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

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

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Acronyms and Abbreviations

AAP	Alliance for African Partnership
AAPI	Accelerating Agriculture Productivity Improvement
AAS	Atomic Absorption Spectroscopy
AFAP	African Fertilizer and Agribusiness Partnership
AFO	AfricaFertilizer.org
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
Al	Aluminum
ANOVA	Analysis of Variance
APEX	Agricultural Policy/Environmental eXtender
ASA	American Society of Agronomy
AVPI	Accelerating Vegetable Productivity Improvement
AWD	Alternate Wetting and Drying
B	Boron
BAU	Bangladesh Agricultural University
BDT	Bangladeshi Taka
BFS	Bureau for Food Security
BPCU	Bio-Based Polymer-Coated Urea
BRRI	Bangladesh Rice Research Institute
C	Carbon
Ca	Calcium
CA	Conservation Agriculture
CASC	Conservation Agriculture Service Center
CE SAIN	Center of Excellence on Sustainable Agricultural Intensification and Nutrition
CH_4	Methane
CIMMYT	International Maize and Wheat Improvement Center
CIRAD	Centre de Coopération Internationale en Recherche Agronomique pour le Développement
CN	Concept Note
CO_2	Carbon Dioxide
CRF	Controlled-Release Fertilizer
CSM	Cropping System Model
CSO	Community Service Organizations
CSSA	Crop Science Society of America
CSW	Continuous Standing Water
CT	Conventional Tillage
Cu	Copper
DALRM	Department of Agricultural Land Resources Management
DAP	Diammonium Phosphate
DCD	dicycandiamide
DI	De-Ionized
DICTA	Directorate of Agricultural Science and Technologies
DLS	Dynamic Light Scattering

DSSAT	Decision Support System for Agrotechnology Transfer
EAC	East African Community
ECOWAS	Economic Community of West African States
EDTA	Ethylenediamine Tetraacetic Acid
EIAR	Ethiopian Institute of Agricultural Research
EnGRAIS	Enhancing Growth through Regional Agricultural Input Systems
ES	Elemental Sulfur
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FAR	Food security through climate Adaptation and Resilience in Mozambique
FDP	Fertilizer Deep Placement
Fe	Iron
FMC	Field Moisture Capacity
FOM	Fresh Organic Matter
FP	Farmers' Practice
FQA	Fertilizer Quality Assessment
FTF	Feed the Future
FTIR	Fourier-Transform Infrared Spectroscopy
FY	Fiscal Year
GDA	General Directorate of Agriculture
GFSS-HCP	Global Food Security Strategy-Honduras Country Plan
GHG	Greenhouse Gas
GLMM	Generalized Linear Mixed Model
HOI	Honduras Outreach Inc.
IADB	Inter-American Development Bank
ICRAF	World Agroforestry Centre
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IER	*Institut d'Economie Rurale*
IFAD	International Fund for Agricultural Development
IFDC	International Fertilizer Development Center
IFEW	International Fertilizer Experts Working
IHCAFE	*Instituto Hondureño del Cafe* (Honduras Coffee Institute)
INERA	*Institut de l'Environnement et de Recherche Agricole*
ISFM	Integrated Soil Fertility Management
ISO	International Organization for Standardization
ISPM	Instituto Superior Politecnico de Manica
ISRA	Institut Senegalais de Recherche Agricole
ISRIC	World Soil Information
K	Potassium
KALRO	Kenya Agricultural and Livestock Research Organization
KeFERT	Kenya Fertilizer Roundtable
LCC	Leaf Color Chart
LIV	Local Improved Variety
M&E	Monitoring and Evaluation
MAP	Monoammonium Phosphate
MCC	Millennium Challenge Corporation
MELS	Monitoring, Evaluation, Learning, and Sharing

Mg	Magnesium
MIR	Marketing Inputs Regionally (IFDC project)
Mn	Manganese
MoALF&I	Ministry of Agriculture, Livestock, Fisheries, and Irrigation
MSU	Michigan State University
N	Nitrogen
N_2O	Nitrous Oxide
NAC	n-acetyl cysteine
NARC	Nepal Agricultural Research Council
NARES	National Agricultural Research Extension Systems
NGO	Non-Governmental Organization
NIR	Near Infrared
NML	New Markets Lab
NO	Nitric Oxide
NSAF	Feed the Future Nepal Seed and Fertilizer Project
NSF	National Science Foundation
NUE	Nitrogen Use Efficiency
OM	Organic Matter
OS	Optical Sensor
P	Potassium
PEMEFA	Partnership for Enabling Market Environments for Fertilizer in Africa
POXC	permanganate-oxidizable C
PR	Phosphate Rock
PUDP	Prilled Urea Deep Placement
PVP	polyvinylpyrrolidone
RADD	Rwanda Agro-Dealer Development
RAE	Relative Agronomic Effectiveness
RCBD	Randomized Complete Block Design
ReNAPRI	Regional Network of Agricultural Policy Research Institute
RUA	Royal University of Agriculture
S	Sulfur
SAL	Sodium Salicylate
SBPCU	Self-Assembly Modified Bio-Based Polymer-Coated Urea
SEM	Scanning Electron Microscopy
SEMEAR	Feed the Future Mozambique Improved Seeds for Better Agriculture
SFT	Soil Fertility Technology
SIIL	Sustainable Intensification Innovation Lab
SMaRT	Soil testing, Mapping, Recommendations development, and Technology transfer
SOC	Soil Organic Carbon
SOILS	Sustainable Opportunities to Improve Livelihoods with Soils
SOM	Soil Organic Matter
SRI	System of Rice Intensification
SSA	Sub-Saharan Africa
SSBPCU	Self-Assembly and Self-Healing Modified Bio-Based Polymer-Coated Urea
SSSA	Soil Science Society of America
STV	Stress-Tolerant Variety
SWAT	Soil and Water Assessment Tool

SWOT	Strengths, Weaknesses, Opportunities, and Threats
TAFAI-Ke	The African Fertilizer Access Index for Kenya
TOR	Terms of Reference
TSP	Triple Superphosphate
UCF	University of Central Florida
UDP	Urea Deep Placement
UF	University of Florida
UGA	University of Georgia
USAID	U.S. Agency for International Development
USAID-H	USAID-Honduras
USD	U.S. dollar
USDA-ARS	U.S. Department of Agriculture Agricultural Research Service
WAFP	West Africa Fertilizer Program
WFTO	World Fertilizer Trends and Outlook
WSP	Water-Soluble Phosphorus
XRD	X-Ray Diffraction
Zn	Zinc
ZnO	Zinc Oxide
ZOI	Zone of Influence

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's (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 FY2018. 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 evaluated, refined, and adapted for improving nitrogen use efficiency within the context of best management practice. This included:
  - Development and evaluation of enhanced efficiency N fertilizers and delivery of secondary and micronutrients.
  - Overcoming fertilizer deep placement (FDP) constraints for technology dissemination.
  - Trials in stress-prone areas of Ghana, Bangladesh, Myanmar, and Nepal toward promoting climate resilience and mitigating greenhouse gas (GHG) emissions.
- Activated phosphate rock (PR) to improve use efficiency and accessibility of phosphatic fertilizers to farmers in SSA. The following sub-activities are in progress:
  - Completion and analysis of ongoing greenhouse trials and field trials in Ghana and Kenya.
  - Activated PR demonstrations on soils with varying pH in partnership with PR producers.
- Balanced crop nutrition research to improve fertilizer recommendations that increase crop yields, protect soil health, and improve farmer profitability. This included:
  - Efficient incorporation of micronutrients into NPK fertilizers and evaluation of multi-nutrient fertilizers through laboratory, greenhouse, and field trials.
  - Facilitation of site- and crop-specific fertilizer recommendations through nutrient omission trials in Ghana and Senegal, maize nutrient deficiency mapping and development of balanced fertilizer for rice production in Mozambique, and expanding spectral analysis techniques to fertilizer analysis.

- Research toward developing climate-smart cropping systems through integrated soil fertility management (ISFM) and conservation agriculture (CA). This included
    - Initiation of research on nutrient recycling using black soldier fly larvae.
    - Assessment of changes in soil organic carbon and nitrogen stocks under conservation agriculture production systems in Cambodia.
    - Evaluation of the role of legumes in rice-based farming systems in Mozambique.
    - Evaluation of CA practices in combination with the use of activated phosphate rock in northern Ghana.
- Efforts to improve the existing soil dynamics model in the Decision Support System for Agrotechnology Transfer (DSSAT) Cropping System Model using soil and agronomic data generated by IFDC over past years (crosscutting activity).

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:
    - Organization of the Kenya Fertilizer Roundtable meeting.
    - Contribution to USAID BFS Agriculture Core Course on agricultural input policies.
    - Contribution to a joint World Fertilizer Trends and Outlook (WFTO) report issued by the Food and Agriculture Organization of the United Nations (FAO).
    - Participation as a consortium member of the Partnership for Enabling Market Environments for Fertilizer in Africa (PEMEFA).
    - Technical briefs on fertilizer markets and policy reforms in Bangladesh and Ghana.
- 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:
    - An impact assessment study on the Kenya fertilizer subsidy program.
    - Initial activities toward 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:
    - Documentation of fertilizer quality assessments conducted in Benin, Burkina Faso, and Liberia to inform fertilizer quality policy development.

- Journal manuscript submitted on the achievements and lessons learned from fertilizer quality assessments across sub-Saharan Africa (SSA) and in Myanmar.
- Discussion paper on changes in the cost of supplying fertilizer in West Africa.
- Initiation of a draft report on The African Fertilizer Access Index for Kenya (TAFAI-Ke).
- 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.
- Ongoing enhancement of monitoring and evaluation (M&E) capacities of IFDC soil fertility research projects.
- Initiation of a research paper documenting the benefits of expanding fertilizer deep placement among women farmers in Bangladesh.
- Additional steps toward collaborative activities to improve fertilizer use, access, and market development in Honduras and Guatemala.
- Initiation of research on factors that constrain fertilizer supply and demand in West Africa.

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

Workstream 3 covers activities implemented under the recently launched SOILS Consortium, a collaboration among IFDC, Feed the Future Innovation Lab for Collaborative Research on Sustainable Intensification (SIIL) at Kansas State University, and USAID. The primary goal of the SOILS Consortium is to improve soil fertility in the most vulnerable regions of sub-Saharan Africa. The following activities were accomplished during the reporting period:

- Establishment of SOILS organizational structure and planning.
- Core Partner meetings.
- Launch of SOILS Consortium.
- Development of Core Partner concept note.

Cross-Cutting Issues Including University Partnerships and Knowledge Management

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

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

With the primary emphasis on translational research, one of the main objectives of Workstream 1 is to bridge the gap between scientific research and effective technology dissemination to the smallholder farmers in FTF countries. The technology dissemination process depends on conducting research on well-characterized sites with a collection of site-specific data on soils, daily weather, socio-economics, and management. The proposed activities within Workstream 1 are expected to result in (a) increased agricultural productivity; (b) improved soil fertility, soil health, and plant nutrition; (c) increased climatic resilience through increased abiotic and biotic stress-tolerance; (d) reduced nutrient losses; (e) greenhouse gas (GHG) mitigation; and (f) overall improved resource use efficiency (nutrients, water, land, and labor). The overall goal is to close the yield gap and produce more with less.

During the 2019 workplan, Workstream 1 activities were categorized as follows: (a) technologies developed, refined, and adapted to improve nitrogen use efficiency; (b) activated phosphate rock (PR) evaluation and validation to improve PR reactivity and P efficiency; (c) balanced crop nutrition; (d) sustainable intensification practices; and (e) improving the cropping system model for soil sustainability processes. The last of the ongoing activities from the FY2018 workplan are also reported in one of the above categories. All reported activities are being conducted in partnership with national agricultural research extension systems (NARES) in FTF countries or areas targeted for FTF countries. The research activities carried out at IFDC headquarters or university partners support and complement field activities. Below is a summary of activities for this reporting period.

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

Urea is the most widely used fertilizer in the world; however, its use efficiency is generally low at 30-45%. The major focus of this activity is improving N use efficiency by minimizing N losses while increasing productivity. This can be accomplished by developing/using alternatives to urea, modified and coated urea products, synthetic and natural coatings, additives/amendments (organic, biofertilizers, bio-stimulants), nano-materials/nano-micronutrients (PR, elemental sulfur [ES], zinc [Zn], boron [B]), and implementing innovative practices such as mechanized fertilizer deep placement (FDP). With N application in Africa already low, increased efficiency of applied N is key to achieving greater productivity and profitability and minimizing environmental impacts. The research trials reported here were conducted under on-farm, greenhouse, and laboratory conditions, targeting: (a) development and/or evaluation of more efficient N fertilizers; (b) resolving technology dissemination constraints to FDP; and (c) promoting climate resilience and minimizing GHG emissions from N fertilizers. The research trials reported here were conducted under on-farm, greenhouse, and laboratory conditions to: (a) determine the effects of secondary and micronutrients, coatings, and controlled-release fertilizers on nitrogen use efficiency; (b) quantify the effect of subsurface fertilizer application on improved nutrient use efficiency; and (c) evaluate whether fertilizer best management practices can improve stress tolerance.

1.1.1 Development and Evaluation of Enhanced Efficiency N Fertilizers

Developing smart fertilizer products that are climate-resilient, require one-time application, have high N use efficiency, and reduce reactive N and P additions to the environment is one of the major focuses of this sub-activity. Promising enhanced efficiency products available in the market are being evaluated under field conditions in sub-Saharan Africa and South Asia. These enhanced efficiency fertilizers are ideally suited for farmers in the focus countries, since they face greater climatic vulnerability than their developed country-counterparts.

1.1.1.1 Development of Modified Urea Products

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

Developing Hydrophobic and Controlled-Release Fertilizer

The use of controlled-release fertilizers (CRFs) is an effective approach to improve nutrient use efficiency and to reduce environmental pollutants. Current CRFs are usually coated with petroleum-based synthetic materials, such as polyolefins, acrylic resin, and polysulfones. The synthetic materials are usually difficult to produce on a large-scale and involve either toxic or complicated production processes. Moreover, the raw materials are derived from non-renewable resources and are often nondegradable, resulting in severe environmental pollution, depletion of fossil fuels, and the reduction of energy security. However, most biomaterials, such as cellulose and starch, are hydrophilic and easy to hydrolyze. To meet these challenges, we are evaluating renewable materials (soybean oil, castor oil, alginate) as effective coatings for CRFs, in partnership with the University of Florida (UF). We are applying nanotechnology and chemical grafting techniques for the preparation of hydrophobic and self-assembling and self-healing bio-based nanocomposite coating materials to encapsulate granular urea. Three biopolymers will be prepared, including bio-based polymer coated urea (BPCU), self-assembly modified BPCU (SBPCU), and self-assembly and self-healing modified BPCU (SSBPCU). The newly-synthesized CRFs are expected to achieve slow and controlled nutrient release using hydrophobic and environmentally-friendly coating materials. Currently, UF is in the process of producing the first trial of the biopolymer coated products to be tested. The initial characterization test will be done using SEM, XRD, and FTIR to understand the coating products in terms of surface morphologies, roughness, elemental compositions, and distribution. Along with the characterization, nutrient release measurements will be conducted using an ISO 18644 method and an accelerated method (standard method in China) to plot the percent N release as a function of time.

Improving N Use Efficiency and Delivery of Secondary and Micronutrients

IFDC's in-house research focused on coating with a multi-nutrient polyhalite material and micronutrients using various binders, additives, and methodologies and on improving the nutrient use efficiency of the urea fertilizer. Samples from the coating trials were included in a short-term incubation test to evaluate the release properties of the coated urea (Table 1). Sixteen coated products were tested in conjunction with two check products and two commercially available slow-release products. The products were incubated and analyzed for three time periods: 1 day, 7 days, and 21 days. A segmented flow system was used for each incubation cup to analyze for urea-N, NH_4-N, and NO_3-N based on KCl extraction, in order to quantify the rates of N transformation of the products. Each cup contained 10 milligrams of N, based on a chemical analysis of each product, and was pre-incubated and maintained at a 75% field moisture capacity in three replicates.

A few of the products showed improvement in N release efficiency. Compared to the uncoated urea, polyhalite-coated urea (Treatment 17) contained unconverted urea-N by Day 7 (Figure 1) and had more ammoniacal-N (Figure 2) and less nitrate-N (Figure 3) by Day 21, thereby indicating urease and/or nitrification inhibition. Such characteristics could improve N use efficiency by reducing volatilization loss, nitrous oxide emission, and nitrate-N leaching loss. A similar inhibition response was obtained with Treatment 16 (boric acid, copper sulfate, and polyhalite-coated urea). These treatments, along with urea formaldehyde resin plus polyhalite-coated urea (Treatment 18) and neem oil plus polyhalite-coated urea (Treatment 19), performed similarly to Agrotain (Treatment 4) and Agrotain plus polyhalite-urea (Treatment 20). The lower nitrate-N content by Day 21 confirmed a slower ammoniacal-N conversion of these products. The polyhalite content of these products was approximately 10%, except for Treatment 17, which had a polyhalite content of 20%.

