized fertilizers, such that farmers are reluctant to purchase appropriate fertilizers at market prices.

Unblocking these constraints, providing extension services, and establishing on-farm demonstrations for increasing farmer awareness, developing efficient distribution networks, and financing key investments to expand markets can accelerate the development and distribution of better fertilizers and lime products. Such efforts require coordination of multiple actors in the fertilizer sector: importers and suppliers, policymakers, regulatory bodies, laboratory services, experts in geostatistical information collection and mapping, and research and extension entities (both government and non-government).

To facilitate this coordination, the Ministry of Agriculture, Livestock, Fisheries, and Irrigation (MALFI), in collaboration with various partners, including IFDC, held a roundtable meeting bringing together fertilizer stakeholders. The objective of the roundtable was to review major constraints facing farmers to access and use fertilizers and soil amendments (particularly lime), and to reach consensus on the need to address these challenges through formation of a multi-disciplinary Kenya Fertilizer Platform. A Fertilizer Platform is a public-private mechanism composed of key stakeholders involved in fertilizer access, quality, and use. This platform’s purpose is to resolve key fertilizer issues, to facilitate multi-stakeholder dialogue, coordination, and information exchange, and to take action under a public-private taskforce on an ongoing basis.

The workshop was held in Nairobi on October 16-17, 2018, in conjunction with the fertilizer sector. It involved structured presentations, discussions, and exhibitions. Preparatory meetings were held across private and public stakeholders from the fertilizer sector through several formal and informal consultations by IFDC and MALFI officials. The meetings discussed the motive behind the workshop. The agenda was divided into the following themes, which impact fertilizer quality, availability, and cost.

- Fertilizers, Soils, and Crop Nutrition under Changing Climate
- Fertilizer Importation, Blending, Marketing, Distribution, and Use
- Policy, Laws, and Regulations
- Investment and Financing Opportunities and Experiences Learned from Other Input Sectors
- The Way Forward

KeFERT partners included IFDC (technical and organizing) and MALFI with support from Tegemeo Institute, Edgerton University, AFAP, One Acre Fund, KEPHIS, Kenya Agricultural and Livestock Organization (KALRO), AGMARK, Fertilizer Association of Kenya, Kenya Markets Trust, KEBS with support from USAID FTF, BFS, MAADEN, UK Aid, AGRA, KCDMS, and ICL Fertilizers, Ltd.

Participants were stakeholders in the fertilizer sector, including public officials, private fertilizer company representatives, research institutions, development partners, and donors.

The outcome of the KeFERT workshop was the formation of the Kenya Fertilizer Platform. Fertilizer roundtables were used to develop priorities for the fertilizer sector, leading to an action plan for the Fertilizer Platform. More than 200 stakeholders from the public and private sectors provided input to the roundtables. This is expected to become an annual event.

2.1.2 Capacity-Building Activities: Policy Reforms

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

At the request of BFS policy advisors in Washington, D.C., in partnership with Rutgers University FTF Policy Research Consortium, a presentation was given on the importance and impact of agricultural input policies. The presentation took place during the USAID BFS-sponsored agriculture core training for staff from inter- and intra-agencies involved in U.S. Government international development activities. The training was conducted as a participatory discussion on December 13, 2017 in Washington, D.C. and covered the importance of agro-input policies for seeds, fertilizer, pesticides, and agricultural equipment; it discussed impacts of policy reforms on the respective sectors for better food security and for improving incomes and welfare among smallholder farmers in developing countries. The training session content was prepared in collaboration with the BFS policy team and the Rutgers consortium.

At the request of the BFS policy team, another presentation was made in Bangkok on May 7, 2018, at the Policy Core Course by the Rutgers Consortium to participants from the regional USAID mission and from six Asian countries. These presentations were further updated during August 2018 and submitted to be a part of the core program for future BFS-USAID policy trainings.

2.1.3 Documenting Fertilizer Trends and Outlook: IFDC-FAO Collaboration

This year IFDC contributed to two initiatives (described below) of the Food and Agriculture Organization (FAO) of the United Nations (UN). The collaboration is under an existing and long-lasting MOU between IFDC and FAO.

2.1.3.1 The World Fertilizer Trends and Outlook to 2022 (WFTO-2022)

IFDC is a member of the International Fertilizer Experts Group (IFEG), a World Bank initiative that has been carried out by the FAO for the past 20 years. The IFEG comprises two PIOs: FAO and IFDC through the Fertilizer Research Program. The group also includes representatives of the global fertilizer industry (the International Fertilizer Association [IFA], Fertilizer Europe, The Fertilizer Institute [TFI], and the Fertilizer Association of India [FAI]). Each of the participating organizations is considered an expert in a given nutrient source and/or world region.

The group meets annually for two to three days. Before the meeting, each member elaborates projections, this time to year 2022, of consumption, demand, production, and supply of the three key fertilizer nutrients for different regions of the world. The purpose of the meeting is to reach a consensus on the projections, using a dynamic that resembles a Delphi approach, and estimate supply-demand balances at the world and regional levels. IFDC makes projections pertaining primarily to Africa and specifically to SSA countries.

The output of the annual work and the meeting is a joint WFTO report issued by FAO. In addition, each member of the group can make use of the generated data and information to issue additional reports at the member's discretion. The WFTO does not elaborate details on the African region; therefore, for the next fiscal year, IFDC will generate a second report on "Africa Fertilizer Trends and Outlook 2018-2022," based on IFDC's projections and drawing from the IFEG projections to 2022 with a focus on Africa/SSA, emphasizing current and former FTF recipient countries.

2.1.3.2 The Code of Conduct for Fertilizer Management (CoCoFe)

The CoCoFe initiative was introduced by FAO during the IFEG meeting in 2016, taking advantage of the group dynamic. The code would institute international standards and guidelines on practices to ensure the responsible mining, production, trade, quality and safe use of fertilizer (organic and inorganic) for food production. The code would help to ensure innocuousness, reduce environmental contamination and reduce fertilizers' effects on climate change. It was also expected for countries, members of the UN, to voluntarily adopt the CoCoFe to serve as the basis for policies and national legislation related to fertilizer production, trade, and use. It is expected to also help regulators and extension officials outline the roles and responsibilities of the multiple stakeholders involved in various aspects of fertilizer management, including governments, industry, universities, NGOs, traders, farmers' organizations, etc. The CoCoFe was not intended to provide specific recommendations on field application of fertilizer, i.e. rates, placement, timing, etc., but rather provide broader recommendations on what should be considered when designing strategies to manage fertilizers sustainably.

Early in FY18, FAO invited IFDC to take part in the initial consultation and participate in the discussions, elaboration, and revision of the CoCoFe. The outcome of the initial consultation was reported in the previous Semi-Annual Report.

In further consultation, IFDC commented that focus should not be only on fertilizer use to minimize the negative externalities related to the environment and human health but it should also involve the production side of fertilizer. The fertilizer industry could help further reduce the negative externalities from fertilizer use by investing in developing more efficient fertilizer products. This would include "smart" fertilizer products congruent with crop genetics (seed) technological advances, complemented with more efficient fertilizer use techniques.

Listed below are the comments made by IFDC to the final draft of the CoCoFe document:

- The document seems to address fertilizer overuse while downplaying underuse. Soil degradation must be also addressed. As it stands, the document may contribute to the negative perception of fertilizer by focusing mostly on overuse. Underuse can also have negative environmental impacts, not only through soil degradation, but also by reducing the biodiversity of flora and fauna.
- With respect to "monitoring the production" of fertilizer – the document does not elaborate enough to address the production and beneficiation process of fertilizer, especially in the context of reducing contaminants and then minimizing their effects on humans, animals, and the environment, by also addressing fertilizer handling and use.

- Economic analysis is being shortened and is rarely mentioned, and yet the additional cost emanated from the CoCoFe implementation will determine what is approved. Recommendations should consider cost and benefit analysis for evidence-based policy or regulatory recommendations before they are approved. Some recommendations are not realistic or non-applicable to fertilizer; therefore, they should be removed.
- Inorganic fertilizer and organic materials should be clearly defined and differentiated since nutrients content in organic sources depends on the source of the organic materials, which becomes a problem when making nutrient use recommendations according to soil conditions and crops, especially in the context of ISFM.
- The document contributes to the skepticism of fertilizer use when inorganic fertilizers are labeled as chemical products. The use of the word "chemical" feeds into the argument of those who are opposed to the use of fertilizer since it makes it comparable to actual ag-chemicals (pesticides, herbicides, fungicides, etc.). Inorganic fertilizer should be labeled as such, inorganic or mineral rather than chemical.
- The development of new products should not be limited to the private industry. National universities and other organizations, such as IFDC, can develop or support the development of new fertilizer products, in many cases, in collaboration with the private industry.

As of July 2018, CoCoFe was finalized. Despite the widespread concern of the industry and other participants in the consultation that more time was needed to socialize the document among stakeholders who will potentially be affected by the CoCoFe, the executive committee decided to present it for approval at the 26th Session of the FAO Agricultural Committee (COAG) during October 1-5, 2018, before being presented to the governments of country members of the UN.