Table 1. Treatment List of the Coated Products for Incubation Studies

Treatment	Product
1	Check
2	Urea
3	ESN
4	Agrotain
5	Rapeseed Oil, Polyhalite / Urea
6	Cornstarch, Polyhalite / Urea
7	HD-50R, ZnO, $CuSO_4 \cdot 5H_2O$, Polyhalite / Urea
8	HD-50R, UF, Polyhalite / Urea
9	Vegetable Oil, Wax, Polyhalite / Urea
10	Phosphate Rock, Polyhalite / Urea
11	Phosphate Rock, Wax, Polyhalite / Urea
12	HD-50R, Wax, Polyhalite / Urea
13	Phosphate Rock, ZnO, $CuSO_4 \cdot 5H_2O$, Wax, Polyhalite / Urea
14	Sugar, Polyhalite / Urea
15	H_3BO_3, $CuSO_4 \cdot 5H_2O$, Polyhalite / Urea
16	H_3BO_3, $CuSO_4 \cdot 5H_2O$, Polyhalite / Urea
17	Polyhalite / Urea
18	UF Resin, Polyhalite / Urea
19	Neem Oil, Polyhalite / Urea
20	Agrotain, Polyhalite / Urea

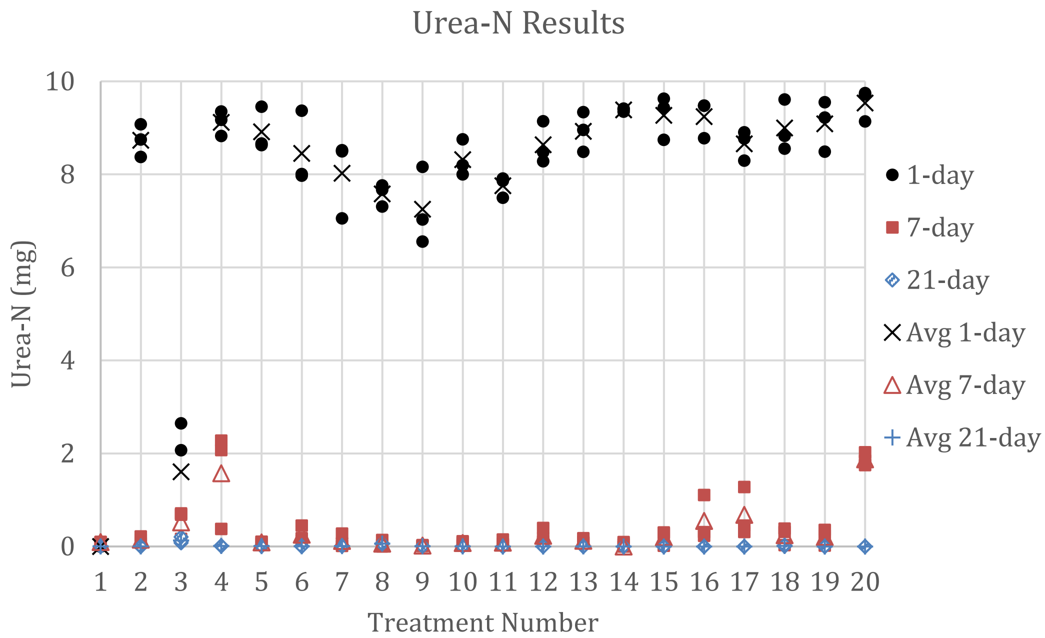


Figure 1. Urea-N Release from Each Treatment for Three Incubation Periods

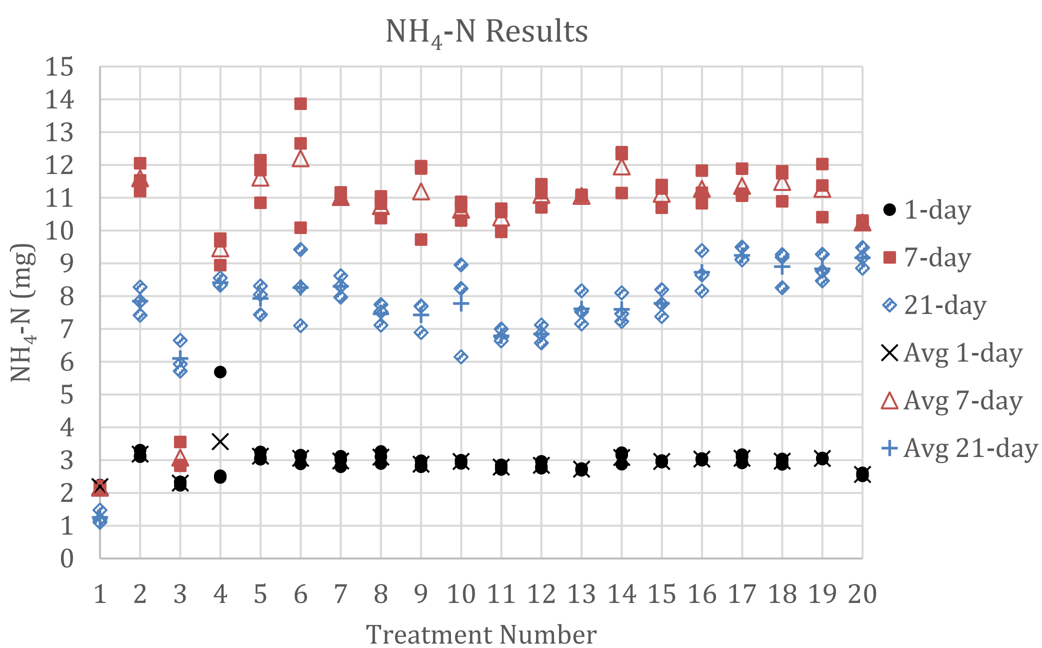


Figure 2. NH_4-N Release from Each Treatment for Three Incubation Periods

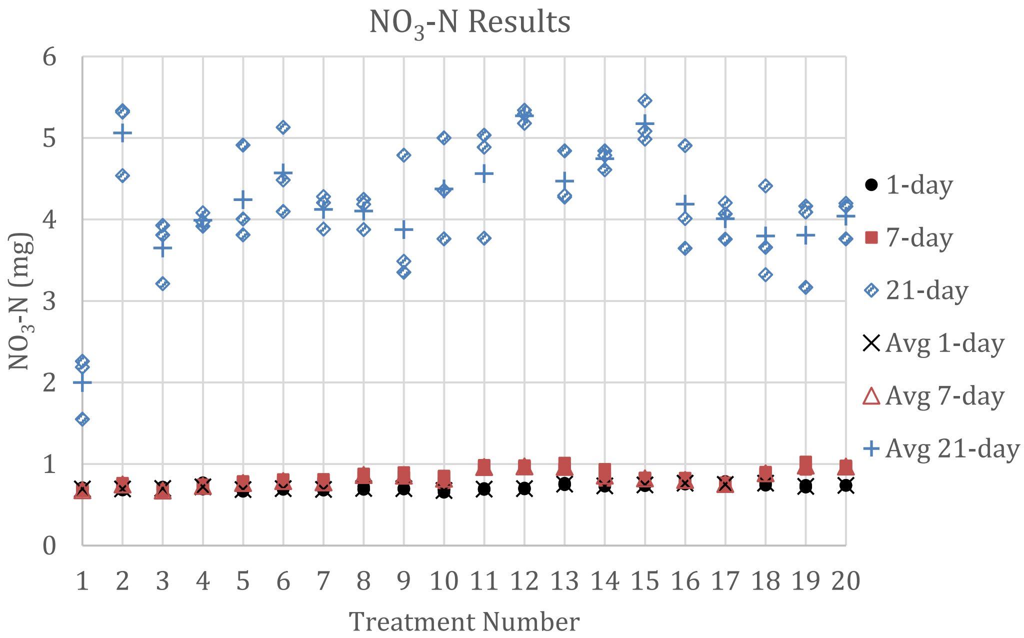


Figure 3. NO_3-N Release from Each Treatment for Three Incubation Periods

Improving Nano-Zinc Coated Urea

The partnership between IFDC and UCF involves the development of nano-zinc coated urea fertilizer for efficient delivery of zinc micronutrients and improved N use efficiency. Urea is coated with ZnO nanoparticles synthesized with different capping agents to improve Zn release and uptake (Figure 4). A combination of urea, sodium salicylate (SAL), and n-acetyl cysteine (NAC) was used as the capping agent to improve Zn solubility and plant uptake.

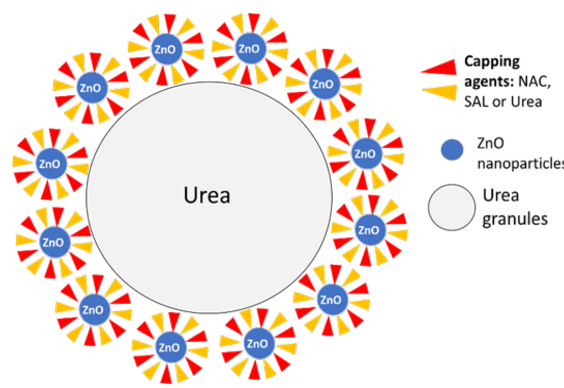


Figure 4. Schematic of Urea Coated with ZnO Nanoparticles

NAC-SAL ZnO, NAC-Urea ZnO, and Urea-SAL ZnO nanoparticles were synthesized using a sol-gel method at room temperature, following a published protocol [PloS One 13 (10), 2018] with further modification to accommodate two surface capping agents. Nanoparticles were characterized by Atomic Absorption Spectroscopy (AAS), Infrared Spectroscopy (FTIR), Zeta potential, and Dynamic Light Scattering (DLS). The results are presented in Table 2. As expected, particles coated with NAC have a negative surface charge. Particles' surface charge may affect their uptake by plant roots, depending on the charge on the root surface. Particle charge is also important to the interaction with plant cells.

Table 2. **Particles Characterization by DLS, Zeta Potential and AAS**

Sample	Average Diameter (nm)	Zeta Potential (mV)	Zinc Content (%, w/w)
NAC-SAL ZnO	116	-17 ± 6.71	18
NAC-Urea ZnO	123	-16.4 ± 8.35	19
Urea-SAL ZnO	135	+27.6 ± 3.47	22

Because NAC and SAL have a higher molecular weight than urea, 163.2 g/mol, 160.1 g/mol, and 60.0 g/mol, respectively, NAC-SAL ZnO has a lower percentage of Zn content per gram of nanoparticle.

The FTIR spectra of the samples are presented in Figure 5. The characteristic band of Zn-O, around 1386 cm^{-1}, can be found in all the spectra. The peaks for the amine group (N-H) of urea can be found at around 3450 cm^{-1} and 1625 cm^{-1}. The primary amide group of urea and secondary amide group of SAL have peaks at 1585 cm^{-1} and 1535 cm^{-1}, respectively.

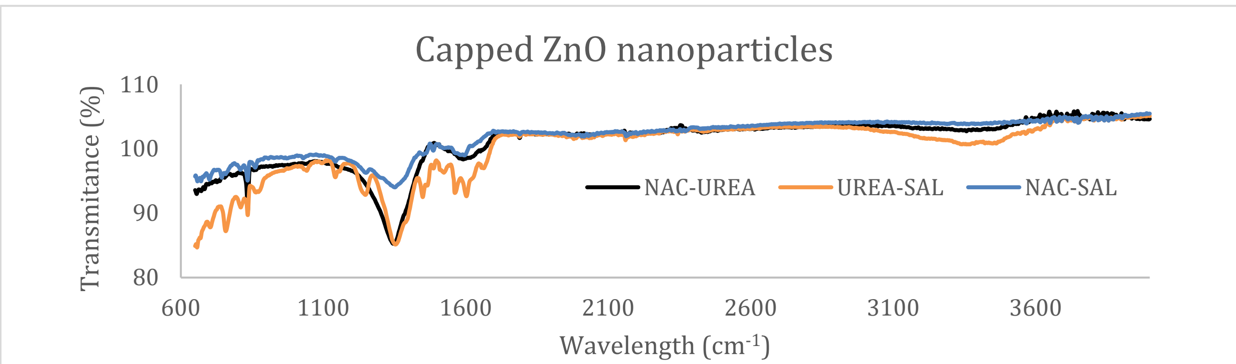


Figure 5. ***FTIR Spectra of NAC-Urea (black), Urea-SAL (green), and NAC-SAL (blue)***

Figure 6. ***Urea Coated with Urea-SAL ZnO (green), NAC-SAL ZnO (blue), NAC-Urea ZnO (red), Bulk ZnO (yellow), and Control Mix (white)***

Urea granules were coated with double capped ZnO nanoparticles using a mix of mineral oil, ethanol, and polyvinylpyrrolidone (PVP) binder. Food coloring was added to differentiate samples and to observe coating uniformity (Figure 6).

The release of Zn after 24 hours of dialysis against deionized (DI) water is shown in Figure 7. The same amount of coated fertilizer (0.5 g) was placed inside each dialysis bag (3.5 kDa cutoff), which was then placed inside a 50 mL conic tube containing 30 mL of DI water. The tubes were agitated for 24 hours.

Samples (dialysate and bag) were digested before AAS measurements. The percentage of zinc released after 24 hours was calculated by the mass of zinc released (dialysate) divided by the total zinc mass (dialysate + remaining zinc in the dialysis bag). As expected, the percentage of zinc released from the urea coated with nanoparticles was at least two times greater than the percentage of zinc released by the fertilizer coated with bulk ZnO.

The release of zinc from urea fertilizer coated with double capped nanoparticles is being investigated using sand columns. Moreover, tomato plants are being grown in organic soil with the addition of 3% (w/w) urea fertilizer coated with ZnO nanoparticles. Qualitative and quantitative evaluations of the plants will be done by measuring physiological development and yield. Bulk ZnO and urea only are being used as control. The role of particle charge on soil interactions will be evaluated in a sand column experiment.

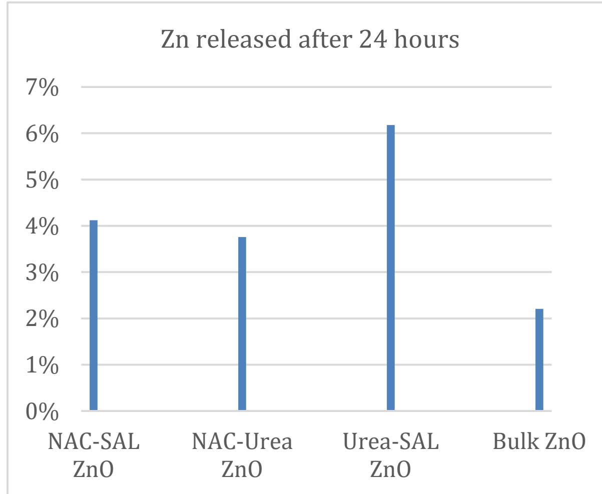


Figure 7. Percentage of Zinc Released after 24 Hours Dialysis Against DI Water

1.1.1.2 Field Evaluation of Modified Urea-S Products

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

Urea-Sulfur Evaluation in Bangladesh and Nepal

Two field trials were established with sulfur-enriched urea fertilizers in sulfur-deficient areas of Bangladesh in November 2018. The trials were established to determine the optimum rate and efficient source of urea-sulfur fertilizers. Ten treatment combinations from different sulfur sources (Thiogro ES 13%, Thiogro ESS 13%, Thiogro ES 75%, and Gypsum) and different sulfur rates (0, 25, 50, and 75 kg S/ha) are being evaluated in maize. These trials are in progress and will be reported in the next semi-annual report.

Figure 8. Evaluation of Urea-Sulfur Fertilizers in North-West Part of Bangladesh (Sulfur-Deficient Site)

In Nepal, these sulfur-enriched urea fertilizers (Thiogro ES 13% and Thiogro ESS 13%) are being evaluated, along with the conventional fertilizer management practice, in 35 tomato, 56 cauliflower, and 48 wheat trials. This evaluation is in partnership with CIMMYT Nepal under the Feed the Future Nepal Seed and Fertilizer (NSAF) project.

Urea-Sulfur Evaluation: Ghana

Field evaluation of the effectiveness of sulfur-enhanced urea fertilizer for upland crop production was carried out at 12 sites in the three northern regions of Ghana (Northern, Upper East, and Upper West) within the ZOI of the USAID-FTF interventions (Figure 9). Six treatments with four replications (blocks) (24 plots) were laid out in a randomized complete block design (RCBD) at each site. The treatments included: (i) Thiogro ES (13% S) applied at 25 kg S/ha; (ii) Thiogro ES (13% S) applied at recommended S rate (50 kg/ha); (iii) Thiogro ES (13% S) applied 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.

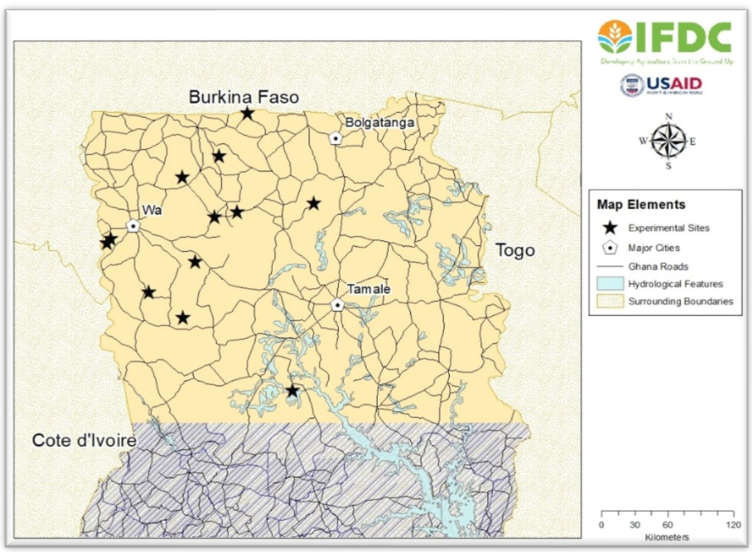


Figure 9. Map of Northern Ghana showing the Locations (black dots) of the Experimental Sites

Although maize straw and grain yields differed among the 12 experimental sites, the pattern of treatment effects across all sites was consistently similar.

The mean values of all measured parameters across all 12 locations are presented in Table 3. However, grain yields specific to individual sites are presented in Figure 10. The low straw yield for the S-check treatment (No S) is consistent with the "very low" S concentration designation of the soil at the sites, suggesting that S application was required for optimum plant growth and productivity. Sulfur fertilization significantly increased straw yields, regardless of the S fertilizer source. Applying the Thiogro ES fertilizer at 25 kg S/ha was as effective as applying ammonium sulfate at a recommended rate of 50 kg S/ha; there were no significant differences between the straw yield emanating from these two treatments (Table 3). Laboratory incubation and leaching studies show that S is released slowly from the Thiogro ES fertilizer, with less S and N losses associated with the product than with ammonium sulfate fertilizer. This suggests that S and N released from the Thiogro ES product could match plant demand at various physiological growth stages, leading to efficient utilization of the nutrients and minimal losses.

Consistent with straw yields, grain yields also increased significantly with S application relative to the S-check treatment (Table 3, Figure 10). Applying the Thiogro ES at 25 kg S/ha, 50 kg S/ha, and 75 kg S/ha increased grain yield from an average of 4.9 mt/ha (No S) to 6.8 mt/ha, 7.5 mt/ha, and 7.8 mt/ha, respectively (Table 3). Similar to the straw yields, there were no significant differences in grain yield from the Thiogro ES applied at 25 kg/ha and the ammonium sulfate fertilizer applied at the recommended rate of 50 kg S/ha (Table 3, Figure 10).

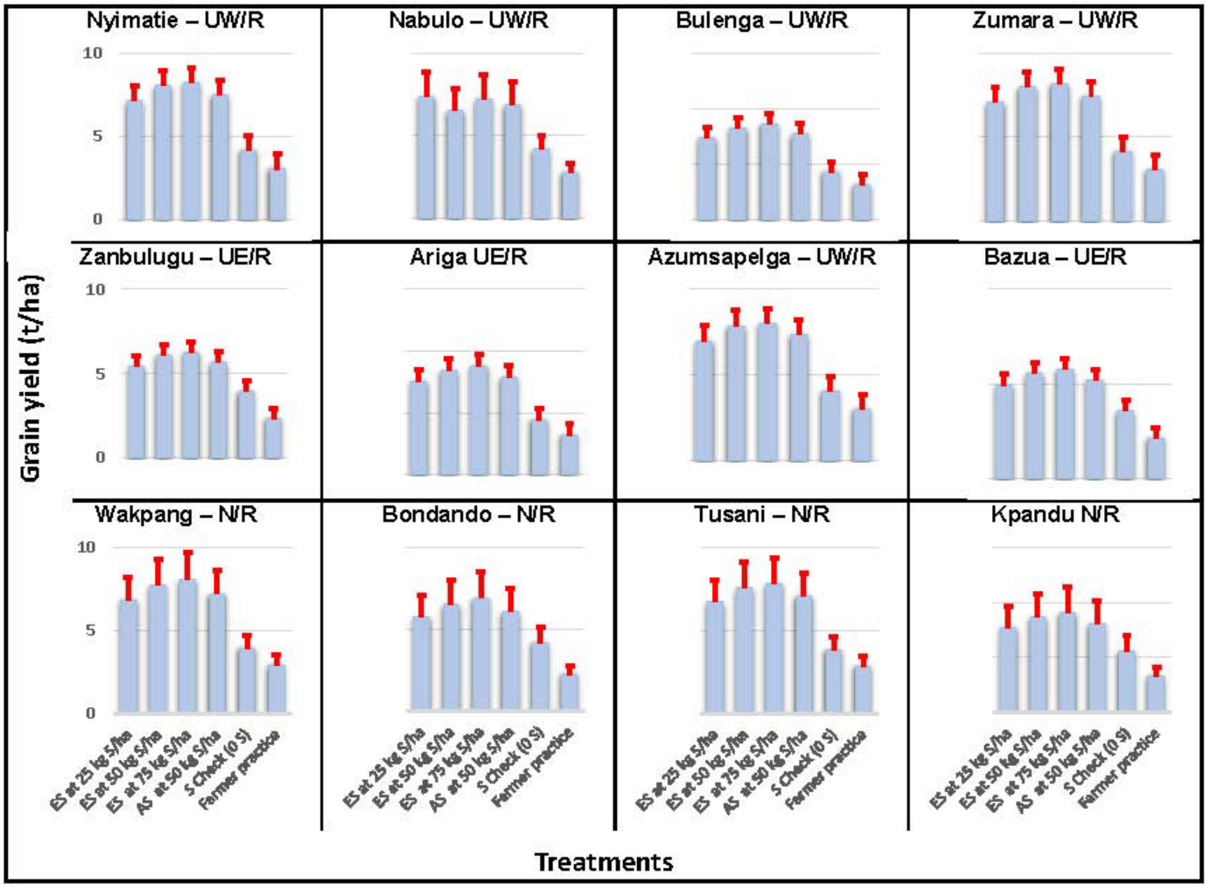
As expected, S application resulted in significantly greater S concentration in the grain, relative to S-check (Table 3). This confirms the low S status of the experimental sites. Although equal quantities of N were applied to all plots, including the S-check treatment (except the farmer practice treatment), grains of treatments that received S had increased N concentrations (Table 3) due to N-S synergism.