2.1.4 Partnership for Enabling Market Environments for Fertilizer in Africa

IFDC is member of the Partnership for Enabling Market Environments for Fertilizer in Africa (PEMEFA), a Michigan State University (MSU)-led consortium of five organizations.[1] The consortium has been conducting a lecture series to build consensus and get other organizations involved to build synergies. A seminar was held on April 5, 2018, at MSU, East Lansing, Michigan, on "Agricultural Policy and Regulation in Sub-Saharan Africa: Lessons for Increasing Investment." This meeting had 25 participants and attendees, including professors from agricultural economics and other departments, graduate students, and staff from the MSU Feed the Future Innovation Lab for Food Security Policy. Three presentations were made by PEMEFA principal investigators from IFDC, MSU, and New Markets Lab (NML). Another meeting was held on April 17, 2018, at Georgetown University, organized through NML on "Understanding the Enabling Environment: How Laws, Regulations, and Government Programs Support Trade and Agricultural Development." It was attended widely by both development and research institutions in Washington, D.C.

Ongoing activities are to finalize a fleshed-out grant proposal and concept note and develop a policy brief on a Regional Fertilizer Regulatory Framework. The latter will outline the rationale and proposed methodology for studying the impacts of a Regional Fertilizer Regulatory Framework on fertilizer trade and use in a given region. The concept was presented by one of the partners at the "Fertilizer Economics – Decision Making and Data Gaps" workshop, sponsored by

[1] MSU, AFAP, ReNAPRI, New Markets Lab, and IFDC.

the Bill & Melinda Gates Foundation in Kigali, Rwanda, on September 4, 2018. The concept note is to be finalized by December 2018.

2.1.5 Policy Briefs on Fertilizer Policies and Market Development

IFDC's engagement in the fertilizer and input policy reform processes, particularly with policies that have had significant impact on poverty and food security, are captured and documented as short policy briefs, either through the IFDC team or through engagement with partners in Africa, Asia, and Latin America and the Caribbean, for wider dissemination. Since 2015, policy briefs focusing on fertilizer market development through private sector participation were initiated (Ghana, Uganda, and Mali).

2.1.5.1 Brief: The Impact of Fertilizer Subsidy on Productivity and Production in Ghana

In efforts to promote economic growth and poverty reduction by increasing agricultural productivity, MoFA in Ghana instituted a Fertilizer Policy. The goal of this policy is to create a competitive fertilizer subsector that can supply adequate quantities of quality and affordable fertilizer. Agronomic experiments suggest that increasing the consumption and use of good quality fertilizer is necessary to address declining soil fertility and low productivity. Therefore, as an integral part of the fertilizer policy, MoFA instituted the Fertilizer Subsidy Program (FSP). In addition, 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 MoFA to the role of facilitator.

IFDC has developed a brief on the impact of the FSP on agricultural productivity in Ghana. Since the introduction of the FSP and increased participation of the private sector, the quantity of fertilizer supplied and apparent consumption have increased.

According to MoFA, since the 2008-09 season, an estimated U.S. $220 million has been spent on subsidizing 814,000 tons of fertilizer as of 2015-16. The annual cost of the FSP increased from U.S. $14.4 million to U.S. $57 million by 2012-13 and then began to decrease through 2015-16 (Table 19).

Table 19. Estimated Quantities and Cost of Subsidized Fertilizer in Ghana, 2008-2015

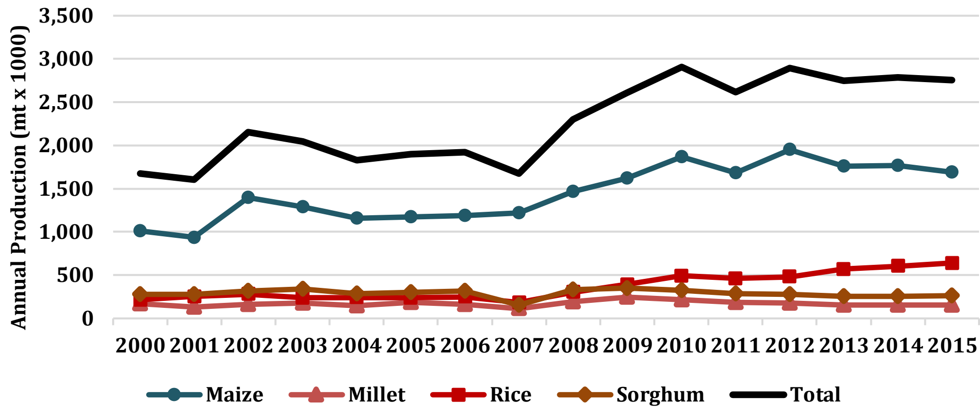
	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16
Fert. Consumption (mt)	125,567	261,057	324,399	129,668	372,680	288,874	143,451	289,822
Subsidized (mt)	43,176	72,795	91,244	176,278	173,755	166,807	0	90,000
Cost (U.S. $ x 1,000)	14,356	23,958	19,301	41,834	57,022	54,098	0	10,135

Data source: FAO, CountryStat, MoFA.

Note: GH¢ were converted to U.S. $ using annual average exchange rate according to http://www.investing.com/currencies/usd-ghs-historical-data.

From 2008 to 2015, there was an apparent increase in fertilizer consumption in Ghana attributed to the effects of the FSP. However, fertilizer use (kg/ha) did not show a substantial increase during the same period. Since introduction of the FSP, the overall average rate of fertilizer use increased from an estimated 8 kg/ha in 2008 to 12 kg/ha in 2013 (http://www.allAfrica.com, 2016). Smallholder farmers' use rate was reported to be lower as well, with nitrogen fertilizer at 6 kg/ha (World Trade Organization, 2014). With the reinstatement of FSP in 2015, MoFA's expectations were to continue increasing application rates to 20 kg/ha by 2020, advancing closer to the 50 kg/ha target outlined in the 2006 *Abuja Declaration*.

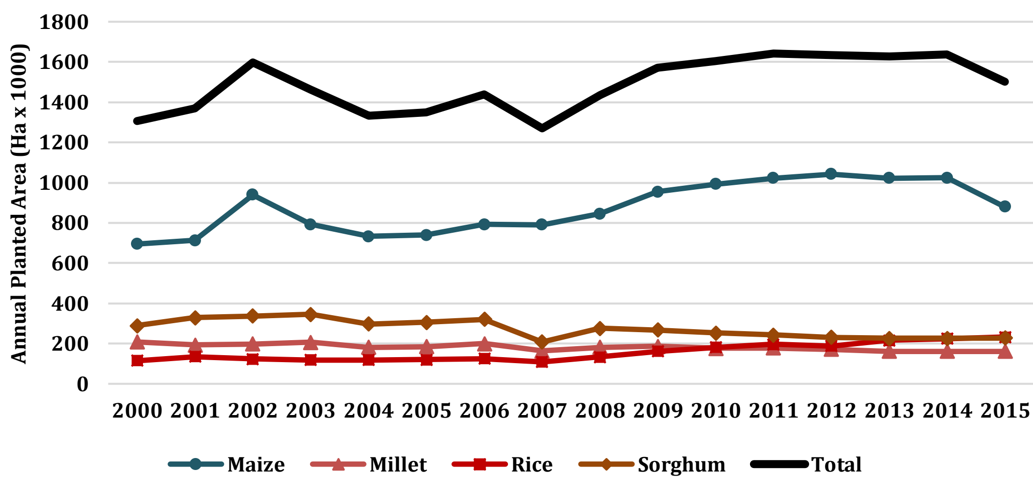
Cereal production targeted by the FSP (maize, millet, rice, and sorghum) has increased in recent years, but the average yield of 1.83 mt/ha (as of 2015) is still considered low productivity. Overall cereal production increased by 20% with a compound average growth rate (CAGR) of 2.6% per year. Rice and maize experienced the largest percentage increase and CAGR according to MoFA data (Figure 45). This increase, particularly yield, could be attributed to increased fertilizer use due to FSP (Table 20).



Data source: MoFA (2015).

Figure 45. Total Cereal Production in Ghana

However, the increase in overall cereal production could also be partially attributed to an increase in planted area and a shift from land allocated to sorghum and millet to land allocated to rice, maize, and other commercial crops (Figure 46 and Table 20).



Data source: MoFA (2015).

Figure 46. Planted Areas for Cereals in Ghana

Table 20. Percentage Change in Cereal Production, Planted Area, and Yields (2008-2015 period)

	2008-2015 Percentage Changes in:		
	Production	Planted Area	Av 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%

Data source: MoFA (2015).
Note: Average yield is estimated by dividing production by planted area.

The analysis suggests that not much has been achieved in increasing the fertilizer application rates and cereal output growth, despite the increase in fertilizer consumption facilitated by the FSP and larger private sector participation in the fertilizer market. The recorded agricultural production growth perhaps can be attributed to shifting cropland usage to crops of higher economic importance to farmers. Production growth could also be a result of increasing overall cropland and higher yields from the increased use of productivity-enhancing inputs, such as fertilizer. Still, in the case of the crops considered in this analysis, production and productivity have improved, although at a substantial financial cost that may not justify the high financial commitment from the GoG through the FSP. Moreover, the opportunity cost of devoting public funds to subsidizing fertilizer, instead of investing in other rural and agricultural development projects, could be substantial.

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 a sufficient condition 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 on the proper use of productivity-enhancing inputs; more importantly, the strategy must focus on investing in infrastructure to incentivize private investment so that businesses expand into rural areas to provide services and supply productivity-enhancing technology closer to farmers at lower costs. This same investment will help reduce costs related to long-distance travel, allowing farmers better access to agro-dealers and extension services to seek advice and, more importantly, access output markets to increase farmers' incomes. In addition, government policies should aim to increase farmers' access to credit by supporting credit programs for fertilizer use and to address the macroeconomic imbalance, which is greatly impacting high interest rates.

2.1.5.2 Technical Brief: Regional Economic Integration and the Trade of Agro-Inputs and Outputs

In efforts to present a conceptual framework to analyze the effect of regional integration on the trade of agro-inputs and outputs, a technical brief "*The Economics of Regional Integration and the Effects on Agro-Input and Output Trade,"* was developed to explain the importance of regional economic integration (REI). The document illustrates what REI is and the different levels of integration. It then illustrates and analyzes the effect of an REI, making use of a partial equilibrium framework before elaborating on the economics of REI and its potential effect in the context of agro-input and output trade at four levels: a) reduction in cost of agricultural production, b) increase in production and in agriculture diversification, c) increase in overall input and output trade, and d) shifts in origin and/or destination of traded inputs and output.

The framework can also be used to identify and quantify the effect of policies, legal or regulatory changes that affect input/fertilizer trade, at a country level or regional level, such as the Economic Community of West African States (ECOWAS) in West Africa and East African Community (EAC) in East Africa.

2.2 Impact Assessment Studies

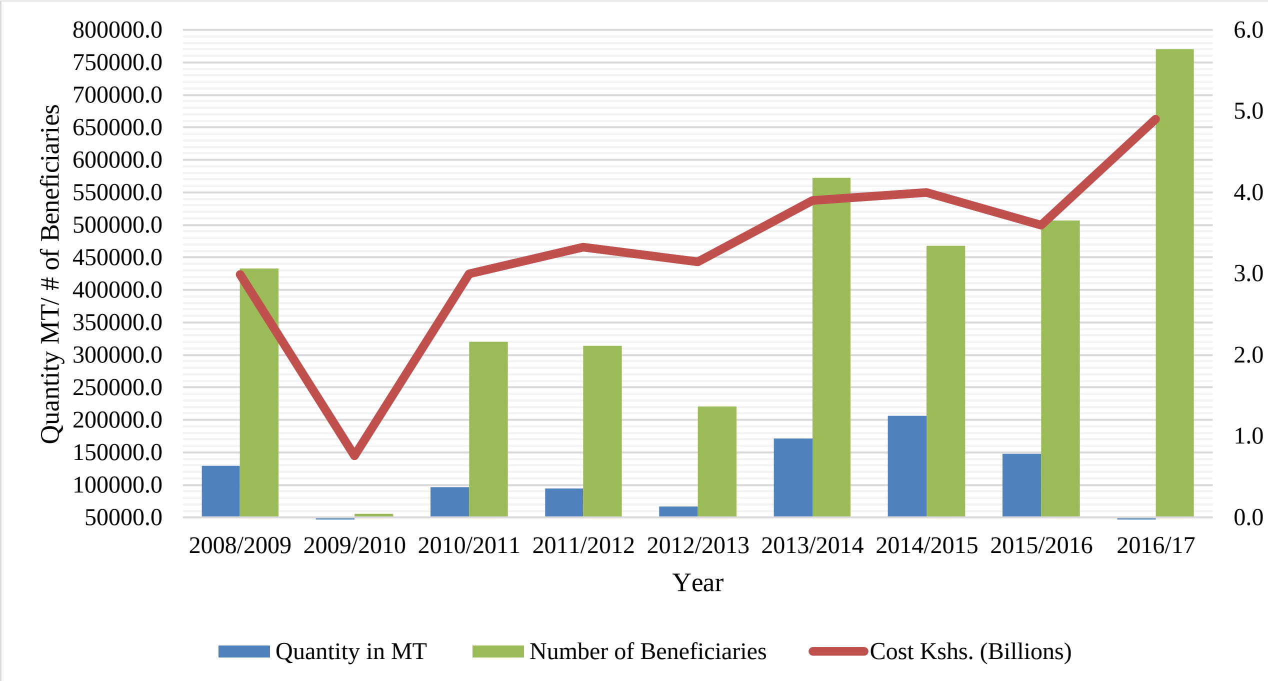
To support policy reforms for developing input markets and value chains, IFDC conducts impact assessment studies not only to provide feedback on the performance of policy changes and supporting programs but also to provide lessons learned for future policy reforms and implementation. During FY18, this sub-activity included research activities on (a) assessing the impact of Kenya's fertilizer subsidy program and (b) assessing the effectiveness and impact of agro-dealer development/input supplier networks toward improved access to and use of technologies among farmers and effects of market interventions in Rwanda.

2.2.1 Impact Assessment Study on the Kenya Fertilizer Subsidy Program

Since the 1990s, the Kenyan government has implemented several policies and regulatory reforms aimed at improving fertilizer market development and infrastructure through increased private sector participation and investments. In addition, the government has been implementing input subsidy programs (ISPs) that target resource-poor farmers and provide benefits from improved agro-input use on a wider scale. Further, to improve the operational efficiency of the fertilizer sector and reduce overall fertilizer cost, an initiative to cut market transaction costs as outlined in the Kenya Vision 2030 strategy (2008) has been adopted. The initiative includes encouraging fertilizer bulk procurement, blending, and local manufacturing by domestic entrepreneurs to ease constraints along the value chains. These initiatives are expected to increase access to fertilizers, reduce fertilizer prices, and induce higher adoption among farmers. In this context, bulk procurement was incorporated into the National Cereals and Produce Board (NCPB) to import and distribute large quantities through its network of depots.

From the 2008/09 cropping season to 2017 (long rains season), the Kenyan government reached nearly 3.7 million farmers, distributing around 1,106,030.50 mt of fertilizers (Figure 47). This cost the government of Kenya an estimated Kshs. 29.6 billion, over a period of nine years, with an annual budget estimated at around Kshs. 3.1 billion (~ U.S. $310 million).

The proposed ISP assessment will be conducted at both micro and macro levels and across various stakeholders at different stages of the fertilizer value chain during FY19. Partners include IFDC, Tegemeo Institute, Ministry of Agriculture, KALRO, and AGRA. This is a cost-sharing activity, with funding from BFS, AGRA, and the Ministry of Agriculture.



Source: Ministry of Agriculture and Irrigation, Kenya. 2017.
Notes: Series 1 refers to the quantity of fertilizers procured for distribution; series 2 refers to number of beneficiaries; and, the line graph indicates the expenditure on ISPs (Billions of Kshs.)

Figure 47. Fertilizer quantities procured annually (MT), number of beneficiaries, and expenditure (Kshs Billions)

2.2.2 Effectiveness of Agro-Dealer Development Programs Toward Sustainable Input Supply and Technology Transfer in SSA

An assessment was implemented focusing on the determinants of sustainability of input suppliers and their impact on input market development in selected countries in SSA. The analysis seeks to identify the attributes of successful agro-dealers; the existing input market policies and their effect on these supplier networks; and the role of input financing in building efficient networks.

During FY18, it was proposed to continue the field-level impact assessment of the Rwanda Agro-Dealer Development (RADD) programs implemented in two phases, during 2010-13 and 2014-16. This activity will be initiated by the Agribusiness-Focused Partnership Organization (AGRIFOP), a local Rwandan community service organization involved in capacity building of agro-dealer programs in Rwanda, and AGRA, who is actively engaged in implementing agro-dealer development programs in Rwanda and elsewhere in Africa. Detailed discussions were held during January 2018 with Mr. Fred Muhuku, Agro-Dealer Programs Specialist at AGRA, through IFDC's East and Southern Africa regional office in Nairobi, to request AGRA's assistance in enabling logistics in Rwanda and data documentation (baseline and end-line survey data from previous programs in Rwanda). AGRA has agreed in principle to share any relevant information regarding agro-dealer programs in Rwanda for this proposed study.

The work began in October 2018, and the assessment progress from the field surveys will be provided in the semi-annual report, with the final draft expected by September 2019.

2.3 Economic and Market Studies

IFDC's economic studies provide useful information for public and private decision-making and identify relevant areas for policy changes and supporting programs to streamline the flow of fertilizers at reduced prices for smallholder farmers. The economic studies include evaluation of various soil fertility-enhancing technologies in terms of economic returns and efficiency for small farm adoption and financial returns to various actors in the value chain; conducting stakeholder analyses and assessment of cost buildups and market margins to identify value chain constraints; and market analysis of the supply and demand of fertilizers. IFDC's FY18 work in this sub-activity involves the following key areas: (a) documenting data on fertilizer cost buildups and margins across different countries in SSA; (b) identifying indicators of fertilizer use and access in SSA; (c) supporting policy efforts to harmonize fertilizer quality regulations, based on evidence-based scientific analysis; and (d) initiating a series of micro-economic research studies related to fertilizer technology use, markets, value chains, and environmental implications in partnership with land-grant universities, such as MSU, Rutgers, and the University of Georgia (UGA).