Table 3. Mean Values[a] of the Measured Parameters (Yields and Nutrient Uptake) as Influenced by the Various Treatments

Treatment Description	Straw Yield (mt/ha)	Grain Yield	Grain S Conc. (mg/kg)	Grain S Uptake (kg/ha)	Grain N Conc. (%)	Grain N Uptake (kg/ha)	Straw S Uptake	Straw N Uptake	Total S Uptake	Total N Uptake
Thiogro ES at 25 kg S/ha	11.5a[b]	6.75b	859a	5.80b	0.82a	55.4b	2.06b	11.8b	7.86b	67.2b
Thiogro ES at 50 kg S/ha	12.0a	7.51ab	904a	6.79ab	0.85a	63.8a	2.22b	14.2a	9.01ab	78.0a
Thiogro ES at 75 kg S/ha	12.4a	7.82a	1000a	7.82a	0.82a	64.1a	2.72a	15.9a	10.5a	80.0a
Amm. sulfate at 50 kg S/ha	11.8a	7.06ab	946a	6.68ab	0.84a	59.3ab	2.15b	13.8ab	8.83ab	73.1ab
S Check (0 S)	7.76b	4.85c	155b	0.75c	0.73ab	35.4c	0.58c	8.82c	1.89c	44.2c
Farmer practice	4.75c	2.85d	169b	0.48c	0.66b	18.8d	0.15d	4.79d	0.64d	23.6d
Standard Error	1.87	0.94	148	1.34	0.14	6.48	0.31	2.18	1.96	8.28

a. Numbers are mean values of 48 (12 locations x 4 reps) replicates ± standard error.

b. Means in the same column followed by the same letter are not significantly different (P≥.05), according to the Fisher's protected LSD.



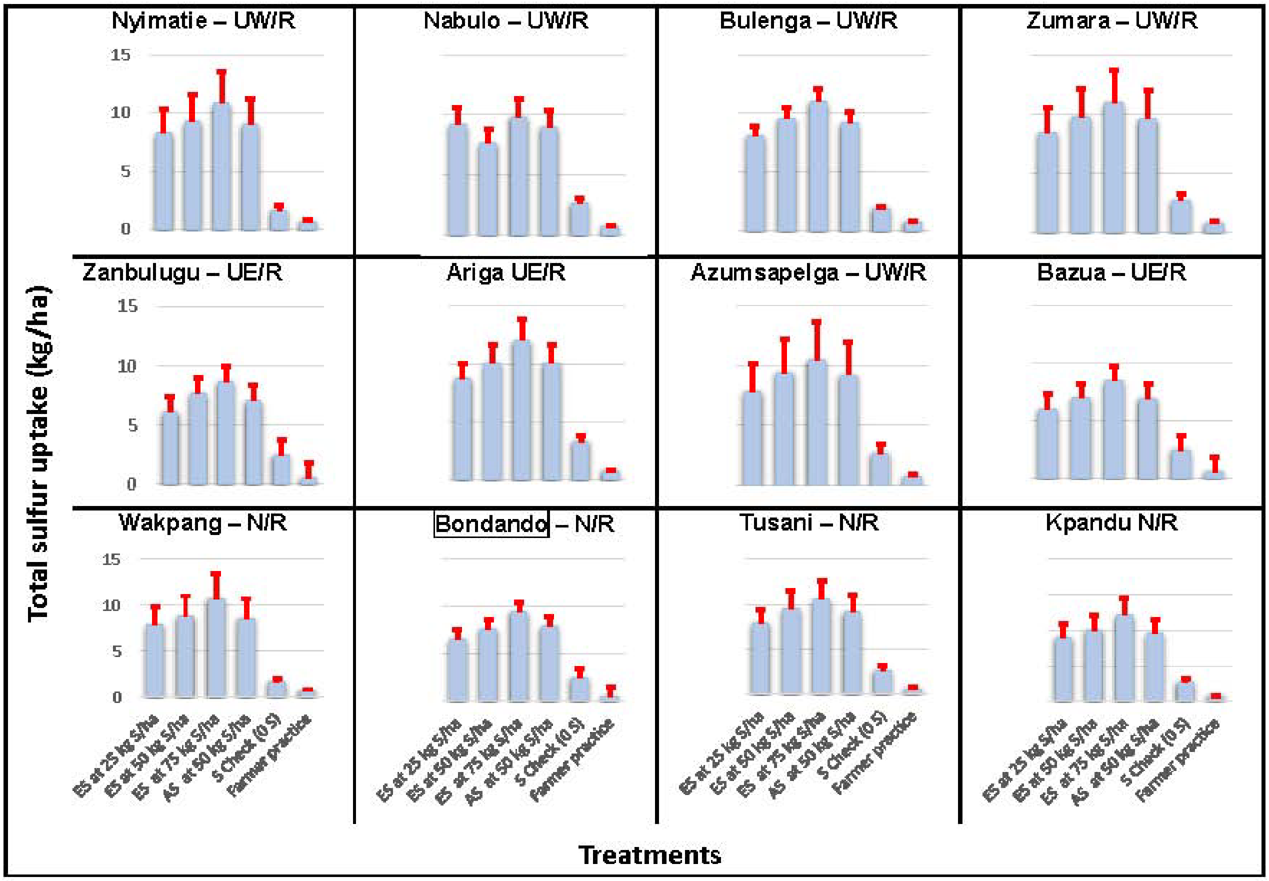
Bars represents means of four replications. Error bars denote standard error.

Figure 10. Maize Grain Yield at Various Locations as Affected by Different S Fertilizer Treatments

Averaged across all 12 sites, S uptake was < 2 kg/ha for S Check (Table 3, Figure 11). However, applying the S product at the rates of 25 kg S/ha, 50 kg S/ha, and 75 kg S/ha resulted in significant increases in S uptake of ~ 7.9 kg/ha, ~ 9 kg/ha, and ~10.5 kg/ha, respectively. Despite the dose-dependent increase in S uptake, the apparent recovery of S ([S uptake fertilized – S uptake no S]/S fertilizer applied x100) was 12-24%. This suggests that substantial quantities of the applied S were not taken up by the plants. Application of S fertilizer increased N use efficiency, which is consistent with the observation from prior studies indicating the synergistic effect of S on N uptake (Figure 12).

For the next reporting period, post-harvest soil analysis as well as residual trials without any S addition are being conducted to ascertain the fate of the residual S. Economic optimum rates for S products based on current (reported here) and residual crops will be determined.

A manuscript entitled "Determination of Economically Optimum Application Rates of Sulphur, Zinc and Boron for Maize Production in Savanna Zones of Ghana" is in preparation for submission to a journal for peer-review and possible publication. Co-authors of this paper are: S. Agyin-Birikorang, I. Tindjina, A.A. Fuseini, H.W. Dauda, U. Singh, and J. Sanabria.



Bars represents means of four replications. Error bars denote standard error.

Figure 11. Total S Uptake of Maize Plants at Various Locations as Affected by Different S Fertilizer Treatments

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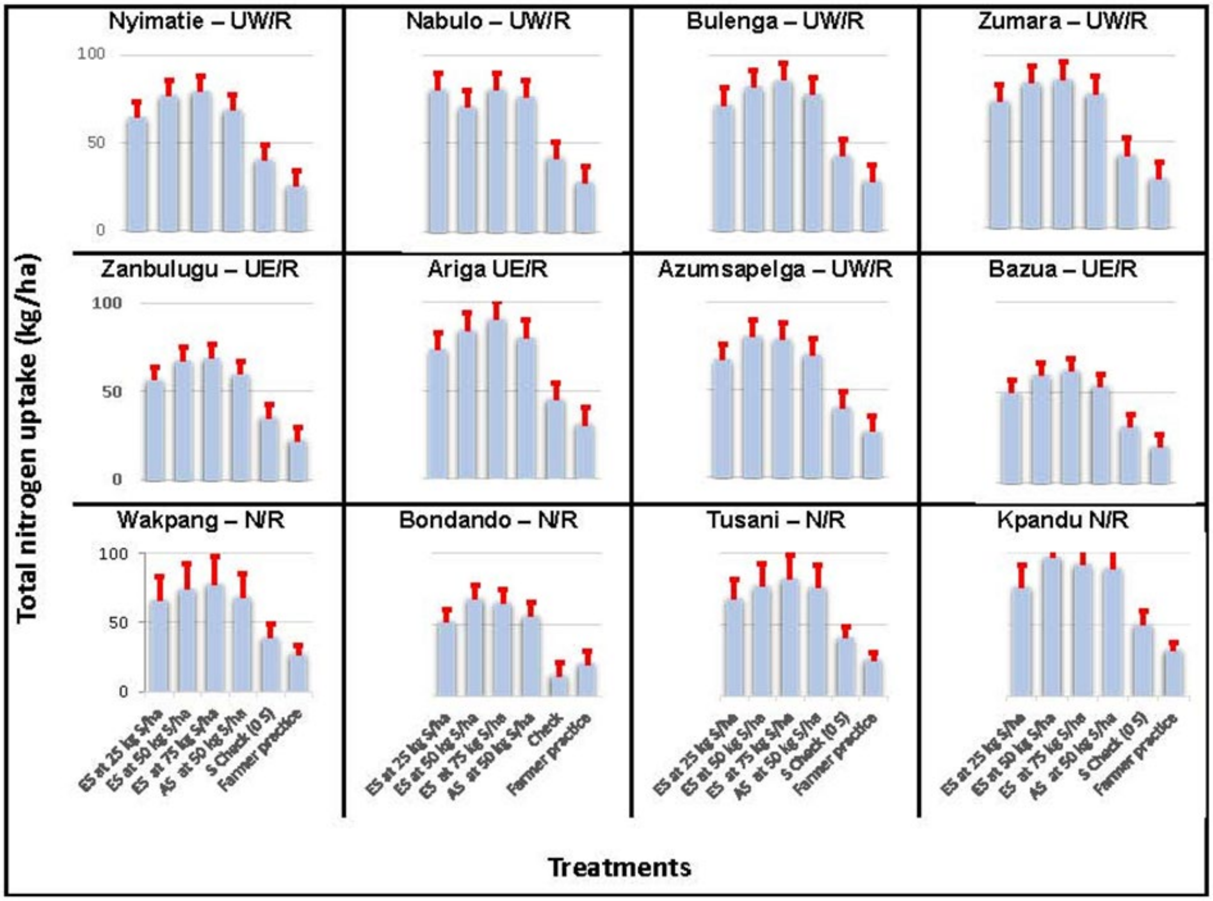


Bars represents means of four replications. Error bars denote standard error.

Figure 12. Total N Uptake of Maize Plants at Various Locations as Affected by Different S Fertilizer Treatments

1.1.1.3 Field Evaluation of Modified Urea: Balanced Subsurface Fertilizer Management (NP, NPK Briquette)

In partnership with national agricultural research extension systems (NARES), IFDC is adapting balanced subsurface fertilizer management (NP, NPK briquette) to intensive rice cropping systems (SRI). A contract was signed with the *Institut d'Economie Rurale* (IER) in Mali and the *Institut de l'Environnement et de Recherche Agricole* (INERA) in Burkina Faso to investigate the performance of FDP in irrigated and lowland rice ecosystems. Reports and publications for this activity will be completed during FY2019.

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

The off-season offers an opportunity for better water supply control for AWD. Trials were set up in February-March 2019 at the Baguineda, Niono, and San field sites in Mali. The field layout was a split-plot design with three replications. The main plot had two water management regimes (AWD and continual irrigation). The subplots had the following five treatments:

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

The *Wassa* rice variety (120–130-day cycle) was used. Yield data are expected by June 2019.

The FDP rice activities in Burkina Faso started this dry season in January 2019 at the Di site and in March 2019 at the Bagre and Bama sites, with the same treatments as in Mali with three replications. The experimental plot size was reduced to 4 m x 3 m at Bama to accommodate the existing irrigation compartments at the site. The 6 m x 5 m size was maintained for the other two sites. Data collection is underway, including the number of tillers per hill and the height of the plants.

Interactive Effects of UDP and Organic Matter: Mail

In Mali, the organic amendment trial was initiated in February 2019, and the rice plants were transplanted in March 2019 at the Niono, San, and Baguineda sites. The field layout was a split-plot design with three replications. The main plot had three rates of compost (0, 1.5, and 3 mt/ha). The compost rates were lower than the anticipated 5 and 10 mt outlined in the initial protocol. This is due to the need to apply homogenous organic materials and the difficulty in accessing Fertinova, the commercial organic fertilizer used in this trial. The subplot treatments were the same as those in the above AWD trial in Mali. The *Wassa* rice variety (120–130-day cycle) was used. Yield data are expected in June 2019.

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

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

T1 = Control, no fertilizer applied
T2 = Conventional recommendation, basal NPK at land preparation and urea broadcast (6-8 weeks after transplanting)
T3 = Basal application of recommended NPK at land preparation + UDP (1.8 g urea briquette for 4 plants = 112.5kg/ha 7-10 days after transplanting)
T4 = FDP, two 2.4 g NPK 33-12-8 briquettes for 4 plants (placed 7-10 cm deep 7-10 days after transplanting)
T5 = FDP, two 2.4 g NPK 33-12-8 + 1.9 Zn

The trials were concluded in December 2018-January 2019. The preliminary yield trend is shown in Figure 13. Complete data analyses and results will be available for the next performance report.

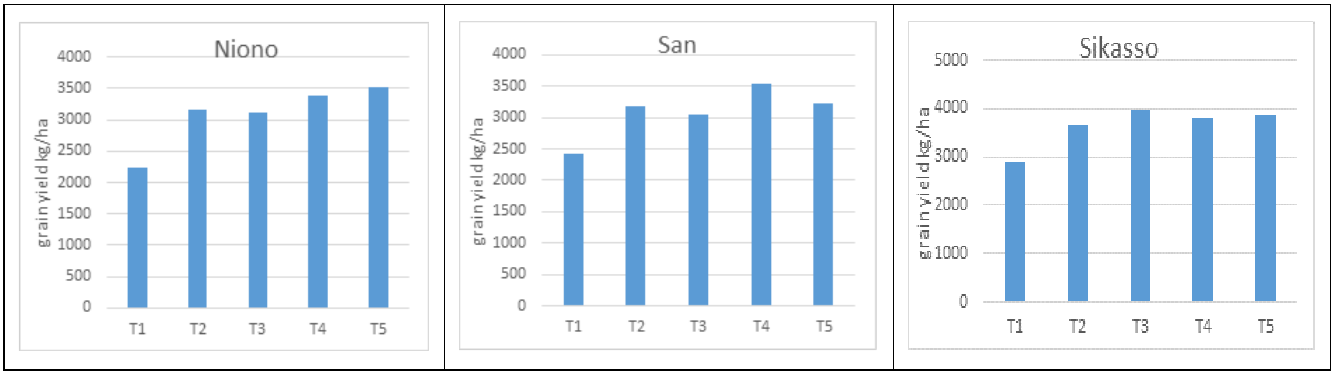


Figure 13. Rice Grain Yield as Affected by Fertilizer Application Treatments at Niono, San and Sikasso Sites in Mali

1.1.1.4 Agronomic and Economic Evaluations of FDP on Winter and Off-Season Vegetables in Mali

Agronomic and economic evaluations of FDP on winter and off-season vegetables in Mali are being conducted in partnership with the World Vegetable Center. The off-season vegetable trials have been completed, and the winter season trials are in progress.

Winter 2018 Vegetable Trials

Tomato, eggplant, okra, and onion plots were established at the Samanko, Bougouni, and Koutiala sites. Corresponding yield data are being analyzed and will be made available in the next report.

Off-Season Vegetable Trials

A second cycle of dry season trials was initiated in December 2018 at the Samanko, Bougouni, and Koutiala sites. The crops involved were tomato, eggplant, and onion. The setup is identical to the trial from the winter season (i.e., three depths of fertilizer placement and four rates of fertilizer, including briquette application). The trials are currently at the harvesting stage, with data collection ongoing to assess the agronomic and economic performance of FDP on vegetable production in Mali. Results will be available in the next report.

A publication on "Quality and quantity of vegetable crop yield as affected by rate and placement of fertilizer briquettes (NP and NPK)" is in preparation.

1.1.2 Disseminating Fertilizer Deep Placement Technology

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

- A better production and distribution model, with briquettes being produced at or near a fertilizer distributor and then distributed to agro-dealers. This model requires higher capacity, robust briquette machines capable of continuous operation, entrepreneurs willing to invest in unsubsidized and higher quality briquette machines, linking fertilizer retailers to briquette manufacturers, and established briquette demand, which exists in several FTF and IFDC countries of operation.

- Sub-surface application of granular urea and multi-nutrient granular fertilizers. This requires the development of applicators at different scales that are capable of deep-placing granular urea at costs that farmers are willing to pay. This eliminates the need to create briquettes, associated challenges with briquette distribution, and quality concerns of multi-nutrient briquettes.

1.1.2.1 Mechanized Applicators

In partnership with Agricultural and Biological Engineering Department at Mississippi State University, an automated mechanical UDP device is being attached to a rice transplanter. This will facilitate the combined application of urea or multi-nutrient briquettes along with the transplantation of rice seedlings. The 8-row transplanter has been assembled (Figure 14), and a detailed drawing (Figure 15) has been prepared for the UDP applicator. Briquettes will be applied in alternate rows by four tanks.

A direct-seeded mechanized applicator developed by National Agro Industries has been shipped to Myanmar for fertilizer deep placement evaluation on rice and maize in Myanmar. Results from both the transplanted rice and direct-seeder-applicator will be represented in the next report.