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

2.3.1.1 Support to the Kenya, Uganda and Myanmar Governments for Fertilizer Quality Policy Development

Fertilizer quality assessments in Kenya, Uganda, and Myanmar markets were conducted in May 2016, May 2017, and November-December 2017 respectively. The quality assessments were based on the principle of "Truth in Labeling." This principle allows for the classification of potential issues as: nutrient content shortages, bag weight shortages, degradation of physical properties, and presence of heavy metals or other contaminants harmful for life or the environment. While the specific origin of the quality problems can be in the manufacturing, mismanagement of the product along the supply chain, adulteration, or a combination of these three categories, the root of fertilizer quality problems, which is pervasive in developing countries, is the absence of or deficiencies in regulatory systems, with limitations in their legal or administrative components.

The fertilizer quality assessment carried out in Myanmar had two additional components: evaluation of the existing regulatory system and fertilizer value chain. The objective of these two components was to search for factors with the potential of deteriorating fertilizer quality besides those directly associated with characteristics of the fertilizers and the conditions in which they are managed. A detailed description of the methodologies used as well as the findings of the quality assessment were presented in the report produced for each country.

Using the fertilizer quality assessment report as the main instrument, IFDC started interacting with the government and the private sector in Uganda, Kenya, and Myanmar during 2018. The main objectives of this interaction were to make them aware of the fertilizer quality situation in the respective countries and to assist them in developing policies to improve the fertilizer quality regulatory systems. Interactions with the governments and private sectors in all the three countries were carried out through the following activities:

1. **Fertilizer Quality Workshops** to deliver a detailed description of the rationale, methodologies, findings, and recommendations from the fertilizer quality assessments.

2. **Discussions with members of the fertilizer trade private sector** to emphasize the role of the private sector in fertilizer quality and the concept of self-regulation. The main message

delivered to the private sector representatives was that, for the self-regulation to be attained, they need (a) to have a good understanding of fertilizer quality, (b) be familiar with all aspects of the regulatory system, and (c) have good relations with regulators. Discussion also included their perception of the government's Fertilizer Quality Regulatory System.

3. **Meetings with government officials involved in fertilizer quality regulation** to discuss whether the fertilizer quality challenges can be addressed with the existing regulatory system or if legal and/or administrative reforms are required to pursue a solution to fertilizer quality problems. These discussions also included funding mechanisms to make the regulatory system sustainable and the necessary steps toward harmonization of the national regulatory system with neighboring countries to create a regional regulatory system.
4. **Training for fertilizer quality inspectors and lab personnel from Myanmar** emphasized the weaknesses of the National Fertilizer Law, with respect to fertilizer quality, quality risk factors in the fertilizer value chain, and training in the fertilizer sampling along the supply chain.

2.3.1.2 Outreach and Dissemination of Findings from FQA

1. Fertilizer Quality Workshops

Uganda**:** The workshop in Uganda was attended by MAAIF representatives from several departments, the National Bureau of Standards, the World Bank director in Uganda, members of the Uganda National Agro-inputs Association, and professors from Makerere University. During the workshops, based on the fertilizer quality assessment of May 2017, presentations were made on the methodology, findings, conclusions, and recommendation; and on the weak points of the regulatory system in Uganda and ways to improve it. The workshop was also an opportunity for AFAP to make a presentation describing the harmonization process of national regulatory systems to create a regional regulatory system in the EAC.

Specific policy and regulatory limitations in Uganda and ways to correct them were discussed in the meeting with government officials. The MAAIF representative call for IFDC assistance for establishing a better regulatory system in Uganda, considering that the current official documents related to fertilizer quality do not contain provisions for fertilizer quality inspections and sample analysis, standards for nutrient content, or bag weight and heavy metal contents in fertilizers.

Kenya**:** The Kenya report was presented to representatives from the Ministry of Agriculture, fertilizer manufacturers, importers/distributors, and representatives of the Embassy of the Kingdom of the Netherlands. Presentations were made on the methodology and findings from the quality survey carried out in April 2016 and on the Kenya Fertilizer Quality Regulatory System, its weaknesses, and a process toward regional harmonization of national regulatory systems in the EAC. The representative for the Minister of Agriculture recognized the need for good fertilizer quality to promote economic growth in Kenya and to improve the standard of living for smallholder farmers. She also recognized the current system limitations to conduct inspections and sample analyses and the administrative obstacles derived from a regulatory system that combines fertilizer and animal feeds under one legal and regulatory umbrella.

Discussion also included issues related to the private sector perception of the national regulatory system and ways to develop policies to improve the capacity of the regulatory system to deal with fertilizer quality issues.

***Myanmar*:** The workshop was attended by ministry officials, fertilizer manufacturers, importers, distributors, dealers, USAID representatives, International Finance Corporation from the World Bank Group, Livelihoods and Food Security Trust Fund (LIFT), MSU, Australian Centre for International Agricultural Research *(*ACIAR), and Myanmar Customs representatives.

Most of the discussion after presentations, was in relation to the lack of tolerance limits for nutrient and heavy metal content in fertilizers under the Myanmar Fertilizer Law. This fact limits the application of penalties for nutrient deficiencies or presence of contaminants in the traded fertilizers.

The workshop audience agreed with the following aspects being essential for the establishment of a culture of good fertilizer quality in Myanmar:

- Upgrading the legal documentation that supports the Fertilizer Quality Regulatory System.
- Applying mechanisms to guarantee self-financial support of the regulatory system.
- Professionalization of fertilizer quality inspectors.
- Enabling the laboratories thorough personnel training and appropriate equipment.
- Conducting agricultural research and extension by the Ministry of Agriculture to increase fertilizer use, demand, and trade growth.
- Constitution of fertilizer trade organizations and promotion of the private sector self-regulation.

The training program was addressed to relevant ministry staff working as fertilizer quality inspectors, lab analysts, or agriculture researchers. They were instructed on the aspects of the Fertilizer Law that need improvement to become an operational and effective fertilizer quality regulatory system. These include: improvements in value chain characteristics with the potential to affect the quality of the fertilizers traded and on procedures to sample and handle collected fertilizer samples, assess the physical properties, verify bag weight, and evaluate the fertilizer storage conditions.

2. Discussion with members of the fertilizer trade private sector

Uganda:

- Grainpulse Ltd. is a company working to promote fertilizer use by smallholders by selling the bulk blends in small packs of 1 to 10 kg. The representative from this company sees the absence of farmers' access to credit and the insufficient extension services by MAAIF as the main obstacles for fertilizer consumption growth in Uganda.

- The Uganda National Agro-inputs Association, UNADA, is an advocate of the private sector self-regulation in Uganda. The association provides services to dealers on financial literacy, good business practices, and the safe use of pesticides. They believe that fertilizer trade organizations play an important role in maintaining fertilizer quality through two-step self-regulation: one practiced by individual dealers and one applied by the trade organizations on their members. They also believe that a lack of credit for smallholders, misinformation about fertilizers, and a lack of soil testing services are the main contributors to low fertilizer use and obstacles for fertilizer trade growth in Uganda. UNADA's recommendations are to develop a Fertilizer Quality Regulatory System and create a National Fertilizer Data Platform. This platform would provide data for the public, which would eventually result in fertilizer consumption and market growth.

- Crop Care Ltd. imports and distributes fertilizers and crop care products in Kenya and Uganda. Quality control of imported fertilizers is ensured through pre-import quality conformity. The company believes that the government regulatory process slows down farming activity due to a lack of synchronization between importation authorizations and crop cycles. They also believe that regulation requires dramatic changes, but there is not hope that the changes will take place without the existence of an effective fertilizer trade organization and strong private sector leaders.

Kenya:

- Meetings were held with the representatives from several of the largest fertilizer importers in Kenya: MEA, ChemAgro, ELGON KENYA, and others. Representatives of these organizations expressed dissatisfaction with the government importations for the subsidy programs since some importers have almost gone out of business due to unfair competition from the government program. The highly evolved private fertilizer trade in Kenya could play an important role in establishing sustainable, good quality Kenyan markets through self-regulation and improvement of government-private sector relationships.
- Representatives of MAVUNO, one of the largest bulk blend manufacturers in Kenya, also expressed dissatisfaction with the government subsidy program considering that their business is affected by the unpredictable timing of importations, the non-working e-vouchers, and the adulteration of subsidized fertilizer. They believe that the private sector could benefit from the fertilizer subsidy if those issues are corrected and if the subsidy is extended to all fertilizers and soil amendments, such as lime.

3. Meetings with government officials involved in fertilizer quality regulation

Uganda: In a meeting with the Commissioner for Crop Inspection and Certification and his staff, the discussion focused on two basic components of the regulatory system that need to be built for a functional fertilizer quality regulatory system in Uganda. One component is the legal instrument to support the application of the "truth-in-labeling" principle and define violations and penalties. The second component is the required administrative tools to be developed for the implementation of the regulatory system. Elaboration of an inspection manual and a manual for fertilizer analysis are also part of the technical documents that are key for implementation of the regulatory system.

Kenya: Discussions with the Director of Policy and Research and the Fertilizer Coordinator at the Ministry of Agriculture focused on explaining the areas where the Kenya Fertilizer Quality Regulatory System needs improvement. These areas include: a) the separation of fertilizer quality control from the animal feed regulatory system, b) the constitution of a technical fertilizer committee, c) development of official manuals for inspection and fertilizer analysis, d) professionalization of fertilizer inspectors, e) upgrading of analytical labs, and f) the creation of a fund specific for financing the regulatory system operation. The director mentioned that the ministry is going through reforms which will facilitate the suggested changes and requested for IFDC assistance to make the regulatory system improvements possible, with potential funding from AGRA and the USAID local mission.

2.3.2 Fertilizer Cost Buildup Studies and Marketing Margin Analysis

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

2.3.2.1 West Africa Fertilizer Supply Cost Buildup Consolidated Report

A consolidated report has been assembled for the West African region, based on country-specific fertilizer supply cost buildup assessments implemented between 2006 and 2016. The report makes an inter-temporal analysis of the changes in the cost of supplying fertilizer, taking into consideration work done by IFDC since 2006 with Chemonics, later in 2009 with the International Food Policy Research Institute (IFPRI), and more recently in 2015-16 with BFS funding.

Since 2006, IFDC has been implementing fertilizer market assessments and studies in different countries in West Africa. Some of these assessments included identifying the supply chain structure and its associated cost from procurement to retail. The analysis presented is based on historical cost buildup in Ghana and Mali since 2006, as representative coastal and landlocked countries in West Africa. Although IFDC has also developed fertilizer supply cost buildups in other countries in West Africa (Senegal, Nigeria, and Côte d'Ivoire), they were not included in the different periods considered in this analysis and, therefore, were excluded from the regional analysis.

In efforts to compare past and more recent performances of the fertilizer supply chain in West Africa, nominal costs were adjusted to constant 2006 dollars, using the consumer price index for the countries included in the analysis. The graphs below present the share of cost, insurance, and freight (CIF) vs. domestic costs, relative to retail cost in West Africa, and the general changes in the cost of supplying urea since 2006.

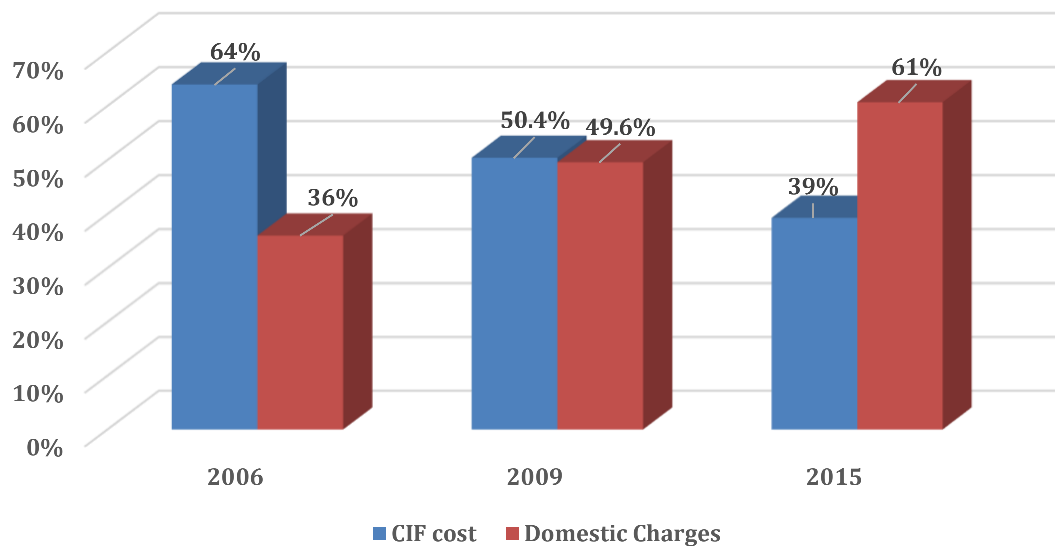


Figure 48. Changes in Cost of Supplying Urea in West Africa Relative to Retail Cost: CIF vs. Domestic Costs (Constant 2006)

Figure 48 shows that the cost of supplying urea in West Africa has experienced a shift between the period of 2006-2015. Until 2006, the CIF cost of urea absorbed up to 64% of the total fertilizer cost at retail; as of 2009, CIF and domestic cost were almost at par, still slightly dominated by CIF cost. However, as of 2015, the cost structure of supplying urea in West Africa took a reversal relative to 2006, with domestic cost absorbing 61% and CIF cost 39% of the total cost of supplying fertilizer at retail. The graph below presents the different domestic cost components to which the increase in domestic supply costs can be attributed to through 2015.

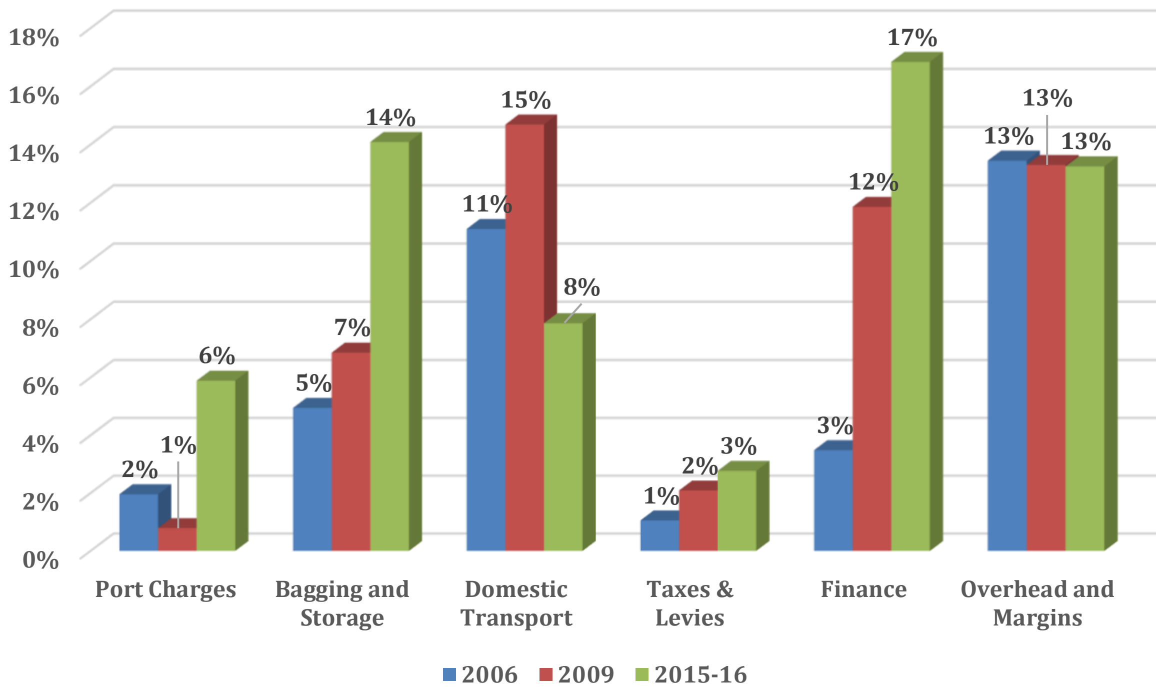


Figure 49. Changes in West Africa Domestic Supply Cost Structure Relative to Retail Cost: 2006-15 (Constant 2006)

As presented in Figure 49, between 2006 and 2015, there has been a gradual increase in most domestic cost components with the exception of domestic transportation, which increased substantially in 2009, compared to 2006, and then decreased in 2015, compared to 2009 and 2006. According to available data, and as presented in the graph above, the overall increase in domestic cost for supplying urea at retail in 2015, compared to 2006 and 2009, can be attributed to increases in port charges, bagging and storage, financing costs, and government taxes and levies. However, the government taxes and levies can be considered negligible. Domestic transportation has not kept up with the increase in domestic supply costs as of 2015. Overhead and margins have remained constant. This increase in the domestic costs are perhaps the result of inflation reflected in the devaluation of and volatile nature of domestic currencies and an increase in the cost of financing, which has a ripple effect on the economy, influencing the increases in the other cost components.

Furthermore, the graphs below present the effect of inflation on the increase in the fertilizer supply cost buildup. According to the available data reflected on the graphs below, while the nominal CIF cost of urea decreased gradually since 2006, the nominal domestic cost gradually increased. However, both domestic and CIF costs present a rapid increase, respectively, when adjusted for the effect of inflation, based on consumer price index, between 2006 and 2015 (constant 2006 local currencies, converted to dollars). This increase is more pronounced between 2009 and 2015.