Figure 14. Procured Machine Showing the Transplanting Unit Where the UDP Application Units Will Be Attached

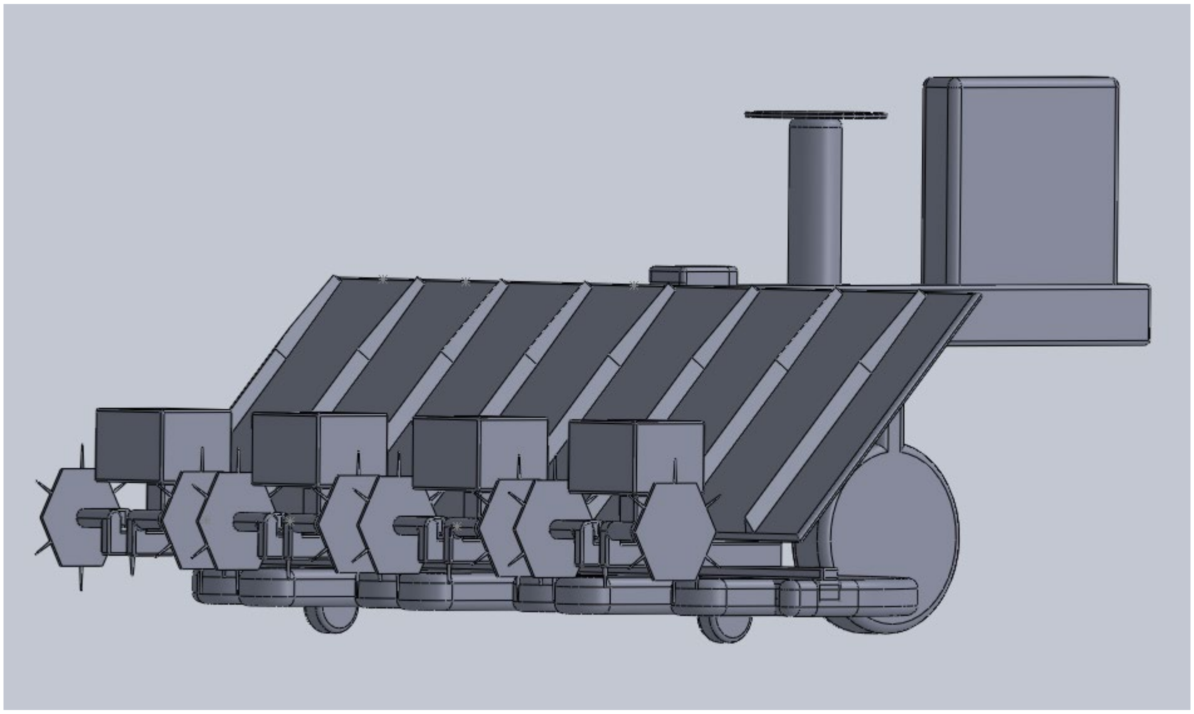


Figure 15. Design of the UDP Application Device with the Tank Attached to the Transplanter

1.1.2.2 High-Capacity Briquette Machine

A prototype high capacity, robust briquette machine will be produced by a private sector partner in Kenya starting in May 2019.

1.1.3 Climate Resilience and Mitigating GHG Emissions

Fertilizers play a unique role of both emitting and sequestering greenhouse gases and improving crop resilience to abiotic and biotic stresses. The reported activities highlight the resilience feature of fertilizer deep placement technology in improving crop yields under unfavorable environments and mitigating GHG emissions. The resilience trials were conducted for at least two seasons and completed during FY2018-19. These include: (a) trials in submergence-prone areas in northern Ghana; (b) trials in submergence-, drought-, salinity-, and soil acidity-prevalent areas in Bangladesh; (c) trials in submergence- and salinity-prone areas in Myanmar; and (d) trials in drought-prone areas in Nepal. The drought trials in Nepal and the submergence trials in Myanmar conducted during the 2018 wet season are reported below. Additional updates below include an economic analysis of fertilizer management practices in Bangladesh, and a list of publications in preparation for northern Ghana.

In addition, we are reporting: (a) an update on capacity building efforts in Bangladesh to calculate the C and N footprint and GHG emissions mitigation, (b) the quantification of N_2O and NO emissions in rice-wheat cropping systems, (c) a life cycle analysis in partnership with Rutgers University (see Section 2.3.4), and (d) an evaluation of soil C, soil N, and GHG modules of the DSSAT model in partnership University of Florida (see Section 1.5).

1.1.3.1 Drought Trial in Nepal

A field experiment under drought-prone areas (rainfed conditions) of Nepal was conducted in partnership with Agricultural and Forestry University (AFU). The objective was to determine the optimum method of N fertilizer placement for different rice varieties, including a local improved variety (LIV), a stress (drought) tolerant variety (STV), and a hybrid variety. Five fertilizer treatments were tested in a split plot design, with rice varieties as the main plots and fertilizers as sub-plots. The five fertilizer treatments were control (0 kg N/ha), urea broadcast (78 and 100 kg N/ha), granular, and urea briquette deep placement (78 kg N/ha). Both granular and briquette urea were deep placed by hand (Figure 16).

Figure 16. Deep Placement of Urea Briquettes (left) and Granular Urea (right) in Drought Trial, Nepal

The UDP treatment produced significantly higher grain and straw yields and agronomic nitrogen use efficiency (kg grain/kg N) across all varieties (Table 4). UDP produced 25% higher yields compared to conventional broadcast or produced similar yields with 25% less urea. The interaction between rice variety and fertilizer treatment on grain yields was not significant. This suggests that UDP is equally effective across all varieties under rainfed drought conditions. On the other hand, the deep placement of granular urea did not have significant effects compared to the split broadcast application of urea. These results are consistent with the previous year's results (wet season 2017). The deep placement of granular urea (PUDP) is as effective as briquette urea (UDP) under favorable weather conditions (as observed in Bangladesh and IFDC greenhouse studies) where the moisture regime can be controlled. However, it may not be effective under unfavorable conditions, such as extended drought and submergence. Unlike briquette urea, the deep placement of granular urea would only be possible with full mechanization.

Moreover, N use efficiency can further be increased by adopting real-time N management practices. Therefore, a separate study was conducted to compare the effects of UDP with different decision support tools for optimum N management. The amount and frequency of N was determined by optical sensor (OS, GreenSeeker), SPAD meter, leaf color chart (LCC) with different basal doses of N, recommended practice, and UDP. The use of optical sensor to determine N requirement reduced the amount of fertilizer by more than 50% compared to conventional broadcast urea. However, UDP produced the highest yields among the other treatments (Table 5). Real-time N management practices, such as the use of OS, SPAD, or LCC, are more useful for skilled farmers, while multiple splits of broadcast application and UDP could be applicable for all farmers, regardless of educational/skill level.

Table 4. Average Panicle, Grain Yield, Straw Yield, and Nitrogen Use Efficiency (NUE) (kg grain/kg N) with Fertilizer Types and Rates across Different Rice Varieties (LIV, STV, and hybrid) in Nepal

Fertilizer	Panicle per m^2	Grain Yield, mt/ha	Straw Yield, mt/ha	NUE (kg grain/kg N applied)
Control-N0	9.60c	3.40c	4.11c	
Broadcast-N78	10.44bc	5.49b	5.87b	26.70c
PUDP-N78	10.36bc	5.91b	6.05b	32.23b
UDP-N78	11.39a	6.83a	6.91a	44.01a
Broadcast-N100	11.23ab	6.63a	6.91a	32.27b
ANOVA (p value)				
Var (V)	0.9318	0.0563	0.4452	0.4453
Fert (F)	0.0024	0.0000	0.0000	0.0000
VxF	0.1073	0.1436	0.5116	0.1941

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

Table 5. Average Panicle, Grain Yield, Straw Yield, and NUE (kg grain/kg N) with Different Decision Support Tools for N Management in Nepal

Fertilizer	N rate (kg/ha)	Panicle per m^2		Grain Yield (mt/ha)		Straw Yield (mt/ha)		NUE (kg grain/kg N)	
Control	0	9.40	b	3.71	d	3.85	b		
OS	42	11.70	ab	6.08	abc	5.35	ab	57.07	a
SPAD	42	11.57	ab	5.34	c	6.38	a	40.48	ab
LCC	50	11.33	ab	5.52	bc	5.59	ab	36.36	ab
OS	50 (25 kg basal)	11.70	ab	6.28	abc	7.08	a	51.47	ab
SPAD	50 (25 kg basal)	11.77	ab	5.98	abc	6.82	a	45.39	ab
LCC	75 (25 kg basal)	13.33	a	6.00	abc	5.77	ab	30.56	b
PU broadcast	100	12.23	a	6.80	ab	7.04	a	30.91	b
UDP	78	12.80	a	6.92	a	6.66	a	41.25	ab
ANOVA (p value)		0.0082		0.0000		0.0047		0.0085	

OS, optical sensor; SPAD, chlorophyll meter; LCC, leaf color chart; PU, prilled urea broadcast; UDP, deep placement of briquetted urea; within a column, means followed by same letters are not significantly different at p <0.05.

Results from the Nepal drought trials will also be used in the PhD thesis (Agricultural and Forestry University, Nepal) of Mr. Bandhu Raj Baral, a senior scientist from the Nepal Agricultural Research Council (NARC).

1.1.3.2 Submergence Trials in Myanmar

Two field trials were conducted in submergence-prone areas (Kangyidaunt and Mawlamyinegyun) in Myanmar during the 2018 wet season. Two fertilizer treatments, farmer's practice (FP) at 75 kg N/ha and briquette urea deep placement (UDP) at 50 kg N/ha, were tested in combination with the LIV and submergence-tolerant varieties (*Swarna sub 1*) (STV) (Figure 17).

Figure 17. Transplanting (left) and Deep Placement of Urea Briquettes (right) in Submergence Trial, Myanmar

Across all varieties, UDP increased grain yield by 12%, with a urea saving of 33%, compared to FP (Figure 18). At the Mawlamyinegyun site, the farmer-preferred, long-duration local variety produced higher yields than the submergence-resistant *Swarna Sub 1*. As long as labor and urea briquettes are available, UDP will be an efficient and effective N management strategy in the stress-prone areas.

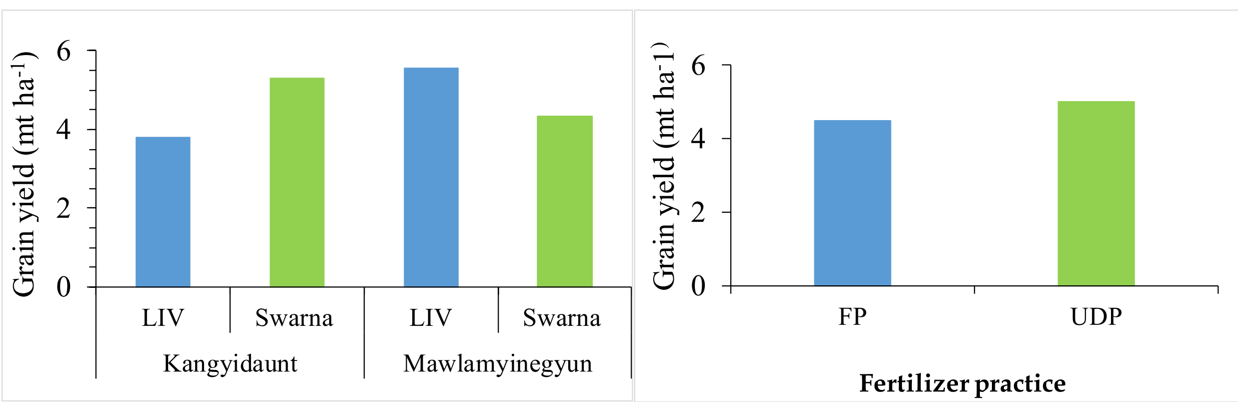


Figure 18. Grain Yield of Different Rice Varieties (Local vs. Submergence-Tolerant) and Fertilizer Management Practices (FP and UDP) at Submergence-Prone Areas in Myanmar During Wet Season 2018

1.1.3.3 Economic Analysis of Submergence-Prone Rice, Bangladesh

An economic analysis performed in salinity- and drought-prone areas in Bangladesh was presented in the previous report. Here, a summary of the economic analysis of three fertilizer management practices – farmer's practice (FP), prilled urea deep placement (PUDP), and briquette urea deep placement (UDP) – under submergence-prone areas is presented. This analysis will help provide a guide for rice farmers to increase yield and economic profit, especially in areas where the conventional fertilizer management practice is inappropriate due to extended submergence conditions. For each fertilizer practice, an analysis was done for technical efficiency, economic efficiency, and profitability indicators across two crop varieties (local and submergence-resistant) (Table 6). A marginal analysis was performed based on a partial budget (i.e., cost that varies across treatments) to determine the fertilization practice that generates the highest economic return to farmers.

Table 6. Technical, Economic, and Profitability Indicators for Three Fertilization Practices Across Two Rice Varieties in Submergence-Prone Environments in Bangladesh

Indicators	Unit	Submergence		
		FP	PUDP	UDP
Grain yield	mt/ha (x1000)	3.5	3.8	3.9
Grain revenue	BDT/ha (x1000)	71.0	76.6	79.3
Total production cost	BDT/ha (x1000)	56.8	52.9	55.1
Technical efficiency				
Grain productivity of fertilizer	kg grain/kg fertilizer	8.5	14.4	14.9
Grain productivity of labor	kg grain/labor unit	43.6	49.3	48.5
Economic efficiency				
Cost per kilogram of grain	BDT/kg	16.1	13.9	14.0
Labor cost per kg of grain	BDT/kg	9.1	8.1	8.3
Fertilizer cost per kg of grain	BDT/kg	2.3	1.4	1.4
Profitability				
Grain net income (profit)	BDT/ha (x1000)	14.2	23.7	24.2
Value-cost ratio (VCR)	BDT/BDT invest	1.2	1.4	1.4
Rate of return on cash investment	%/BDT invest	25	45	44

FP, farmers' practice; PUDP, prilled urea deep placement; UDP, deep placement of urea briquettes; BDT, Bangladesh Taka = USD 0.012.

As with the drought and salinity-prone areas, UDP outperformed FP across all indicators – technical efficiency, economic efficiency, and profitability. PUDP and UDP indicators (yield, revenue, efficiency, etc.) were similar. UDP revenue was 12% higher, and production cost was 3% lower compared to FP. UDP profit, based on the partial budget analysis, was about 70% higher than FP. Marginal and dominance analyses further confirm that UDP is the more efficient fertilization practice in submergence conditions, compared to the current farmer practice (Figure 19). FP has the highest production cost but the lowest net benefits. This clearly suggests that farmers are not using their financial resources properly and, though unknowingly, are contributing to the negative environmental impact of fertilizers (N pollution). Therefore, farmers in areas where urea briquettes are available should be encouraged to transition from FP to UDP, or to PUDP in areas where the deep placement of prilled/granular urea is possible. This allows farmers 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. Moreover, farmers could increase their net profit by adopting a submergence-tolerant variety (*BRRI dhan 52*), compared to the local variety (*Lalmota*) (Figure 19).

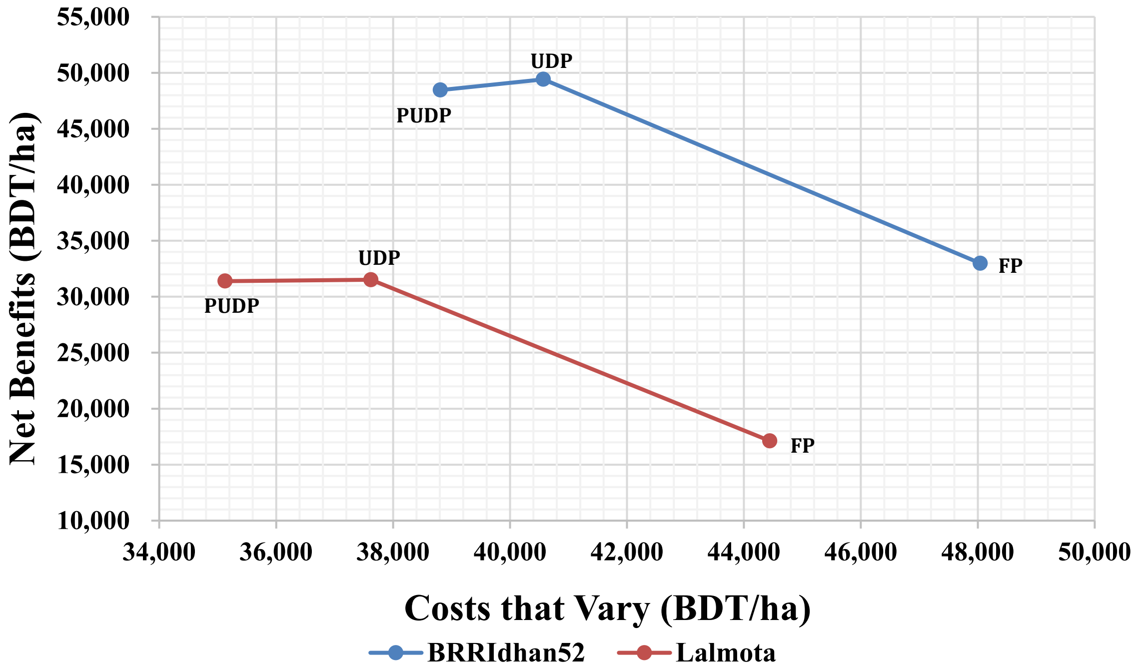


Figure 19. Net Benefit Curves of Three Fertilization Practices for Two Rice Varieties in Submergence-Prone Areas in Bangladesh

Field trial results and a farmer's survey from these environments show that farmers are not adopting recommended practices. According to a survey conducted under drought- and submergence-prone areas in Bangladesh, the majority of farmers use an excessively higher (up to 300%) amount of N and P fertilizers than recommended. On the other hand, the fertilizer nutrient composition in drought-prone areas of Nepal is imbalanced, and farmers use less fertilizer than recommended. These findings, along with the economic analysis, are already incorporated in the training program (i.e., the Feed the Future Nepal Seed and Fertilizer Project and the Fertilizer Sector Improvement Project in Myanmar) to create awareness among farmers about efficient N fertilizer management across stress environments to increase crop productivity and farm profits.

Farm household surveys were conducted across 100 drought- and submergence-prone areas in Bangladesh and 90 drought-prone areas in Nepal. The purpose of these surveys was to determine farmers' knowledge gap on fertilizer management practices in terms of awareness of fertilizer use and access to extension services. The surveys were also designed to help prepare innovative extension approaches to close the knowledge gap. These data were analyzed, and two manuscripts were prepared for journal publication.

1. "Exploring Farmers' Knowledge Gap on Fertilizer Management Practices in a Rice-Based Cropping System in Nepal" (submitted, under review)
2. "Farmers' Fertilizer Management under Stress-Prone Areas in Bangladesh" (draft ready for submission)

1.1.3.4 Trials in Submergence-Prone Areas in Northern Ghana

Climate resilient attributes of subsurface fertilizer application were evaluated in Northern Ghana and reported during FY2018. The following five manuscripts for the trials conducted in FY2018 are now in preparation for journal submission:

1. "One-Time Application of Multi-Nutrient Fertilizer Briquettes for Maize (*Zea mays L.*) Production in Guinea Savanna Area of Ghana." Coauthors are R. Adu-Gyamfi, S. Agyin-Birikorang, M.S. Ahmed, D.A. Twumasi, V.K. Avornyo, and S.N. Obanyi.
2. "Nutrients Leaching in One-Time Briquetted Multi-Nutrient Fertilizer Application Relative to Split Granular Fertilizer Application for Maize Production in Northern Ghana." Coauthors are: R. Adu-Gyamfi, Y. Manu, and S. Agyin-Birikorang.
3. "Agronomic Effectiveness of Urea Supergranules for Maize Production in Northern Regions of Ghana." Coauthors are: S. Agyin-Birikorang, I. Tindjina, R. Adu-Gyamfi, H. W. Dauda, U. Singh and J. Sanabria.
4. "Agronomic Effectiveness of Urea Supergranules for Vegetable Production in Northern Regions of Ghana." Coauthors are: S. Agyin-Birikorang, I. Tindjina, R. Adu-Gyamfi, H. W. Dauda, U. Singh and J. Sanabria.
5. Evaluation of Nutrient Management Strategies for Rice Production in Submergence-Prone Areas of the Savanna Areas of Ghana." Coauthors are: S. Agyin-Birikorang, C. Boubakary, A.R. Issahakku, I. Tindjina, U Singh and J. Sanabria.

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

GHG emissions (CO_2, methane [CH_4], nitrous oxide, ammonia, and nitric oxide) were quantified under greenhouse conditions from urea, enhanced efficiency N fertilizers, organic sources, and methods of application under varying water regimes (50% and 75% field moisture capacity and flooded soils). The aim of this research is to evaluate the effect of inhibitors, coatings, and additives in reducing N losses and GHG emissions and improving fertilizer use efficiency.