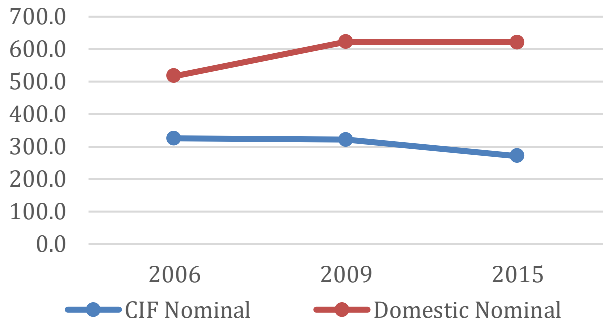


Figure 50. Changes in West Africa Nominal CIF and Domestic Costs ($): 2006-2015

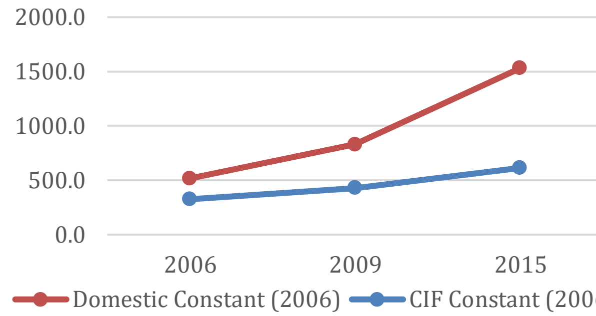


Figure 51. Changes in Constant (2006) CIF and Domestic Costs ($): 2006-2015

When analyzing country specifics, Ghana has a larger influence in West Africa regarding changes in costs of supplying fertilizer. However, the influence of Mali is less, despite Mali being landlocked with no direct access to the seaport. The greater influence of Ghana can be explained by a higher inflation rate experienced between the period being analyzed, reflected in a volatile foreign exchange rate and higher interest rates. In addition, differences in the increases in cost structure between countries are greatly influenced by how fertilizer subsidies are being implemented and whether the country is landlocked.

2.3.3 The African Fertilizer Access Index

The key objective of The African Fertilizer Access Index (TAFAI) is to promote the creation and maintenance of an enabling environment for competitive fertilizer systems serving smallholder farmers. The proposed TAFAI will be a consolidated measure/index of various indicators related to policy, market, research, and development that influence and are responsible for creating an enabling environment for fertilizer market development. The activity will take advantage of the presence of partner organizations, such as AFAP, the International Fertilizer Association (IFA), and other private and public sector organizations in East and West Africa, for the purposes of data documentation and consultations.

No activities were conducted during this reporting period due to logistical and financial issues, as AFAP could not participate in the activity due to lack of funding. It has been further decided that IFDC will modify and continue to prepare a detailed fertilizer access report at a country level viz., Kenya, to support the Kenya Fertilizer Platform initiative. This work will be jointly carried out on a cost-sharing basis with AfricaFertilizer.org staff in Kenya. The preliminary report on the Kenya Fertilizer Access scenario along with key variables will be provided during the semi-annual reporting of FY 2019. The final report on Kenya will also be extensively discussed among the

KeFERT platform stakeholders toward the end of 2019. We plan to further build the TAFAI – detailed country-level work, to other key countries either in East or West Africa, after consultations with stakeholders and partners. This documentation would serve as a scoping document on country-level fertilizer analyses, to be easily accessible for both the public and private sector.

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

Under Workstream 1 and in collaboration with the completed USAID-funded Accelerating Agriculture Productivity Improvement (AAPI) project, an ongoing activity has been to document GHG emissions from UDP use, along with different agronomic and crop management practices in paddy rice in Bangladesh. The results from the ongoing GHG mitigation research have shown that nitrous oxide (N_2O) and nitric oxide (NO) Life Cycle Inventory (LCI) emissions from fertilizers can be controlled via application strategy to levels associated with unfertilized plots. Thus, the reduction of GHG emissions associated with better fertilizer management practices in rice fields is a potential opportunity for Bangladesh to gain carbon credits. This work will complement the agronomic work carried out on the quantification of GHG emissions by the life cycle analysis (LCA) approach in quantification of energy equivalents (in turn, carbon credits and associated income) consumed across different types of fertilization in a paddy-rice system in Bangladesh.

The following progress has been made toward implementing this activity: (i) a graduate-level student (Mr. Ming Zhe) from Rutgers University has been selected to carry out this research as a part of his thesis requirement; (ii) a Terms of Reference has been developed with Rutgers for the proposed research collaboration; (iii) the graduate student has already initiated a detailed literature review on LCA approaches and is finalizing the approach for the present study; and (iv) a final detailed proposal along with methods and preliminary analysis will be provided during the semi-annual reporting of FY19, and the final analytical report will be submitted by October 2019.

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

The most important agricultural input for increasing crop productivity, resiliency, and efficiency is fertilizer. In most rain-fed rice paddy systems, the traditional method of applying nitrogen fertilizer is through broadcasting prilled urea to the surface of wet soil. Broadcasting urea in paddies results in low nutrient absorption rates with 60-70% of nitrogen losses to volatilization, denitrification, leaching, and runoff. Overall, the deep placement of fertilizer as urea briquettes or NPK briquettes has resulted in a 15-25% increase in yield and 25-30% reduction in use of fertilizers.

Data on the adoption and uptake of UDP/FDP by farmers have been documented by IFDC projects in Bangladesh, with funding from USAID and the Walmart Foundation, over the past seven years. UDP technology has been adopted by rice paddy farmers and vegetable growers, along with other crop management practices (broadcasting, alternate wetting and drying, seed varieties, etc.). This research and the existing data available from IFDC surveys on fertilizer adoption/use in Bangladesh have helped to understand both technical efficiency of the uptake and sustenance of adopting the UDP technology by smallholder farmers.

In 2015 and 2016, household surveys were conducted in Southwestern Bangladesh in 125 villages, 92 unions, 29 upazilas, and 10 districts. There were 2,000 households sampled with 16 respondents per village chosen through a three-stage multi-sampling procedure.

The objective of this sub-activity is to assess the effect of adopting FDP technology on crop yields, labor, input costs, farmer revenues, and the impact on the environment of the FTF zones in Bangladesh. The analyses focused only on the Boro season because of its higher uses of irrigation and machinery, which allows for household-level comparisons to prior to the introduction and adoption of the FDP technology. If FDP technology, which implies lower levels of nitrogen fertilizer use, can help farmers achieve higher levels of productivity toward the production possibility frontier, then resiliency and efficiency can be achieved by Bangladeshi farmers at a local scale.

To understand both farmer efficiency and techical productivity, we will implement a stochastic frontier model with a Cobb-Douglas production function to delineate both observable and non-observable bundle of inputs influencing the output. The stochastic nature of the model will be represented by the "$\ln(Y)_i = \beta x_i + \varepsilon_i$" function, where Y_i is the crop yield of the i_{th} farm, βX_i is the translog of a (1 x k) vector of farm inputs with (k x 1) parameters to be estimated; and the error term ε is composed of $(v_i + u_i)$ (Abdulai 2018). This model represents an observed output of the i_{th} farmer to the frontier, and the maximum possible output given the same bundle of inputs, X_i (Zoltan 2011). Further, the technical productivity can be calculated using the Cobb-Douglas functional form shown below:

$$lnY = \beta 0 + ln\ \beta_1 X_1 + ln\ \beta_2 X_2 + ln\ \beta_3 X_3 + ln\ \beta_4 X_4 + ln\ \beta_5 X_5 + ln\beta_6 X_6 + ln\beta_7 X_7 + ln\beta_8 X_8 + ln\beta_9 X_9 + ln\beta_{10} X_{10} + ln\beta_{11} X_{11} + (V_i - U_i)$$

The empirical analysis for Boro 2015 and 2016 is being carried out. Comparing the technical efficiencies, thus maximizing the outputs using UDP, will be analyzed and interpreted. The results of the empirical and economic analysis will be completed and reported in March 2019.

Note: Y is rice yield (kg/h); X_1 is gender (male=1, female=0); X_2 is age; X_3 is education in years; X_4 is the farm size in acres: 1= Landless (0-0.04 acres), 2= Marginal (0.05-0.49 acres), 3= Small (0.50-2.49 acres), 4= Medium (2.5-7.49 acres), 5= Large (7.50-12.35 acres), 6=extra large (>12.35 acres); X_5 is the fertilizer used on the cultivated plots at the household level (1= only urea used, 2= only UDP used, 3= both urea and UDP used); X_6 is household labor; X_7 is whether they have used GF technology before 2015 (Yes= 1, No=0); X_8 is the use of UDP technology for 2015/2016 (Yes= 1, No=0); X_9 is the use of agricultural machinery for production (Scale of 1-5 given a yes/no for 5 agricultural machineries: tractor, power tiller, shallow tubewell, FDP fertilizer applicator and sprayer); X_{10} is the fertilizer intensity use at the household level (scale of 0-10 give a yes/no for 10 different fertilizers); and X_{11} is the ownwership status of agricultural capital (scale of 0-3 given own/rented status for: power tiller, shallow tube well, and sprayer).