Therefore, the effects of different types of N sources (namely, N with nitrification inhibitors, granular urea, potassium nitrate) and application methods (broadcast vs. deep placement) on nitrous oxide and nitric oxide emissions were quantified on two experiments – a rice-wheat cropping system and direct-seeded rice – under GH conditions. In the rice-wheat system, UDP had no significant effects on N_2O and NO emissions (Figure 20). In rice, however, UDP increased emissions when the irrigation regime changed from continuous flooding to AWD. The latter implies that N-savings from UDP can be lost due to wetting and drying cycles in AWD.

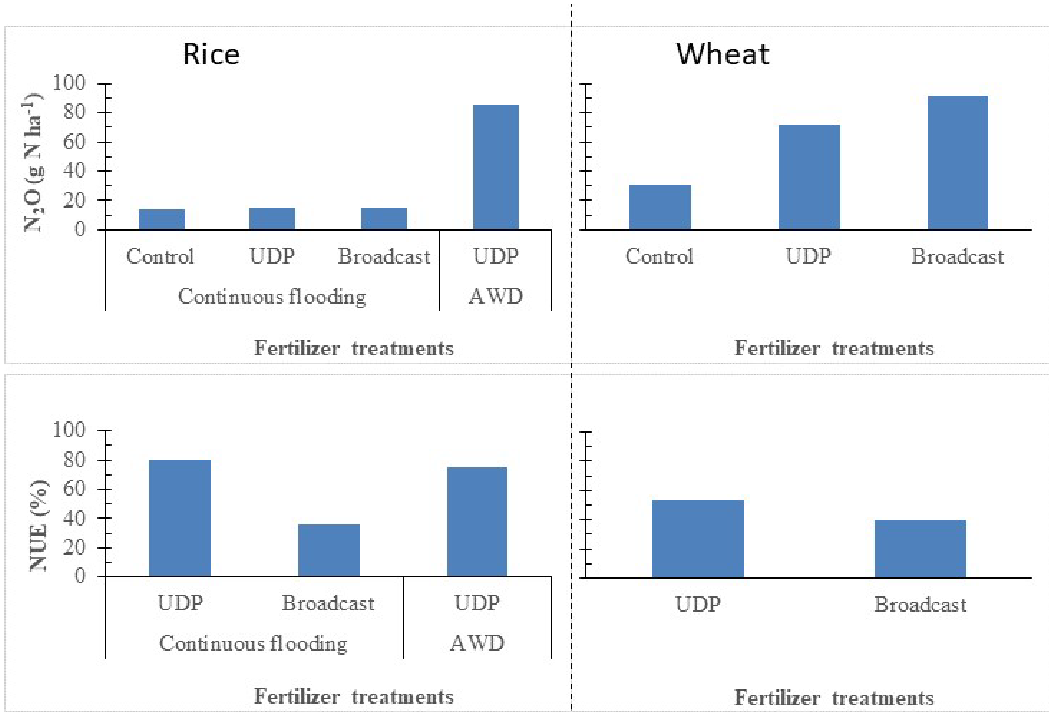


Figure 20. Nitrous Oxide (N_2O) Emissions and Nitrogen Use Efficiency (NUE) from Different Fertilizer Treatments in Rice and Wheat

These results confirmed that UDP, while increasing grain yields and NUE, does not have negative effects on the environment in rice cultivation or in wheat (Figure 20). Similarly, UDP performed well under the direct seeded rice condition, where its effect was similar to the nitrification inhibitor, DCD (results not shown). The following three manuscripts were prepared from these results and submitted for journal publication.

1. "Quantifying nitric oxide emissions from rice wheat system"
2. "Mitigating nitrous oxide emissions from rice-wheat cropping systems with nitrogen fertilizer and irrigation management"
3. "Mitigating nitrous oxide and nitric oxide emissions from direct-seeded rice with nitrification inhibitors and urea deep placement"

1.1.3.6 Capacity Building on Quantification of GHG Emissions and Carbon Credit Estimation

Capacity building of national research institutions and scientists is key to sustaining quality research, particularly in the context of developing climate-resilient technologies. IFDC is continuously working with national research institutions in Bangladesh, namely Bangladesh Agricultural University (BAU) and Bangladesh Rice Research Institute (BRRI), to build the institutional capacity in climate change research. Focus has particularly been on designing mitigation research that includes quantification of greenhouse gas emissions from agricultural systems affected by fertilizer and water management across different crop management systems. Table 7 shows an estimation of the carbon credit associated with alternate wetting and drying

(AWD) irrigation (compared to continuous standing water [CSW]) and UDP (compared to broadcast urea) using data from the BAU site in Boro 2018. The total carbon dioxide (CO_2) equivalent emissions reduction (BAU site) due to AWD irrigation was 0.324 mt/ha, which is equivalent to US$ 11.6/ha, or US$ 52.20 million from the total Boro cultivated area, compared to that from CSW water management. At the BAU site, AWD irrigation reduced CH_4 emissions by only 12% compared to CSW irrigation. This is much lower than the 45% reduction from the farmers' field and BRRI site. Therefore, this value is likely to increase once average emission reduction is calculated for the country. Adoption of UDP reduced CO_2 eq emissions by 1.67 mt/ha, which is equivalent to a carbon credit value of US$ 60.1 million per season from the total Boro cultivated area, compared to urea broadcast. Although estimates vary with sites, soil conditions, and water management, the results show significant reduction in emissions due to AWD and UDP.

Table 7. Seasonal Total GHG Emissions and Carbon Credit Estimation from Different Fertilizer Treatments under CSW and AWD Irrigation in Boro 2018 in Bangladesh

Treatment								
Water Regime	N Fertilizer	CH_4 (kg/ha)	N_2O (g/ha)	Total GHG, CO_2 eq (kg/ha)	Average GHG Emissions (ton CO_2 eq/ha)	Carbon Credit[a] (USD/ha)	Area of Boro Rice (ha)	Total Carbon Credit (million USD)
CSW	Control	87.4	-9.0	2181				
	UDP	117.2	40.2	2947	3.220			
	PU	178.9	143.3	4532				
AWD	Control	77.2	43.0	1948				
	UDP	98.4	80.4	2493	2.896	11.66	4,475,827	52.20
	PU	164.2	340.0	4246				
Both	PU				4.389			
	UDP				2.720	60.08	4,475,827	268.92

a. *Carbon credit = reduced emissions due to AWD or UDP x 36 (1 ton CO_2 eq = USD 36) based on results from BAU.*

The following papers were published and presented during the reporting period:

Islam, S.M.M., Y.K. Gaihre, J.C. Biswas, U. Singh, Md. N. Ahmed, J. Sanabria, and M.A. Saleque. 2018. "Nitrous Oxide and Nitric Oxide Emissions from Lowland Rice Cultivation with Urea Deep Placement and Alternate Wetting and Drying Irrigation," *Scientific Reports*, 8:17623.

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

1.2 Activated Phosphate Rock

All commercially available phosphatic fertilizers contain 100% water-soluble P (WSP). The hypothesis of our proposed research is that 100% WSP is inefficient, both in terms of application efficiency as well as production efficiency. High solubility ensures immediate availability of P for plant uptake. However, high solubility results in leaching losses in coarse-textured soils and under high intensity rainfall events. More importantly, WSP entering the soil solution P pool is rapidly converted to labile P, active P, or stable P pools, and can be rendered unavailable in acidic soils through fixation by iron and aluminum oxides and in alkaline soils as calcium phosphate precipitation. The plant availability of P is strongly affected among labile (more available), active, and stable P (less available) pools. The efficiency of P fertilizers from initial application is only 10-20%. On the other hand, phosphate rock (PR) is relatively insoluble; its direct application is limited to highly acidic soils (pH < 5.5), and preferably, on perennial crops. In contrast to WSP and PR, use of activated PR is neither constrained by soil type nor crop species. Activated PR is produced by compressing or granulating phosphate rock with low amounts of WSP. IFDC has been re-evaluating activated PR, particularly with respect to "activation" with diammonium phosphate (DAP) or monoammonium phosphate (MAP), instead of triple superphosphate (TSP), and using lower proportions of the activating component. The absence of Ca and the presence of ammonium in DAP and MAP promote a greater dissolution of PR.

Results from greenhouse trials and ongoing field trials indicate that activated PR has similar efficacy to commonly used WSP fertilizers (DAP, MAP, and TSP), at a lower cost to farmers. Furthermore, the activation process has, so far, proven effective on low-reactivity PR sources that are not effective on any soil. This is significant due to the number of poorly soluble PR sources in Africa that could be commercialized if the PR is activated. The activation processes (granulation or compression) add little to production costs. WSP fertilizers, by contrast, require enormous investments, in excess of $1 billion. They are also limited to regions with very large deposits, and through an expensive acidulation process, also produce large amounts of phosphogypsum, which is a disposal challenge. The ability to convert national deposits of PR into less expensive, yet effective, phosphate products can greatly reduce the need to import soluble P fertilizers, which are the most expensive of the NPK nutrient fertilizers.

1.2.1 Complete and Analyze Ongoing Field Trials

Ongoing field tests are evaluating the performance of activated PR vs. conventional P fertilizers. During the last quarter of FY2018, 15 on-farm trials involving maize and six on-farm trials involving soybean were established in northern Ghana to evaluate the effectiveness of the activated PRs. 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, using wheat as the test crop. The second trial was established in late August 2018 at a low pH site in Bungoma county and at a higher pH site in Kisumu county, using maize as the test crop. Sites were chosen to evaluate activated PR on low P soils with a range of pH values.

1.2.1.1 Ghana

Figure 21 shows the field sites in Northern Ghana used in the study for maize (15 sites) and soybean (6 sites under neutral soil pH conditions). The sites, all within the zone of influence (ZOI) of the USAID-FTF interventions, were selected based on the soil fertility maps developed for the region, showing that soils in the selected sites were P-deficient and thus likely to show P response.

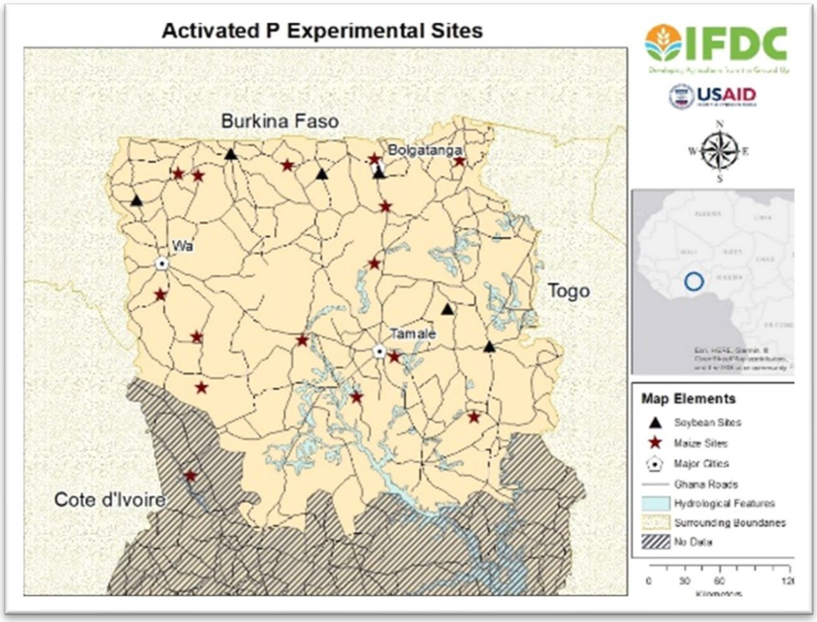


Figure 21. Map of Northern Ghana Showing the Locations of the Experimental Sites for Maize (stars) and Soybean (triangles)

For the maize trials, six treatments with four replications (24 plots) were laid out in a RCBD at each site. The treatments were: (a) Water-Soluble P (DAP); (b) Activated Togo PR (4 PR:1 DAP); (c) Activated Togo PR+urea (4 PR:1DAP + 10% urea); (d) Untreated Togo PR; (e) P-Check (with all other nutrients except P); and (f) Farmer Practice. For the soybean trials, the farmer practice treatment was omitted because it was the same as the P-check treatment, and TSP was used as the WSP fertilizer instead of DAP; otherwise, the treatments were the same as those for the maize trials.

Effect of P Fertilizer Sources on Biomass and Grain Yields of Maize and Soybean

Without P addition (i.e., P-check), maize straw yield from the near-neutral soils was low (~2.59 mt/ha). It was even lower in the acidic soils (~2.39 mt/ha). These results are consistent with the low bioavailable P content of the soils. The addition of P in the form of DAP and activated PR significantly increased straw yield over the P-check treatment, regardless of the soil acidity level (Table 8). However, for the PR treatment, there was a significant soil pH impact on the effectiveness of the product. In the acidic soils, the PR treatment produced significantly higher straw yield, approximately three times greater than that of the P-check treatment. Conversely, in the near-neutral soils, the straw yields from both PR and the P-check treatments were statistically similar. These results suggest that the PR product became reactive in the acidic soil environment. This is consistent with reports that the dissolution of unreactive PRs is significantly improved in acidic soils. A pH effect was also observed with the DAP treatment. However, contrary to the observation of the PR treatments, the DAP was more effective in the near-neutral soil than in the acidic soil, with straw yield being greater in the near-neutral soils than in the acidic soil (Table 8). Studies in acidic soils have shown that low P availability due to adsorption reactions by the soil constituents results in only a small fraction of the P coming into solution for crop utilization

(Siemens et al., 2004; Rashmi et al., 2015). Notably, the effects of soil pH on P availability were eliminated in the activated PR products since straw yields were similar, regardless of pH.

The average grain yields across the acidic and near-neutral soils are presented in Table 8, and the grain yields for all 15 locations are presented in Figure 22. Consistent with the straw yield, the pattern of grain yield from PR application differed with respect to soil pH, but the pattern of grain yield from activated PR remained similar in both the acidic and near-neutral soils (Table 8, Figure 22). In the P-check treatment, maize grain yield from the near-neutral soils was low (1.46 mt/ha), and it was even lower in the acidic soils (~1.2 mt/ha). The addition of DAP and activated PR significantly increased grain yield over the P-check treatment, regardless of soil pH (Table 8). As with straw yield, soil pH also affected the effectiveness of the PR product in terms of grain yield. In the acidic soils, there was a significant difference between the grain yields from the P-check and the PR treatment, with the PR treatment producing over 175% more yield than in the P-check treatment (Table 8). On the other hand, in the near-neutral soils, the grain yields between the PR and P-check treatments were insignificant, only ~10% higher in favor of PR. This confirms that the PR product became reactive in the acidic soil environment. Similar results were previously reported using Togo PR in acidic soils from the interior savanna and forest zones of Ghana (Agyin-Birikorang et al., 2007; Owusu-Bennoah et al., 2002; Abekoe and Agyin-Birikorang, 1999; Abekoe and Tiessen, 1998). The pH effect was again observed with the DAP treatment. Contrary to the observation in the PR treatments, DAP was more effective in the near-neutral soil (average grain yield ~7.7 mt/ha) than in the acidic soil (average grain yield ~6.4 mt/ha) (Table 8). For the activated PR products, the effects of soil pH on P availability were eliminated since maize grain yields were similar regardless of the soil pH.

As expected, the relative agronomic effectiveness (RAE) values (calculated from maize grain yield) showed the effectiveness of the activated PR products. This index was found to be a good parameter to compare differences in effectiveness between P sources (Chien et al., 1996; Owusu-Bennoah et al., 2002). The RAE indicated that, in the acidic soil, the activated PR products were more effective (~4 % more) than DAP, with the PR product being only 33% as effective as water-soluble DAP. However, in the near-neutral soil pH, the activated P products were ~79% as effective as DAP, whereas the PR product was only <3% as effective as DAP. Thus, incorporating a modest amount (20%) of WSP into the PR increased its effectiveness in terms of grain yield by about two-fold in acidic soils and more than three-fold in near-neutral soil.

The average soybean yields across all six locations (neutral soil pH) are presented in Table 8, and the yields for the various locations are presented in Figure 23. The results of both straw and grain yields from the soybean experiments were similar to the pattern observed for the maize experiment (Table 8 and Table 9). The striking difference is that, even in the near-neutral pH, the PR treatment produced considerable yield compared to the maize trials. This suggests that soybean was able to utilize the PR product better than maize in the near-neutral soil. It is likely that soybean was better able to modify the rhizosphere to ensure adequate dissolution and utilization of the PR compared to maize. However, regardless of the ability of soybean to utilize PR, activated PR still produced significantly greater yield than the PR treatment (Table 9, Figure 23). This is consistent with the straw and grain yield pattern of the maize trials. Also consistent with the maize trials, the RAE values further demonstrated the effectiveness of the activated PR products. The RAE indicated that, on average, the activated PR products were ~80% as effective as WSP (TSP), whereas the PR product was ~35% as effective as TSP (Table 9).

Table 8. Mean Values[a] of Straw and Grain Yields, P Uptake, and RAE of the P Sources Tested in Acidic and Near-Neutral Soils

Treatment Description	Sites with Acidic Soils: Straw Yield (mt/ha)	Grain Yield (mt/ha)	Total P Uptake (mt/ha)	RAE (%)		Sites with Near-Neutral Soils: Straw Yield (mt/ha)	Grain Yield (mt/ha)	Total P Uptake (mt/ha)	RAE (%)
WSP (DAP)	12.6 a	6.38a	12.2a	100		15.1a	7.67a	13.2a	100
Activated Togo PR	12.1a	6.58a	11.7a	104		13.3b	6.36a	9.21b	78.9
Activated Togo PR+urea	13.3a	6.61a	13.1a	104		13.3b	6.37a	9.21b	78.9
Togo PR	6.51b	3.33b	2.57b	33.4		2.93d	1.63c	1.08d	2.8
Check (0 P)	2.39c	1.20c	0.54c	-		2.59d	1.46c	0.94d	--
Farmer practice	6.82b	3.42b	3.74b	43.1		7.97c	3.66b	4.52c	39.0

a. Numbers are mean values of 24 replicates (6 locations x 4 reps) for the sites with acidic soils, and 36 replicates (9 locations x 4 reps) for the sites with near-neutral soils. (Values are presented in three significant figures.)

b. Means in the same column followed by the same letter are not significantly different ($P \geq 0.05$), according to the Fisher's protected LSD.

Table 9. Soybean Values[a] of Straw and Grain Yields, P Uptake, and RAE of the P Sources Tested in Near-Neutral Soils

Treatment Description	All Sites with Near-Neutral Soils: Straw Yield (mt/ha)	Grain Yield (mt/ha)	Total P Uptake (mt/ha)	RAE (%)
Water-Soluble P (TSP)	5.77a	2.02a	11.1a	100
Activated Togo PR	5.35a	1.69b	10.5a	80.0
Activated Togo PR+urea	5.43a	1.71b	10.7a	82.7
Togo PR	2.94b	0.86c	3.24b	35.5
Check (0 P)	1.18c	0.22d	0.51c	-

a. Numbers are mean values of 24 replicates (6 locations x 4 reps). (Values are presented in three significant figures.)

b. Means in the same column followed by the same letter are not significantly different ($P \geq 0.05$), according to the Fisher's protected LSD.