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

(Crosscutting all BFS-funded activities)

Under BFS, IFDC proposes to build the internal capacity of the field operations staff on monitoring, evaluation, learning, and sharing (MELS). An IFDC Monitoring and Evaluation (M&E) specialist from Togo enrolled in a PhD program at UGA in August 2018. He will specialize in M&E approaches, gaining comprehensive knowledge on various evaluation tools and techniques to be applied in IFDC field operations upon training.

2.3.7 Improving Fertilizer Use, Access, and Market Development

2.3.7.1 Honduras: HOI-IFDC Collaboration

In early 2017, IFDC, in coordination with Honduras Outreach Inc. (HOI), a private NGO based in Georgia, undertook an outreach activity with the overall goal to help develop public-private partnerships and expand business outside IFDC's current regions of influence. Critical issues facing the Honduran agriculture sector that IFDC could address based on its institutional experiences were identified. HOI, in collaboration with the government of Honduras, is in the process of establishing a research and demonstration farm on irrigation systems in the Agalta Valley, Honduras.

In February 2018, IFDC and HOI personnel and collaborators met at the UGA Strickland Irrigation Research Station (SIRS) to: (i) observe Strickland's research activities, including irrigation and soil and crop fertility management; (ii) explore the possibility of forming a three-institution consortium (HOI, IFDC, UGA/SIRS); and (iii) seek funding opportunities for collaborative work in Honduras.

HOI is currently making an investment to establish an irrigation system in its farm in Honduras, with the collaboration and support from the government of Honduras. The goal of this collaboration and irrigation system is to establish a research and demonstration farm for irrigation and other technologies where public and private institutions, national or international, would have the opportunity to do research on existing and new agricultural products and technologies. Such research would demonstrate various products and technologies' potential for increasing the productivity of the agricultural sector of Honduras, specifically in the Agalta Valley corridor, which has an unexploited potential for increasing agricultural production of both domestically consumed and exported crops. Based on ongoing discussions, IFDC is expected to be one of the international organizations to establish fertilizer demonstrations and fertilization technologies with traditional and alternative crops, in collaboration with other national institutions (e.g., *la Universidad Nacional de Agricultura de Honduras*, *la Escuela Agricola Panamericana*, among others) and the government of Honduras under some form of commitment, such as a Letter of Agreement. The fertilizer and fertilization technologies research and demonstration to be carried out by IFDC in the Agalta Valley are expected to be extrapolated to other countries and, eventually, have a regional impact in Central America.

2.3.7.2 Guatemala: Potential IFDC-DISAGRO Public-Private Partnership

As initial steps toward implementing programs in Guatemala, a training on fertilizer technologies and quality assurance is being planned. This training will be a joint effort between IFDC and a fertilizer industry potential partner in Guatemala, under a public-private partnership and Memorandum of Understanding.

A team from DISAGRO of Guatemala visited IFDC in May to exchange ideas and identify opportunities and for DISAGRO to learn about the capabilities of IFDC to implement programs in Guatemala and Central America. DISAGRO is a fertilizer company with a large share of the fertilizer market in Central America. During their visit to IFDC, potential opportunities were identified for IFDC to provide training and technical assistance to DISAGRO's personnel and make it extensive to government officials and other stakeholders of the fertilizer market in Guatemala and Central America. DISAGRO is interested in supporting the implementation of programs on behalf of smallholder farmers in Guatemala, as part of their corporate social responsibility. This activity will be implemented in FY19.

2.3.7.3 Concept Paper to USAID-Honduras

A concept paper as an unsolicited proposal, titled "Improving the Fertilizer Market and Lowering the Cost of Fertilization to Develop the Coffee Sector in Honduras," was submitted to USAID-

Honduras late in 2017. The paper was submitted following a visit to USAID-Honduras, with the intent of supporting the fertilizer sector and the coffee-producing sector as one of the major agricultural products exported from Honduras and to improve the living conditions of smallholder coffee producers, who have been facing precarious conditions due to coffee leaf rust.

The goal of the proposed activity in the concept paper is to sustainably improve coffee productivity, income, and food security among coffee producers and seasonal workers and incentivize growth of the coffee and fertilizer sectors in Honduras. The objectives are to (a) promote a more favorable policy and regulatory framework to further develop the fertilizer supply value chain to sustain its availability and reduce the cost of supplying fertilizer and (b) reduce the cost of fertilization of coffee by introducing alternative fertilizer and fertilization techniques to increase the efficient use of and the demand for fertilizer among coffee producers and other food crops. IFDC has received a response from USAID-Honduras that it cannot currently support this activity.

Annex 1. University Partnerships

Theme/Activities	Countries	Partnership
Collaboration with U.S. Land-Grant Universities*		
1.1.3 Urea Coating Research: Increase N Efficiency and Nutrient Delivery 1.2.1 and 1.4.1 Improving the DSSAT Cropping System Model for Soil Sustainability Processes	Global	University of Florida – ongoing
Effective Recycling of Nutrients and Evaluation of Biofertilizers Develop Methodologies for Evaluation of Smart Fertilizers and Evaluate Spectral Techniques for Rapid Soil, Plant and Fertilizer Analyses	Global	Auburn University – FY19
1.1.3.2 Effect of Coatings, Inhibitors, and Micronutrients on N Efficiency	Global	University of Central Florida – ongoing
Integrated Best Management Practices for Climate Resilience	Cambodia	Kansas State University – FY19
GHG Mitigation Role of Enhanced Efficiency Fertilizers and Practices Effective Recycling of Nutrients and Evaluation of Biofertilizers	USA	Tuskegee University – FY19
1.1.2.6 Mechanization of Subsurface Fertilizer Application	Global	Mississippi State University – FY19
1.2.1 Facilitate Site- and Crop-Specific Fertilizer Recommendations for Increased Economic and Environmental Benefits from Fertilizer Use.	Northern Ghana	Soybean Innovation Lab, University of Illinois – ongoing
1.2.3 Improved Nutrient Delivery from Multi-Nutrient Fertilizer Granules for Improved Yield, Quality, and Nutrition	Global	Tennessee State University – FY19
2.3.4 Economic and Environmental Implications of UDP Production and Use in Bangladesh – a Life Cycle Analysis Approach (with Workstream 1) 2.3.5 Economic Estimation of Fertilization Methods for Rice Paddy in Bangladesh – a Production Function Analysis (with Workstream 1)	Bangladesh	Rutgers University - ongoing
2.1.4 Partnership for Enabling Market Environments for Fertilizer in Africa (PEMEFA)	SSA	Michigan State University - ongoing
2.3.6 Strengthening MELS Capacity in IFDC – PhD Training for an IFDC M&E Field Staff Member (with Workstream 1)	Global	University of Georgia – ongoing

**Note: All university partnerships involve graduate students/post-doctoral fellows and faculty expertise.*

Annex 2. List of Publications and Presentations for FY18

Publications:

Adisa, I.O., V.L.R. Pullagurala, S. Rawat, J.A. Hernandez-Viezcas, C.O. Dimkpa, W.H. Elmer, J.C. White, J.R. Peralta-Videa, and J.L. Gardea-Torresdey 2018. "Role of Cerium Compounds in *Fusarium* Wilt Suppression and Growth Enhancement in Tomato (*Solanum lycopersicum*)," *Journal of Agricultural and Food Chemistry* 66:5959-5970.

Agyin-Birikorang, S., J.H. Winings, X. Yin, U. Singh, and J. Sanabria 2018. "Field Evaluation of Agronomic Effectiveness of Multi-Nutrient Fertilizer Briquettes for Upland Crop Production," *Nutrient Cycling in Agroecosystems* 110:395-406.

Aung, M., Z.Y. Myint, S. Thura, G. Hunter, U. Singh, and J. Sanabria 2018. "Comparison of Yield Response and Nutrient Use Efficiency Between Urea Deep Place Technology and Farmers' Practice of Surface Broadcasting Urea on Transplanted Lowland Rice in Myanmar," IN *Myanmar Soil Fertility and Fertilizer Management Conference Proceedings*, pp. 47-54, IFDC and DAR, Myanmar.

Bindraban, P.S., C.O. Dimkpa, S. Angle, and R. Rabbinge. 2018. "Unlocking the Multiple Public Good Services from Balanced Fertilizers," *Food Security* 10:273-285.

Dimkpa, C.O., D.T. Hellums, U. Singh, and P.S. Bindraban. 2018. "The Role of Mineral Fertilizers in Climate-Resilient Agriculture: Focus on Myanmar," IN *of the Myanmar Soil Fertility and Fertilizer Management Conference Proceedings*, pp. 221-241, IFDC and DAR, Myanmar.

Dimkpa, C.O. 2018. "Soil Properties Influence the Response of Terrestrial Plants to Metallic Nanoparticles Exposure," *Current Opinion in Environmental Science and Health* 6:1-8

Dimkpa, C.O., U. Singh, I.O. Adisa, P.S. Bindraban, W.H. Elmer, J.L. Gardea-Torresdey, and J.C. White. 2018. "Effects of Manganese Nanoparticle Exposure on Nutrient Acquisition in Wheat (*Triticum aestivum* L.)," *Agronomy* 8:158.