Effect of P Fertilizer Sources on the Above-Ground Total P Uptake of Maize and Soybean

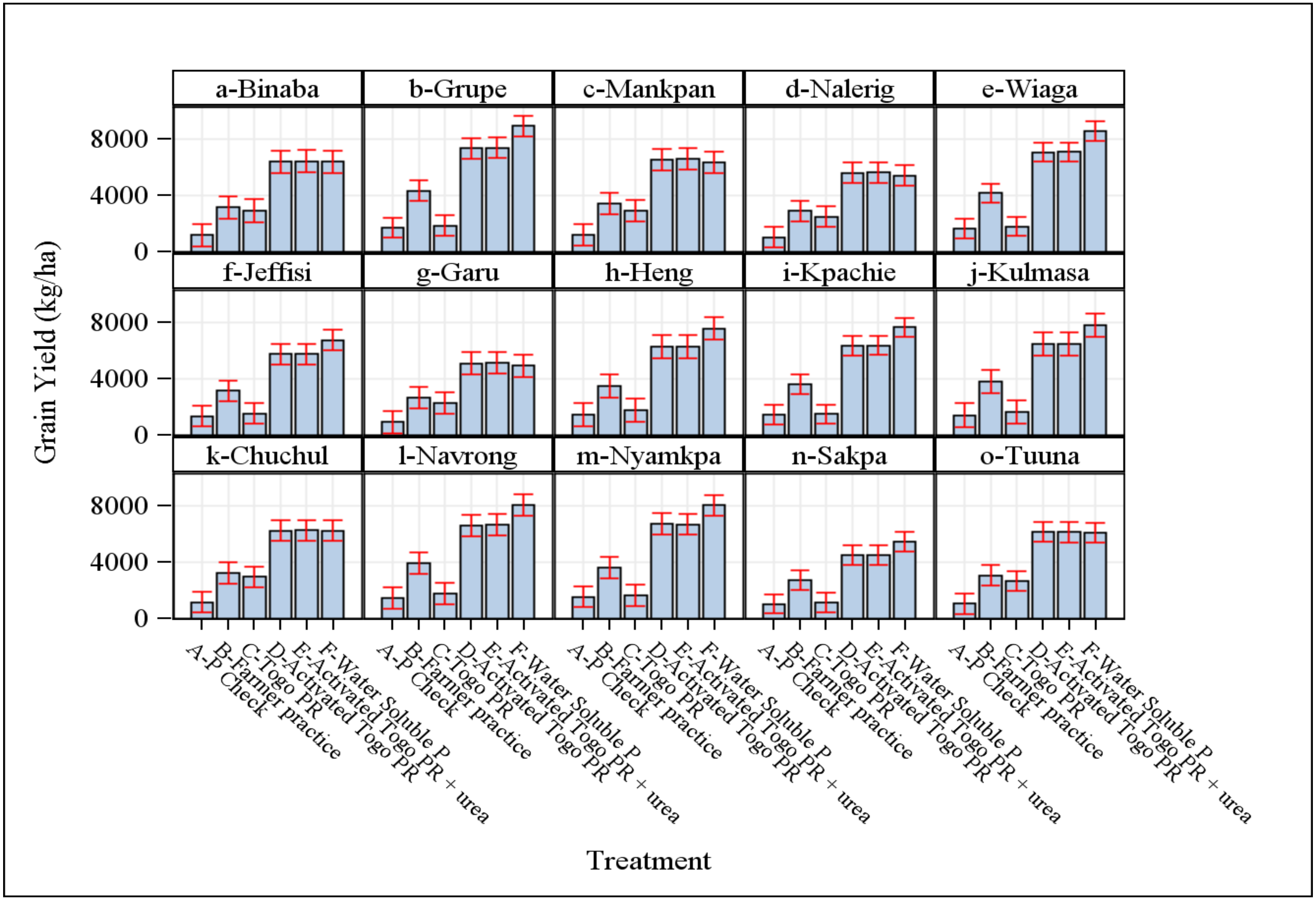
Averaged across all nine sites with near-neutral soil pH, the maize P-check treatment contained 0.84 kg/ha P, whereas the average P uptake (across all 6 sites with near-neutral soil pH) from the soybean P-check treatment was 0.51 kg/ha (Table 8). As expected, all four P sources significantly increased P uptake in both crops, following the order WSP ≥ Activated PR+urea = Activated PR >> PR > P-check. Differences between P uptake from the PR treatment and P uptake from the activated PR treatment represented a quantitative estimation of the contribution of WSP, compacted with the PR. Despite the small quantity of WSP compacted with the PR, the corresponding contribution to P availability from the PR was enormous. For example, in the acidic soil environments (best case scenario for PR), P uptake by maize from the PR treatment was 2.6 kg/ha, and the increase in P uptake from the PR due to activation was > 9 kg/ha (Table 8). A similar pattern was observed for the soybean trials, although the extent of the increase was lower (~7 kg/ha) than for maize (Table 9). This confirms the observation that soybean was able to utilize direct PR application better than maize. As is normal with P fertilizers, the proportion of applied P taken up by the plants was < 20% across all treatments, suggesting that substantial quantities of the applied P were not taken up by the plants. Post-harvest soil analysis is being conducted to ascertain the fate of the residual P. Nevertheless, a follow-up experiment is required to determine the residual effects of the activated PR and the PR products in supplying P to subsequent crops.

The combined results of biomass yield and P uptake indicated that the activated PR products were as effective as the WSP, regardless of the soil pH or the crop, and it was more effective than the raw PR applied directly to both crops. We hypothesized that the modest amount of WSP contained in the activated PR would supply the early P requirement of the crops, which would enhance root development of the crops to deplete P and Ca^{2+} in the dissolution zone. Such reaction was expected to increase P availability from the PR. The presented results clearly support that hypothesis.

Next Steps

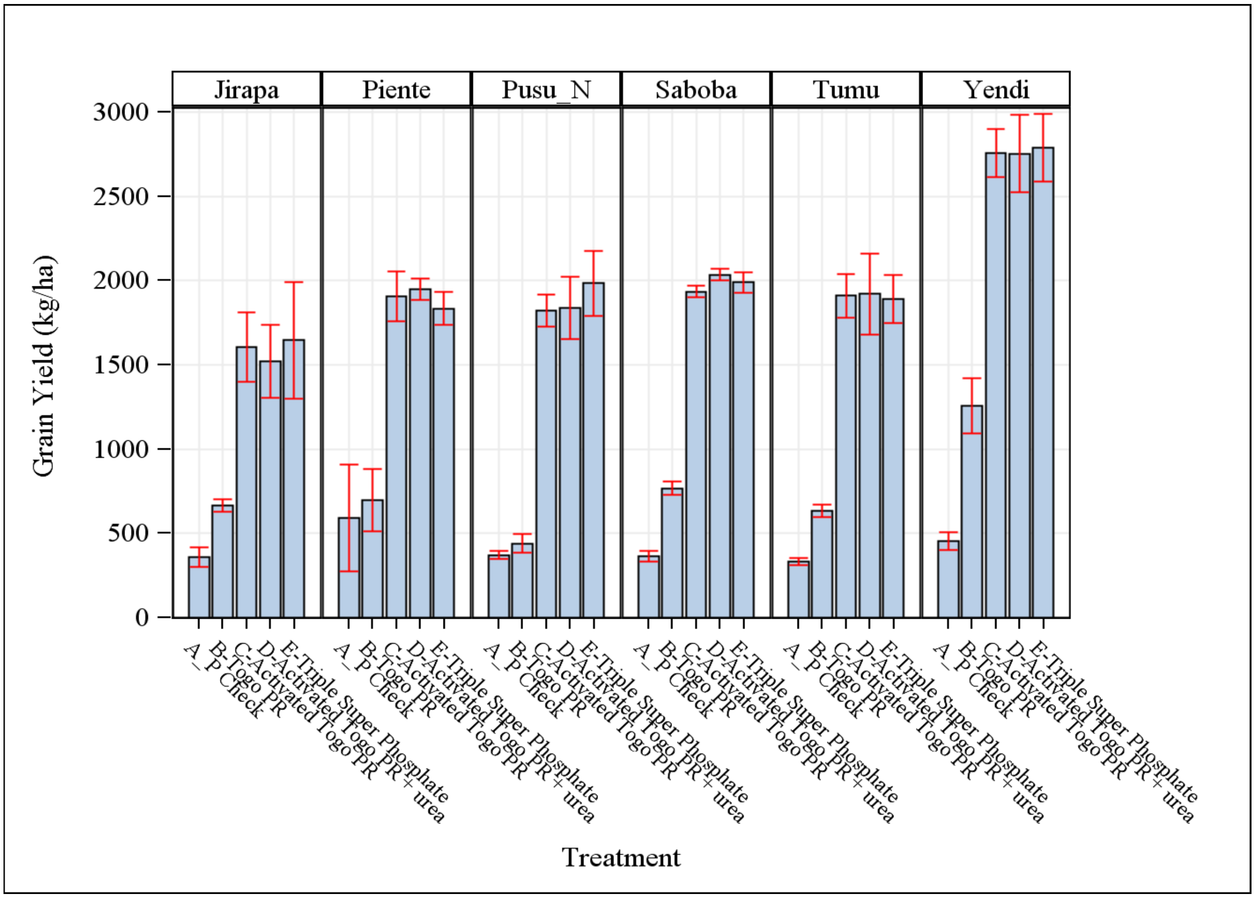
1. Use economic and statistical models to determine economically optimum activated PR application rates.
2. Establish a follow-up trial at the sites utilized for these trials to determine the residual effects of the activated PR.
3. Establish demonstration plots to showcase the effectiveness of the activated PR to farmers.

A full description and results of the above field trial as well as greenhouse studies will be reported in "Field Evaluation of the Effectiveness of Activated Phosphate Rock for Direct Application".



Bars represents mean values of four replications. Error bars denote standard error of the mean.

Figure 22. Maize Grain Yield at Various Locations as Affected by Different P Treatments



Bars represents mean values of four replications. Error bars denote standard error of the mean.

Figure 23. Soybean Grain Yield at Various Locations as Affected by Different P Treatments

1.2.1.2 Kenya

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

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

The wheat sites employed a Latin square design. Yields (Table 10) show that at Uasin Gishu, no significant differences were observed between any of the treatments and that yield levels were relatively high. At Bungoma, the rather unusual result was the under-performance of DAP relative to other treatments. This result is difficult to explain, but one possible reason may be increased Cu deficiency induced by the more soluble P source, DAP. While Cu was applied in this trial, it was previously shown that soil-applied Cu (which was employed in these treatments) had no effect in addressing Cu deficiencies. To better judge the effects of activated PR, it is advised to repeat this trial using a foliar Cu source, both to address Cu deficiencies and to control rust.

Table 10. Wheat Yields from Activated PR Trial

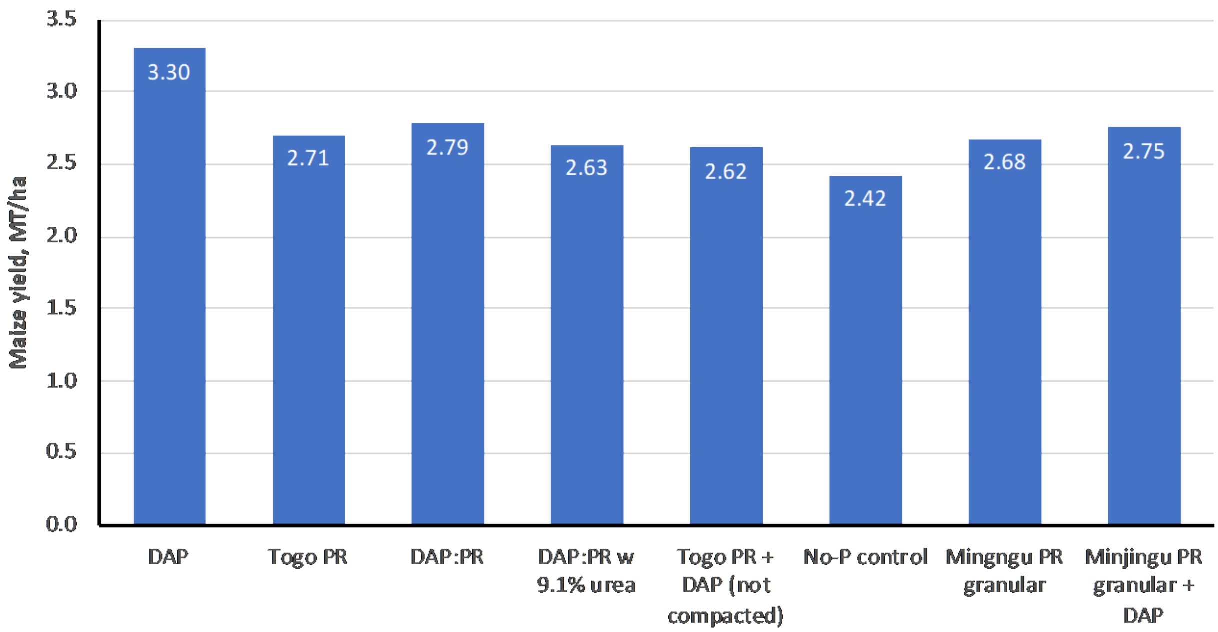
Treatment	Wheat Yield (mt/ha)			
	Uasin Gishu		Bungoma	
DAP	3.87	a	0.93	a
Togo PR	4.15	a	2.32	b
DAP:PR	3.84	a	2.05	b
DAP:PR w 9.1% urea	3.56	a	2.22	b
Togo PR + DAP (not compacted)	3.82	a	2.24	b
No-P control	3.54	a	2.28	b

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

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

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

At Bungoma, a significant block effect was observed ($p<0.001$), with one responding less to DAP than the others. Even considering this block effect, treatment effects were significant only at $p = 0.08$, with DAP significantly out-performing some treatments in some blocks and performing the same in others, and all other treatments being statistically indistinguishable. Overall averages across blocks are shown in Figure 24. Given the severity of the drought, we believe that root access to all P treatments was restricted through most of the season. The trial still sheds some light on how activated PR treatments might perform under water stress.



Treatment means were not statistically different at p≤0.05.

Figure 24. Maize Yields in Activated PR Trial, Bungoma

1.2.2 Conduct PR and Activated PR Demonstrations on Soils of Varying pH with Prominent PR Producers to Capture Their Interest in Activated PR

Thus far, trials have used Togo PR (activated and non-activated) compared to soluble P sources. In these trials, we will use activated PR from PR producers, as they will want to judge the efficacy of the activation process using their own PR source. The results should be enough to make a go/no-go decision as it concerns developing business plans for producing activated PR commercially. To this end, on-farm demonstrations showcasing the agronomic effectiveness of activated PR in Northern Ghana will be established at the onset on the main farming season. Sites for the demonstrations have been selected and sensitization of farmers about the upcoming demonstrations have begun. Each demonstration will have four main plots, including the following treatments: (i) Activated PR, (ii) locally available PR (Togo PR), (iii) WSP, and (iv) farmers' practice. For each demonstration, field days will be carried out at planting and treatment application, at full cob development (green field day), and at harvest (brown field day).

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

Balanced crop nutrition is addressing all deficient nutrients and soil pH constraints. As per Liebig's Law of the Minimum, growth is constrained by the most limiting factor. Most African farmers only have access to NP and NPK fertilizers, but landscape-level soil analyses by IFDC and others have indicated widespread deficiencies of other nutrients, including S, Zn, and B, as well as acidity constraints and associated deficiencies of Ca and Mg. These nutrients are generally inexpensive to supply (needed in smaller quantities), relative to N, P, and K, and can have major impacts on crop yields. Research to date indicates that multiple deficiencies of secondary and micronutrients are the norm rather than the exception and must be addressed simultaneously to optimize response.

In recognition of these wide-scale deficiencies and subsequent crop responses, blenders capable of adding these nutrients to fertilizers have sprung up throughout sub-Saharan Africa and Asia. Providers of compound fertilizers, such as Mosaic, OCP, and Yara, are collaborating to address these deficiencies as well.

Several challenges exist in order to commercialize these products. While IFDC is collaborating with the Bill & Melinda Gates Foundation, the Alliance for a Green Revolution in Africa (AGRA), the World Agroforestry Centre (ICRAF), and ISRIC to map soil-extractable nutrients and pH constraints in several countries to identify the extent of non-NPK deficiencies, critical norms from soil tests are not well understood and not definitive and vary from crop to crop. The lack of clarity on definitive soil norms has led to poor product targeting. Micronutrients may be incorporated as granules, as coatings on NPK granules, or into NPK granules themselves, but the relative efficiency of these different incorporation methods is not completely understood. In addition, the different forms of micronutrients (chemical composition and fineness) affect their efficacy. IFDC activities highlight the importance of balanced fertilization and fertilizers and the most cost-effective and efficient ways of delivering these nutrients to maximize productivity, profitability, and nutrient use efficiency. All field trials include the collection of soil data, weather data, and socio-economic data to facilitate site-specific fertilizer recommendations and technology transfer to other sites.

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

Activities focus on the improved delivery, distribution, and efficiency of nutrients (N, P, K, Zn) supplied from multi-nutrient fertilizer granules. The effect of improved nutrient efficiency will be quantified with respect to increased yield, improved mineral nutrient and protein content of grains, and quality of protein.

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

Zn deficiency is widespread, affecting both crop yields and human nutrition. As interest in multi-nutrient fertilizers increases, incorporating Zn efficiently into fertilizer compounds and blends has become an increasing priority. Zinc is reactive with phosphate fertilizers, forming poorly soluble Zn phosphates, which are not adequately available to plants. Many forms of Zn that can be incorporated into fertilizers exist commercially, including but not limited to zinc oxide, nano zinc oxide, zinc sulfate, zinc oxysulfates, zinc fluvate, zinc polyphosphates, and chelated zinc products, such as Zn EDTA. Zn is commonly applied into basal fertilizers to address early Zn demands and may also be combined with urea in topdressing formulations, thus avoiding reactions with basal fertilizer phosphates. Zinc sources in their various forms can be applied as granular products, coated onto granular NPK fertilizers in blending facilities, coated onto urea, or incorporated into compounds. However, little definitive information is available on efficient ways of incorporating Zn into fertilizers. This activity includes laboratory, greenhouse, and field evaluations of various rates, sources, and methods of Zn delivery under a wide range of soil pH and soil organic matter contents.

Development of Nano-Zinc Coated Urea

The development of nano-zinc coated urea fertilizer for efficient delivery of zinc micronutrients and improved nitrogen use efficiency in partnership with UCF was reported in Section 1.1.1.1.

Greenhouse Trial Evaluating the Effects of Zn on Sorghum Yield and Nutrient Use Under Limited Water Conditions

A greenhouse trial evaluating the effects of Zn on sorghum yield and nutrient use under limited water conditions was completed. The study aimed (a) to quantify the effect of Zn on sorghum vegetative and reproductive growth under water-limited conditions; (b) to evaluate the effect of drought on nutrient uptake in sorghum; and (c) to evaluate the role of Zn in modulating the effect of drought on nutrient uptake in sorghum. To this end, a slightly acidic (pH 6.87) soil in an 8 kg pot was amended with NPK (98:100:275 mg/kg soil). The N source was from a single urea briquette per pot. Zn was also amended as bulk- (≥ 1000 nm) or nano- (≤ 100 nm) oxide powder. The bulk Zn oxide was administered at 3 mg/kg, while the nano-ZnO powder was administered at 3 mg/kg and 5 mg/kg. Thereafter, sorghum was planted in the soil at one seed/pot. Approximately one month after planting, the plantlets were exposed to drought conditions (50% of the field moisture capacity [FMC]). Two control treatments were set up: one with water provided at 80% FMC + Zn and the other with water at 50% FMC – Zn. All treatments at 50% FMC represented a drought condition that was maintained throughout the duration of the study. Vegetative growth and reproductive yield were evaluated, along with the accumulation of nutrients by the plants, as affected by drought and Zn fertilization.

Table 11 indicates that, in the absence of Zn, drought negatively affected all facets of sorghum growth and yield. Grain yield decreased by as much as 76% (compared to Optimum and Drought Control). Notably, the inhibition of tiller and panicle production by drought was completely reversed, and even promoted, by Zn (compare Control vs other treatments). Although Zn mitigated the drought-induced inhibition of shoot biomass production and grain yield, the levels of these variables were not returned to the non-drought status by Zn. Collectively, these findings demonstrate that Zn fertilization can be used as a climate-smart strategy to mitigate drought-induced suppression of sorghum productivity.

Table 11 further shows the negative effect of drought on nutrient uptake in the absence of Zn fertilization. Above-ground (shoot + grain) accumulation of N, P, K, S, Ca, Fe, Cu, and Zn was inhibited, while that of Mg and Mn were promoted under all drought conditions. However, the inhibition of N, K, S, Zn, and Cu accumulation was mitigated when Zn was included in the drought treatment, although levels were not fully reversed to the levels in the optimum treatment (non-drought control).

Table 11. Effects of Drought on Vegetative Yield, Grain Yield, and Nutrient Acquisition in Sorghum and the Modulation of Drought Effects by Zn Fertilization

Treatment/ Variable	Optimum (Non-drought + ZnO nano) (3 mg Zn/kg)	Control (Drought - Zn)	Drought + ZnO bulk (3 mg Zn/kg)	Drought + ZnO nano (3 mg Zn/kg)	Drought + ZnO nano (5 mg Zn/kg)
Number of tillers	2.7	2 (-26%)	3 (+11%) (+50%)	3.3 (+22%) (+65%)	3.7 (+37%) (+85%)
Number of panicles	2.3	2 (-13%)	3 (+30%) (+50%)	2.7 (+17%) (+35%)	3 (+30%) (+50%)
Shoot biomass yield (g dry wt.)	39	24 (-38%)	29 (-26%) (+21%)	29 (-26%) (+21%)	28 (-28%) (+17%)
Grain yield (g dry wt.)	15.3	3.6 (-76%)	10.6 (-31%) (+194%)	5.9 (-61%) (+64%)	10.2 (-33%) (+183%)
Above-ground N accumulation (mg/plant)	563	400 (-29%)	544 (-3%) (+36%)	406 (-28%) (+1.5%)	492 (-13%) (+23%)
Above-ground P accumulation (mg/plant)	176	165 (-6%)	99 (-44%) (-40%)	118 (-33%) (-28%)	123 (-30%) (-25%)
Above-ground K accumulation (mg/plant)	1,091	596 (-45%)	718 (-34%) (+20%)	655 (-40%) (+9.9%)	685 (-37%) (+15%)
Above-ground S accumulation (mg/plant)	140	63 (-55%)	83 (-40%) (+32%)	79 (-44%) (+25%)	73 (-49%) (+16%)
Above-ground Ca accumulation (mg/plant)	375	330 (-12%)	379 (+1%) (+15%)	409 (+9%) (+24%)	378 (+1%) (+15%)
Above-ground Zn accumulation mg/plant	2.2	0.3 (-86%)	1.8 (-18%) (+500%)	0.6 (-72%) (+100%)	0.8 (-64%) (+167%)
Grain Zn accumulation (mg/kg)	45	19 (-58%)	50 (+11%) (+163%)	38 (-16%) (+100%)	36 (-20%) (+89%)
Above-ground Fe accumulation (mg/plant)	14.9	5.96 (-60%)	4.14 (-72%) (-31%)	3.83 (-74%) (-36%)	4.86 (-67%) (-18%)
Above-ground Cu accumulation (mg/plant)	0.2	0.13 (-35%)	0.13 (-35%) (0%)	0.15 (-25%) (+15%)	0.15 (-25%) (+15%)
Above-ground Mg accumulation (mg/plant)	113	126 (+12%)	97 (-14%) (-23%)	99 (-12%) (-21%)	101 (-11%) (-20%)
Above-ground Mn accumulation (mg/plant)	5.19	5.38 (+4%)	4.76 (-8%) (-12%)	6.26 (+20%) (+16%)	5.42 (+4%) (+0.7%)

Values are means of 3 replicates. Percentage differences in upper and lower parenthesis, respectively, are comparisons between Control 1 and all other treatments and between Control 2 (excluding Control 1) and other drought treatments.

Under drought stress, Zn influenced nutrient acquisition differently, depending on the particle size. Bulk ZnO influenced N (increased), P (reduced), K (increased), Zn (increased), and Fe (increased) to a greater degree than nano ZnO. On the other hand, nano ZnO influenced Ca (increased), Cu (increased), and Mn (increased) more than bulk ZnO. Surprisingly, grain Zn concentration was increased more with bulk ZnO than with nano ZnO under drought conditions. This was surprising because of the supposedly better solubility and, thus, bioavailability of nano ZnO. A dose-specific effect on nutrient accumulation was also observed with the nano ZnO. At the higher application rate (5 mg Zn), the accumulation of N, P, K, Zn, and Fe was greater compared to the lower rate (3 mg Zn). Unlike total Zn uptake, grain Zn was slightly higher at the lower nano ZnO exposure rate than at the higher rate.

Details of the differential partitioning of these nutrients in root, shoot, and grain will be described in an upcoming journal publication. Overall, these results demonstrate that Zn can influence the uptake of nutrients under drought stress, leading to improvement in productivity under an otherwise adverse production condition. The improvement of grain Zn by Zn fertilization indicates the efficiency and relevance of agronomic fortification for improving the nutritional quality of food produce, which can be hard hit by environmental stressors such as drought. A follow-up study in which the effect of Zn on wheat productivity and nutrient dynamics under drought stress, with and without organic matter (OM) amendment in the soil, is currently underway. The study will, among other things, demonstrate the degree to which Zn modulates crop response to drought stress and how improving the soil OM content alters Zn effects on drought-impacted plants

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

Similar to the deficiency of Zn, widespread deficiencies of S, Cu, and B affect crop yields in our target countries. S and Cu deficiencies also affect human nutrition. Although B is the second most deficient micronutrient in crops (after Zn), it has no apparent role in human nutrition. Sulfur, a macronutrient, plays an important role in enhancing the methionine and cysteine (sulfur containing amino acids) content in legumes and has been shown to increase the nutritional quality of protein and to increase the proportion of legume protein that can be utilized by humans and non-ruminant livestock. Deficiencies of micronutrients, such as Zn and Cu, also increase the susceptibility of crops to infectious disease. The elemental sulfur (ES) evaluation trials to quantify S and N efficiency reported under Section 1.1.1.2 was partially funded by Shell.

Micronutrient Omission Trial Using a Combination of Zinc (Zn), Copper (Cu), and Boron (B)

A greenhouse-based micronutrient omission trial using a combination of zinc (Zn), copper (Cu), and boron (B) was completed with a publication. The objectives of the trial were: (i) to evaluate the differences in plant response to a mixture of conventional (bulk) vs nano Zn, Cu and B oxides and (ii) to assess the effects of nano and bulk Zn, Cu, and B omissions from the balanced nutrient fertilizers on the plant responses. In summary, soybean was exposed to the mixture of nano- (≤ 100 nanometer [nm]) and bulk-scale (≥ 1000 nm) oxide Zn (2 mg Zn/kg), Cu (1 mg Cu/kg), and B (1 mg B/kg) particles in soil and to omissions of each nutrient from the mixed systems. Compared to the control, mixtures of oxide particles of both sizes significantly (p<0.05) promoted grain yield and overall (shoot and grain) Zn accumulation, but it suppressed overall P accumulation. However, the mixed nano-oxides, not the mixed bulk-oxides, specifically stimulated shoot growth (47%),

flower formation (63%), shoot biomass (34%), and shoot N (53%) and K (42%) accumulation. Compared by particle size, the omission of individual elements from the mixtures evoked significant responses that were nano- or bulk-specific, including shoot growth promotion (29%) by bulk B; inhibition (51%) of flower formation by nano Cu; stimulation (57%) of flower formation by bulk B; grain yield suppression (40%) by nano Zn; B uptake enhancement (34%) by bulk Cu; P uptake stimulation by nano Zn (14%) or bulk B (21%); residual soil N (80%) and Zn (42%) enhancement by nano Cu; and residual soil Cu enhancement by nano Zn (72%) and nano-B (62%). Zn was responsible for driving the agronomic (biomass and grain yield) responses in this soil, with concurrent ramifications for environmental management (N and P) and human health (Zn nutrition). Overall, compared to bulk micro-elements, nano-scale micro-elements played a greater role in inducing plant responses. More broadly, the findings from the study indicated that in a fertilizer regime involving multiple elements, specific elements can promote distinct responses in the plant and that, within each element, the particle size of the fertilizer material is also important. Moreover, the fact that Zn, the most limiting nutrient in the test soil among the tested nutrients, evoked the strongest responses highlights the critical need to conduct soil tests prior to developing fertilizer recommendations. A manuscript entitled "Addition-Omission of Zinc, Copper, and Boron Nano and Bulk Oxide Particles Demonstrate Element and Size-Specific Response of Soybean to Micronutrients Exposure" has been published in the journal *Science of the Total Environment.* The article can be accessed at:
https://www.sciencedirect.com/science/article/pii/S0048969719306308?via%3Dihub

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

1.3.2.1 Best-Bet Trials in the Savanna Areas of Ghana

Nutrient omission studies were conducted in 96 sites across the entire savanna (Sudan and Guinea savanna) agroecological zones of Ghana in FY2018. The overall objective of the study was to use the SMaRT concept (Soil testing, Mapping, Recommendations development, and Technology transfer) to develop fertilizer recommendations for the northern regions of Ghana. Specific objectives were to quantify crops' response to S, Zn, and B, relative to the blanket NPK recommendation. The study also evaluated the synergistic effects of liming and balanced fertilization on the growth and productivity of maize in acidic soils, since a vast portion of the land in the study area had acidic soils with pH <6. The study sites fall into the USAID-FTF ZOI in Ghana.

Based on the soil fertility maps developed by IFDC, soils in the sites selected for the trials were grouped as acidic (pH <6) or near-neutral (pH >6). The acidic soils were further sub-divided into strongly acidic (pH <5.5) and moderately acidic (pH 5.5 – 6). Collectively, soils at 44 sites fell within the near-neutral classification, 23 in the moderately acidic classification, and 29 in the strongly acidic classification.

The trials consisted of a treatment containing the blanket N-P-K fertilizer recommendation; a treatment with the complete suite of potentially limiting essential plant nutrients, based on the soil fertility maps developed for the region ("balanced" treatment); and a set of omission treatments in which one essential limiting nutrient from the "balanced" treatment was omitted. At all locations, six treatments with four replications (24 plots) were evaluated, including: (i) Balanced (supplying all limiting nutrients), (ii) Minus Sulfur (- S), (iii) Minus Zinc (- Zn), (iv) Minus Boron

(- B), (v) NPK Only, and (vi) Check (0 nutrient). For the sites with near-neutral soil, the treatments were laid out in a RCBD. The plot size was 5 m x 5 m (25 m^2). Each plot consisted of six rows of maize 5 m long. Each treatment was randomly assigned to a plot within each block. For the sites with acidic soils, the experiments were laid in a split plot design. The first factor, liming treatment, was applied on the main plots, and the second factor, the six fertilization treatments stated above, were randomized on the subplots.

Effects of Balanced and Imbalanced Fertilization on Maize Grain Yield

Across the sites with near-neutral soils, average maize grain yield from the check treatment (no fertilizer application) was ~1.4 mt/ha. Applying only NPK, as practiced by most farmers in the area, increased maize grain yield to an average of ~4.5 mt/ha. However, by applying the complete suite of limiting nutrients, maize grain yield increased to an average of ~7.5 mt/ha (Table 12 and Figure 25), which is, on average, a ~68% increase in maize yield compared to the blanket application of NPK only. Compared to the "balanced" fertilizer treatments, the omission of S (- S treatment) reduced maize grain yield by an average of ~34%; omission of Zn resulted in an average of ~28% yield reduction; and omission of B resulted in an average of ~14% yield reduction (Table 12). Addition of S and Zn to the blanket NPK (i.e., - B treatment) resulted in an average maize yield increase of ~49%. Similarly, the addition of Zn and B to the blanket NPK (i.e., - S treatment), increased maize yield by an average of ~23%, while the addition of S and B (i.e., - Zn treatment) to NPK resulted in an average yield increase of ~29%, compared to NPK only (Figure 25).

Results from sites with moderately acidic soils followed similar trends, except that, in general, maize yields were lower from the moderately acidic soils than from the near-neutral soil (Table 12, Figure 25). As expected, maize grain yields from the strongly acidic soils were relatively lower compared to yields from the near-neutral and moderately acidic soils. Despite the low yield from the strongly acidic soils, fertilizer application significantly increased maize yield, and omission of a limiting nutrient (e.g., S) affected maize yield negatively (Table 12, Figure 25).

Combined Effects of Liming and Fertilization Treatments on Maize Grain Yields

Lime application significantly increased maize yield in the strongly acidic soils, regardless of the fertilizer treatment. Across sites in the strongly acidic soils, applying lime only, without any fertilizer, increased maize yield by an average of ~64%. For plots that received only NPK, liming increased yield by an average of ~57%. For the treatment with a complete suite of limiting nutrients, lime application resulted in an additional maize grain yield increase of ~53% (Table 13, Figure 26). For the moderately acidic soils, although there were significant interactive effects of liming and fertilization on maize grain yield, the magnitude of yield increases due to liming was not as large as in the strongly acidic soils. For example, whereas lime application alone increased maize yield in the strongly acidic soils by an average of ~64%, in the moderately acidic soils, the average increase due to liming was 31% (Table 13, Figure 26). For plots that received NPK only, liming led to an increase in yield of ~28%, and for the treatment with a complete suite of limiting nutrients, lime application resulted in an additional maize grain yield increase of ~27% (Table 13, Figure 26).

The combined data suggest that regardless of the nutrient omitted, the addition of the micronutrients and secondary nutrients to the soils with near-neutral pH significantly increased maize yield; for the strongly acidic soils, liming (reducing Al toxicity and Ca nutrition) is critical to increasing maize productivity. However, these results are from a one-season experiment only; they need to be repeated to validate the results.

Table 12. Effects of Imbalanced Fertilization in Grain Yields of Maize Produced in Soils of Different Acidity Levels

Treatments	Near-Neutral[a]		Moderately Acidic[b]		Strongly Acidic[c]		Moderately Acidic + Lime[d]		Strongly Acidic + Lime[e]	
	Grain Yield (mt/ha)	Average Decrease in Grain Yield (%)	Grain Yield (mt/ha)	Average Decrease in Grain Yield (%)	Grain Yield (mt/ha)	Average Decrease in Grain Yield (%)	Grain Yield (mt/ha)	Average Decrease in Grain Yield (%)	Grain Yield (mt/ha)	Average Decrease in Grain Yield (%)
Balanced	7.53 ± 1.65	-	5.30 ± 1.38	-	3.72 ± 1.07	-	6.76 ± 1.68	-	5.69 ± 1.17	-
Minus S	5.49 ± 1.20	34.2	3.92 ± 1.11	26.8	2.75 ± 0.61	26.1	4.93 ±1.08	28.4	4.10 ± 0.77	27.9
Minus Zn	5.78 ± 1.27	28.3	4.38 ± 1.27	17.4	3.49 ± 1.05	6.24	5.19 ± 1.32	23.2	4.87 ± 0.84	14.4
Minus B	6.66 ± 1.46	13.9	4.96 ± 1.93	16.9	3.67 ± 1.08	1.36	5.98 ± 1.48	11.8	5.04 ± 1.01	11.4
NPK only	4.48 ± 0.98	45.4	3.13 ± 1.59	40.6	2.27 ± 0.92	26.1	4.02 ± 1.25	43.7	3.56 ± 0.64	37.8
Check	1.40 ± 0.32	84.1	0.96 ± 0.27	81.7	0.71 ± 0.22	60.3	1.26 ± 0.32	80.6	1.17 ± 0.19	79.3

a. Numbers are mean values of 176 (44 locations x 4 reps) replicates ± standard deviation from the mean.
b. Numbers are mean values of 92 (23 locations x 4 reps) replicates ± standard deviation from the mean.
c. Numbers are mean values of 116 (29 locations x 4 reps) replicates ± standard deviation from the mean.
d. Numbers are mean values of 92 (23 locations x 4 reps) replicates ± standard deviation from the mean.
e. Numbers are mean values of 116 (29 locations x 4 reps) replicates ± standard deviation from the mean.

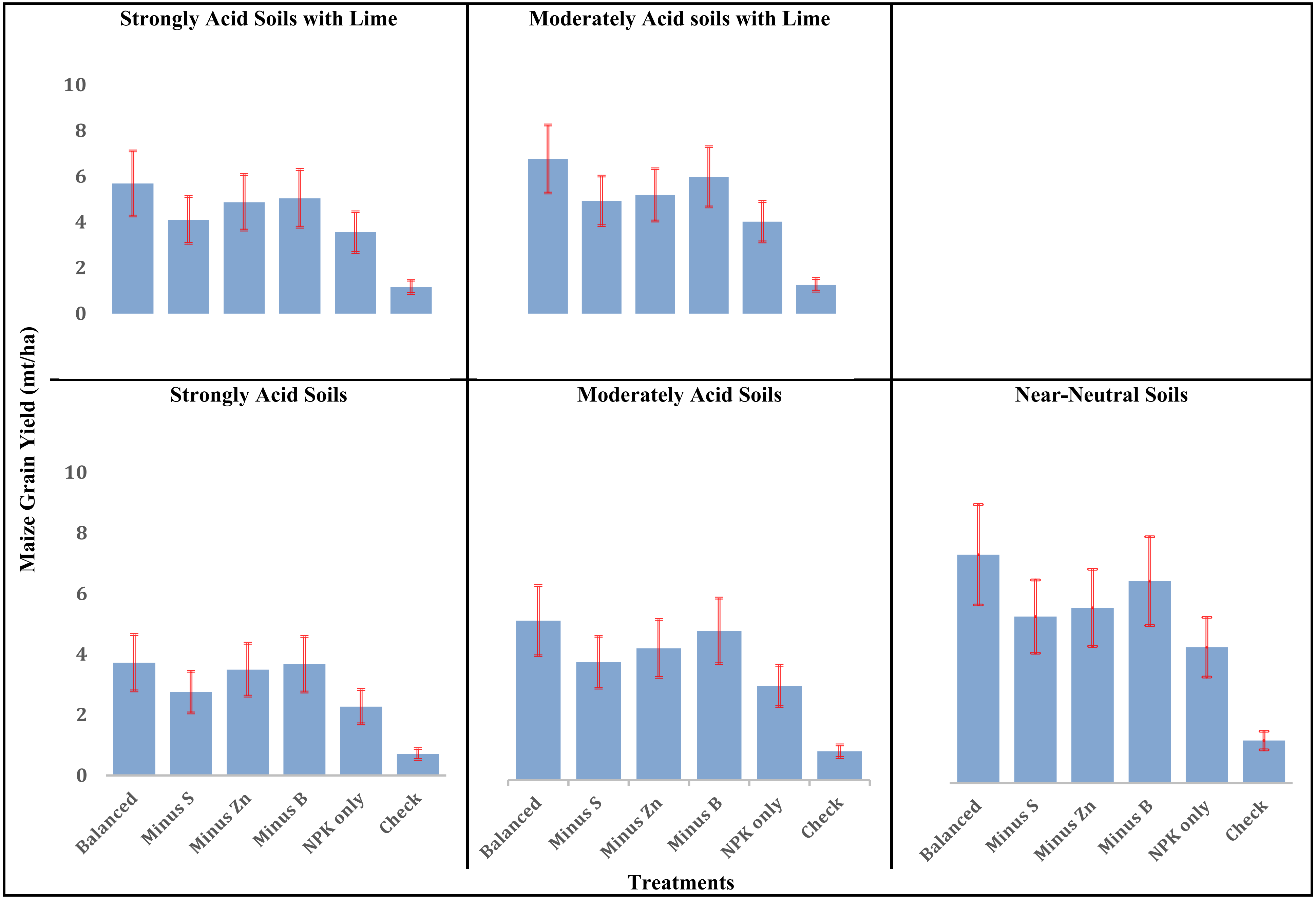


Figure 25. Average Maize Grain Yields as Affected by Omission of Limiting Essential Nutrients

Table 13. Effects of Liming on Grain Yields of Maize Produced in Soils of Different Acidity Levels

Treatments	Strongly Acidic Soils[a]			Moderately Acidic Soils[b]		
	No Lime	With Lime	Average Increase in Grain Yield	No Lime	With Lime	Average Increase in Grain Yield
	Grain Yield (mt/ha)		(%)	Grain yield (mt/ha)		(%)
Balanced	3.72 ± 1.07	5.69 ± 1.17	53.0	5.30 ± 1.38	6.76 ± 1.68	27.5
Minus S	2.75 ± 0.61	4.10 ± 0.77	49.1	3.92 ± 1.11	4.93 ±1.08	25.8
Minus Zn	3.49 ± 1.05	4.87 ± 0.84	39.5	4.38 ± 1.27	5.19 ± 1.32	18.8
Minus B	3.67 ± 1.08	5.04 ± 1.01	37.3	4.96 ± 1.93	5.98 ± 1.48	20.6
NPK only	2.27 ± 0.92	3.56 ± 0.64	56.8	3.13 ± 1.59	4.02 ± 1.25	28.4
Check	0.71 ± 0.22	1.17 ± 0.19	64.8	0.96 ± 0.27	1.26 ± 0.32	31.3

a. Numbers are mean values of 116 (29 locations x 4 reps) replicates ± standard deviation from the mean.
b. Numbers are mean values of 92 (23 locations x 4 reps) replicates ± standard deviation from the mean.