Dimkpa, C.O., U. Singh, P.S. Bindraban, W.H. Elmer, J.L. Gardea-Torresdey, and J.C. White. 2018. "Exposure to Weathered and Fresh Nanoparticle and Ionic Zn in Soil Promotes Grain Yield and Modulates Nutrient Acquisition in Wheat (*Triticum aestivum* L.)," *Journal of Agricultural and Food Chemistry 66:*9645-9656.

Elmer, W.H., R. DeLaTorre Roche, L. Pagano, S Majumdar., N. Zuverza-Mena, C. Dimkpa, J. Gardea-Torresdey, and J.C. White. 2018. "Effect of Metalloid and Metallic Oxide Nanoparticles on *Fusarium* Wilt of Watermelon," *Plant Disease* 102:1394-1401.

Fugice, J., C. Dimkpa, and L. Johnson. 2018. "Slow and Steady: The Effects of Different Coatings on Nitrogen Release in Soil," *Fertilizer Focus* Sept./Oct. pp. 12-13.

Fugice, J., S. Agyin-Birikorang, and C. Dimkpa 2018. *IFDC Evaluation of Portable Soil Testing Kits – Lessons Learned*, IFDC, Muscle Shoals, Alabama.

Gaihre, Y.K., U. Singh, S.M.M. Islam, A. Huda, M.R. Islam, and J.C. Biswas 2018. "Efficient Fertilizer and Water Management in Rice Cultivation for Food Security and Mitigating Greenhouse Gas Emissions," IN *Myanmar Soil Fertility and Fertilizer Management Conference Proceedings*, pp. 214-220, IFDC and DAR, Myanmar.

Hasegawa, T., T. Li, X. Yin, Y. Zhu, K. Boote, J. Baker, S. Bregaglio, S. Buis, R. Confalonieri, J. Fugice, T. Fumoto, D. Gaydon, S.N. Kumar, T. Lafarge, M. Marcaida III, Y. Masutomi, H. Nakagawa, P. Oriol, F. Ruget, U. Singh, L. Tang, F. Tao, H. Wakatsuki, D. Wallach, Y. Wang, L.T. Wilson, L. Yang, Y. Yang, H. Yoshida, Z. Zhang, and J. Zhu 2017. "Causes of Variation Among Rice Models in Yield Response to CO_2 Examined with Free-Air CO_2 Enrichment and Growth Chamber Experiments," *Scientific Reports* 7:14854. DOI: 10.1038/s41598-017-13582-y.

Islam, S.M.M., Y.K. Gaihre, J.C. Biswas, M.S. Jahan, U. Singh, S.K. Adhikary, M.A. Satter, and M.A. Salaque. 2018. Different N Rates and Methods of Application for Dry Season Rice Cultivation with Alternate Wetting and Drying Irrigation: Fate of N and Grain Yield. *Agricultural Water Management* 196:144-153.

Jayne, T.S., N. Mason, W. Burke, and J. Ariga 2018. "Taking Stock of Africa's Second-Generation Agricultural Input Subsidy Programs," *Food Policy* 75:1-14.

Leonardo, W., G.W.J. van de Ven, A. Kanellopoulos, and K.E. Giller. 2018. "Can Farming Provide a Way Out of Poverty for Smallholder Farmers in Central Mozambique?" *Agricultural Systems* 165:240-251.

Nagarajan, L., A. Naseem, and C.E. Pray 2018. "Contribution of Policy Change on Maize Varietal Development and Yields in Kenya," *Journal of Agribusiness in Developing and Emerging Economies* (accepted).

Nagarajan, L., and C.E. Pray 2018. "Millets: Finding a Way into Our Diet," interview published by SPANDAN India. http://www.spandan-india.org/cms/data/Article/A2018323112610_11.pdf.

Sanabria, J. 2018. "Fertilizer Quality Assessment in the Myanmar Dry Zone," IN *Myanmar Soil Fertility and Fertilizer Management Conference Proceedings*, pp. 242-254, IFDC and DAR, Myanmar.

Singh, U., M. Aung, and J. Fugice 2018. "Role of Yield Potential and Yield-Gap Analyses on Resource-Use Efficiency Improvement," IN *Myanmar Soil Fertility and Fertilizer Management Conference Proceedings*, pp. 22-37, IFDC and DAR, Myanmar.

Thigpen, J. 2018. "Ongoing Improvements and Applications of the CERES-Rice Model," *Agrilinks Newsletter*, February 28, https://www.agrilinks.org/post/ongoing-improvements-and-applications-ceres-rice-model.

Wendt, J. and L.W. Mbuthia. 2018. "A Conceptual Framework for Delivering Improved Fertilizers to Smallholder Farmers in Africa," IN *Myanmar Soil Fertility and Fertilizer Management Conference Proceedings*, pp 169-175, IFDC and DAR, Myanmar.

Presentations:

Agyin-Birikorang, S. 2018. Intensive Training Program on Soil Sampling and Analysis for Fertilizer Recommendation, March 26-29, Tamale, Ghana.

Agyin-Birikorang, S. 2018. International Training and Study Tour on Technology Advances in Agricultural Production, Water and Nutrient Management, August 20-September 1, Alabama, Arkansas, Tennessee, Missouri, Iowa and Washington, D.C.

Agyin-Birikorang, S. 2018. Northern Ghana Soils and Fertilizer Workshop: The State of Soil Fertility in Northern Ghana, Fertilizer Recommendations, Utilization and Farm-level Access; April 10-12, Mövenpick Ambassador Hotel, Accra, Ghana.

Agyin-Birikorang, S. 2018. "Feeding 9 Billion People on the Planet in the Era of Climate Change and Dwindling Agricultural Land Resources Begins with Effective Soil Fertility Management," presentation at the Soil Fertility Training, March 26-29, Tamale, Ghana.

Agyin-Birikorang, S. 2018. "Moving from Blanket Fertilizer Recommendations to Site- and Crop-Specific Fertilizer Recommendation: A Case Study of Maize and Soybean Production in Northern Ghana," presentation at the Soil Fertility Training, March 26-29, Tamale, Ghana.

Agyin-Birikorang, S. 2018. "Soil Fertility Mapping to Facilitate Site and Crop-Specific Fertilizer Recommendation for Northern Ghana," presentation at the 2018 Northern Ghana Soils and Fertilizer Workshop, April 10-12, Accra, Ghana.

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," presentation at the 2017 ASA, CSSA and SSSA International Annual Meeting, October 22-25, Tampa, Florida.

Ariga, J.M. 2017. "Fertilizer Value Chains in Developing Countries: A Summary of Key Economic, Policy, and Equity Issues," presentation at a seminar sponsored by the Serve-Learn-Sustain program, October 19, Georgia Tech University, Georgia, https://serve-learn-sustain.gatech.edu/our-mission-and-vision.

Ariga, J.M. 2018. "Fertilizer Use and Value Chains in SSA," presentation at Agricultural Policy and Regulation in Sub-Saharan Africa: Lessons for Increasing Investment seminar, April 5, Michigan State University, East Lansing, Michigan.

Ariga, J.M. 2018. "Introduction: Understanding Subsidies," presentation at the IFDC International Workshop on Developing Private Sector Agro-Input Markets – Lessons Learned and Emerging Perspectives on Subsidy Programs, February 19-23, Jinja, Uganda.

Ariga, J.M. 2018. "Policy Reforms and Fertilizer Market Development: The Kenyan Experience," presentation at Agricultural Policy and Regulation in Sub-Saharan Africa: Lessons for Increasing Investment seminar, April 5, Michigan State University, East Lansing, Michigan.

Ariga, J.M. 2018. "The Economic Rationale for Fertilizer Quality Regulations," presentation on behalf of the Partnership for Enabling Market Environments for Fertilizer in Africa (PEMEFA) at the IFDC International Workshop on Developing Private Sector Agro-Input Markets – Lessons Learned and Emerging Perspectives on Subsidy Programs, February 19-23, Jinja, Uganda.

Ariga, J.M., N. Mason, and K. Kuhlmann. 2018. "Preliminary Findings from the PEMEFA Synthesis Report," presentation on behalf of PEMEFA at the IFDC International Workshop on Developing Private Sector Agro-Input Markets – Lessons Learned and Emerging Perspectives on Subsidy Programs, February 19-23, Jinja, Uganda.

Dimkpa, C. 2018. "Application of Nanotechnology in the Fertilizer Industry," presentation at the IFDC International Training and Study Tour on Advances in Agricultural Production, Water and Nutrient Management, August 20-September 1, Muscle Shoals, Alabama.

Fuentes P. 2018. “Economics of Fertilizer Production, Markets, Marketing, Policies and Subsidies,” presentations at the Mohamed VI Polytechnic University (M6PU) Professional MSc in Fertilizer Technologies, April 21-27, Morocco.

Jahan, I. 2018. “Fertilizer Subsidy Policy of Bangladesh and Its Use,” presented at the Argus NPK, Water Soluble and Micronutrient Fertilizer Workshop in India 2018, New Delhi, India.

Nagarajan, L. 2017. On behalf of Rutgers University and IFDC, PowerPoint presentation at USAID BFS Agriculture Core Course: Policy, Governance, and Standards – Agriculture Input Policy training conducted on December 13, 2017, in Washington, D.C.

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