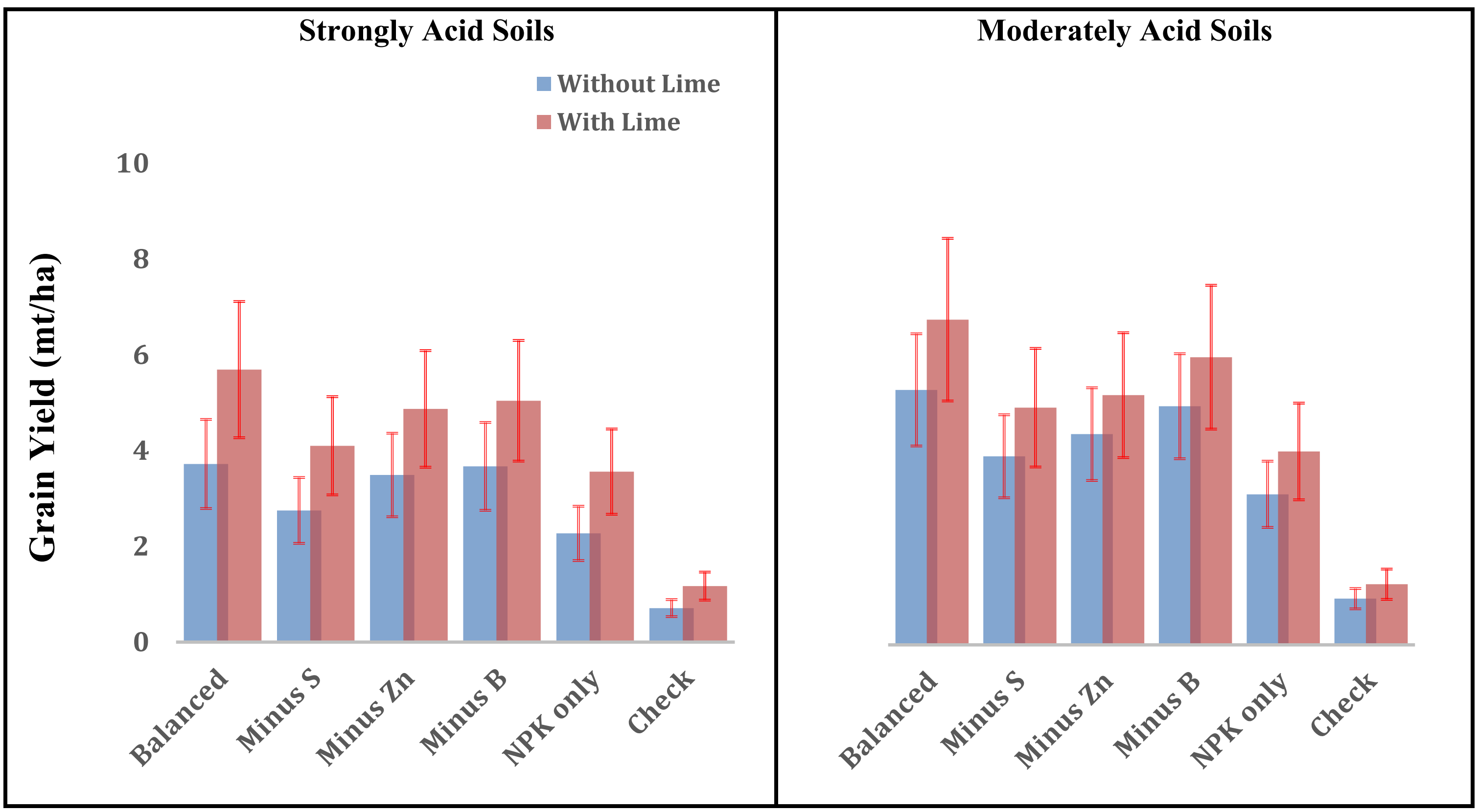


Figure 26. Effects of Liming and Fertilization Treatments on Yield of Maize Grown on Soils of Different Acidity Levels

Next Steps

1. Plant tissue analyses to determine nutrient uptake on selected plots.
2. Based on lessons learned from the FY18-19 trials, we have refined our approach for the FY19 and repeated the trials at selected (few) locations to validate the results of FY19.
3. Conduct economic analyses to determine if the value of losses due to nutrient omission and/or liming are large enough so that their inclusion is economically justified.
4. Based on the economic analysis, develop a "best-bet" formulation and recommendation for the region.

1.3.2.2 Correlating Crop Response to Soil Analysis

The objective of this research is to provide the evidentiary basis for interpreting both wet chemistry and spectral analyses into robust fertilizer recommendations for focus food crops. This will ensure that the value of ongoing soil mapping efforts by IFDC and others is valorised to its maximum potential, and its accuracy is understood. Using omission trials to determine individual nutrient responses, we will directly correlate wet chemistry and spectral scans of soils from research plots. Multivariate correlations will be employed to understand which soil variables should be included in interpretations. For spectral analyses, machine learning algorithms will be employed to identify the spectral signals that lead to the best correlations of response for individual nutrients. The results from ongoing and proposed omission trials (Section 1.3.2.1) will be used for this activity.

Analysis of Unreplicated Balanced Fertilization Experiments

Due to land restrictions, agricultural experiments on smallholder farms are often conducted without actual replications. Using fields as replications and performing the analysis of variance (ANOVA) with a RCBD model can result in misleading conclusions about a treatment's performance. A better alternative is using the spatial variability modeling features of the Generalized Linear Mixed Model (GLMM) to generate an error term that can perform unbiased hypothesis tests. Non-replicated trials conducted across 175 farmers' fields in Burundi to estimate the response of red beans to three fertilizer treatments were used to test the above hypothesis. A paper presenting the statistical methodology for the analysis of the above experiment by J. Sanabria and J. Wendt, "Statistical Analysis of Non-Replicated Experiments in Farmers' Fields. A Case of Balanced Fertilization Trials for Bean in Burundi," has been accepted for publication in *Agronomy Journal*.

1.3.2.3 Expanding Spectral Analytical Techniques to Fertilizer Analysis

The objective of this research is to create the opportunity to use low-cost spectral capabilities and eventually set up "laboratories" in countries or regions lacking good quality analytical laboratories for fertilizer testing. By using low-cost spectral techniques, these countries will be able to conduct, for the first time, a qualitative analysis of fertilizer samples. Since the last report, progress has been made in collaboration with the private company Optionline. Optionline has developed a low-cost near-infrared (NIR) instrument that can rapidly evaluate the nutrients in fertilizer samples. A significant amount of research has been done using this technique for plant tissue, soil, and fertilizer analyses. However, the successful use of this technology has been reported mainly in institutions where sample matrices do not vary a lot. For this project, IFDC participated in initial discussions and research planning.

In partnership with ICRAF, we have been trying to better understand and verify the validity of the methodology. Although results have been promising, the analyses did show weaknesses with some samples. Under ongoing collaboration with ICRAF, simple models are being developed to recognize if a given fertilizer is within a range or not. This will enable government bodies, such as regulators, to quickly and cost effectively evaluate fertilizers in the market. It will also allow IFDC to commence testing specialty products that are currently in the market.

So far, some very promising results have been obtained with NIR compared to a colorimetric methodology. The initial assessment has shown models with R^2 between 0.78 to 0.98, when using a quantitative model (Figure 27).

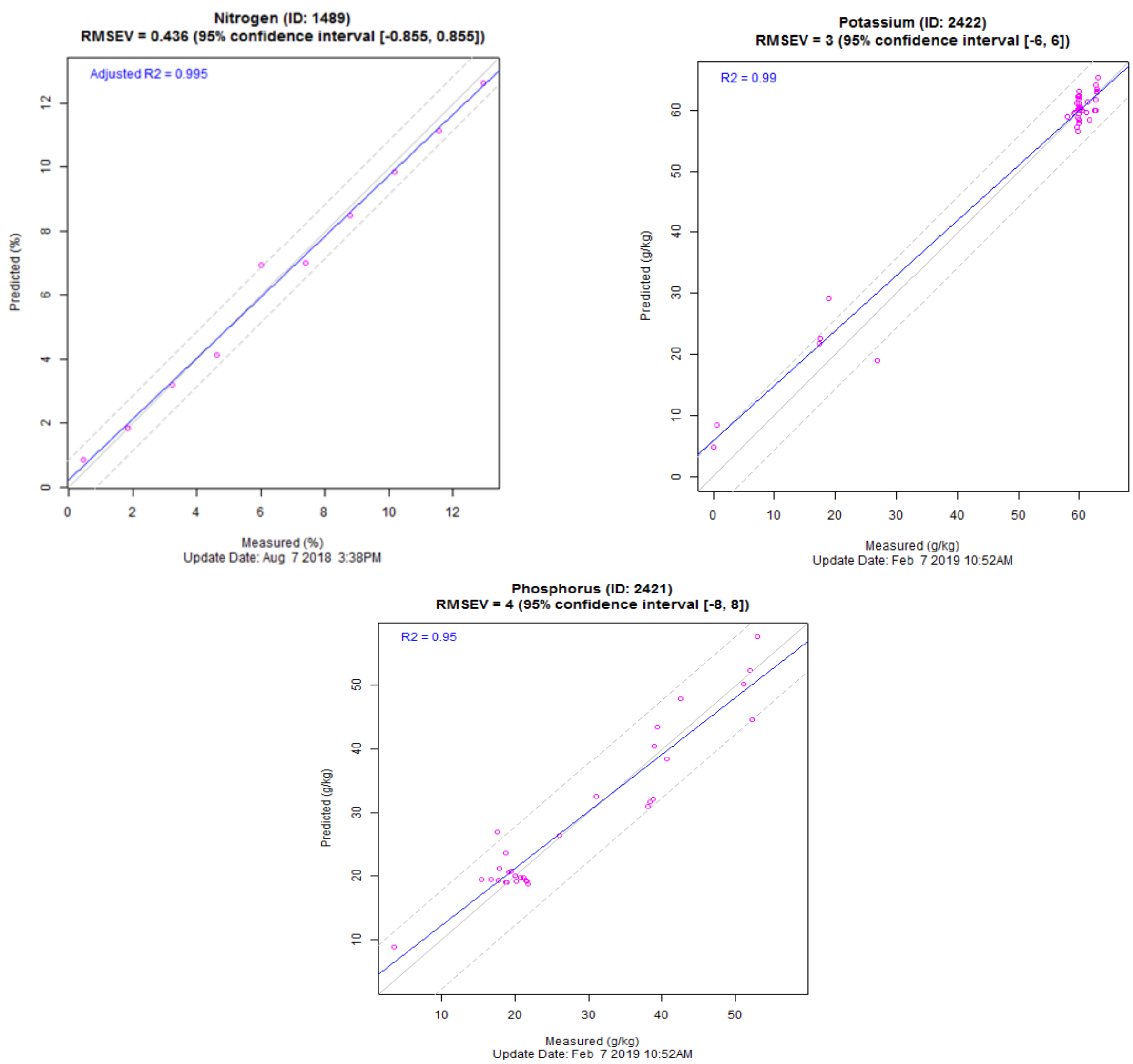


Figure 27. Nitrogen, Potassium and Phosphorus Measurements of NIR Compared to Colorimetric Analysis

Besides fertilizer assessment, IFDC and Optionline have begun initial testing of an innovative technique for soil and plant analyses. Figure 23 shows examples of the initial results on corn sap analysis for phosphate and copper, compared to colorimetric methods. Opportunities exist to improve the methodology and evaluate its application in the agriculture sector.

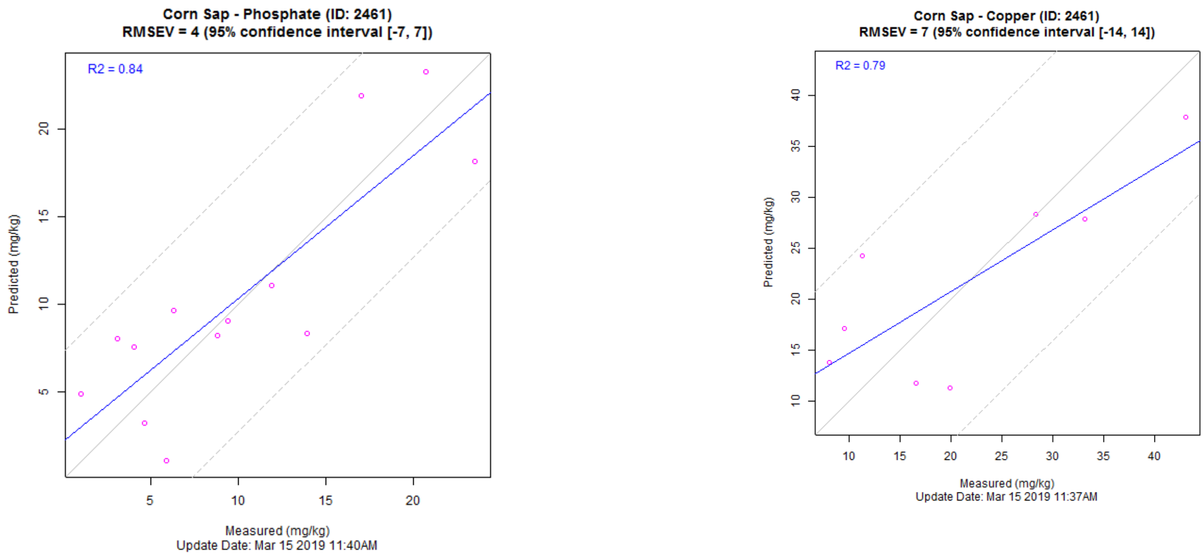


Figure 28. Corn SAP Analysis for P and Cu Comparison with Colorimetric Methods

1.3.2.4 Maize Nutrient Deficiency Mapping in the Beira Corridor, Mozambique

Under this activity, IFDC, in partnership with the African Fertilizer and Agribusiness Partnership (AFAP), Instituto Superior Politècnico de Manica (ISPM), and the fertilizer company Yara, have continued to collect soil samples in the Mozambique-Beira corridor to understand likely deficiencies in maize. The process involves soil sampling and mapping of nutrient deficiencies, soil acidity constraints, and other soil-related production constraints.

The initial idea was to support the above partners in developing soil maps. Unfortunately, these partners did not collect soil samples in maize-based farming systems. Therefore, efforts were centered on technical backstopping for the FAR (Food security through climate Adaptation and Resilience in Mozambique) project in Buzi district. Using its own funds, the FAR project collected and analyzed soil samples in the rice-based farming systems. Based on our experience, linkages were made between the FAR project and potential service providers for soil nutrient mapping. A tender has been launched by FAR, and the received proposals are being analysed. FAR expects to develop three maps (three sub-locations); each map will have a spatial resolution (pixel-size) of 250 m x 250 m. The main soil fertility parameters and nutrients to be mapped are pH (KCl), Total C, P, K (ppm), K (saturation), S, Mg (ppm), Mg (saturation), Ca (ppm), Ca (saturation), Zn, Cu, and B.

The objective of the maps is to ascertain areas with potential nutrient and soil pH constraints, as well as toxicities and salinity, that need to be corrected. Such maps will be valuable tools for fertilizer companies to target their products for crop-specific needs, based on their best interpretation of the results. IFDC can provide backstopping in the interpretation of the results so that companies can produce fertilizer blends that address crop needs as well as maximize the return on investment. Maps are also powerful tools for informing policy and agricultural research priorities. Many countries are unaware of the extent of the various nutrient and soil acidity constraints affecting yields. Thus, soil maps can spark interest in the need to develop and support balanced fertilizers.

The role of IFDC, through BFS-USAID funding, is to provide backstopping to the FAR project. This is an on-going activity, and we expect to provide the maps in the next report.

1.3.2.5 Development of Balanced Fertilizer for Rice Production in Mozambique

Based on soil analysis results and expert knowledge, IFDC, in collaboration with Yara, developed a rice fertilizer blend that has been demonstrated to smallholder farmers in Buzi district, central Mozambique. This is part of IFDC's support to the FAR project. Simultaneously, IFDC, in collaboration with Yara, local agro-dealers, farmers, and government extension officers, established 15 on-farm nutrient omission trials in the rice-based cropping systems of Buzi district. These trials are to evaluate yield response and economic returns to sulphur, zinc, boron, copper, and lime products. Copper was applied as basal and foliar applications (topdressing). The omission trials were combined with the evaluation of urea briquettes and slow-release urea. Both demonstration and omission trials were established at the onset of the 2018/19 cropping season (December 2018), and yield results will be reported in the next annual report after the crops are harvested.

Figure 29. Farmers Discussing the Performance of Fertilizer Blends during a Field Day

Field days are ongoing activities in close collaboration with Yara, smallholder farmers, and the government extension officers. The IFDC FAR project has established 148 on-farm demonstration trials of new fertilizer blends.

1.3.2.6 Nutrient Omission Trials in Senegal

The aims of this activity are to conduct nutrient omission and rate trials to quantify the effect of key nutrients, including secondary and micronutrients, on millet and peanut yields and economic returns in Senegal. Within the integrated soil fertility management (ISFM) – conservation agriculture (CA) trials, improved nutrient management practices and high-yielding stress-tolerant varieties will be common. The proposed activity will be conducted with NARES partners, specifically ISRA (Institut Senegalais de Recherche Agricole). A draft of the testing protocol has been developed and is being finalized with ISRA to begin the omission trials in June 2019. In addition to major NPK nutrients, S, Zn, and B will be included in the fertilizer formulations to be evaluated. The test crops are millet and peanut. The anticipated sites are Bambey, Nioro, and Tambacounda for millet and Nioro and Kolda for peanut. Details of the trial setup will be made available in the next report.

It is expected that 60-100 nutrient omission trials will be established in various agro-ecological zones of Senegal for millet and sorghum.

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

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

1.4 Sustainable Intensification Practices: Integrated Soil Fertility Management

Poor residue and fallow management and a focus on monocropping (rice, wheat, maize, cassava), combined with soil inherently low in organic matter, can result in increased vulnerability to climatic variability and environmental degradation. Such negative effects of agricultural intensification without integrated soil fertility management (ISFM) and conservation agriculture (CA) are evident in the social, economic, and environmental impacts in South Asia, Southeast Asia, and sub-Saharan Africa. The activities described below combine ISFM and CA to develop climate-smart cropping systems for rice in Cambodia and Mozambique, and for maize in Ghana.

1.4.1 Nutrient Recycling

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

Effective recycling of nutrients using black soldier fly larvae to enhance shelf-life and use efficiency of poultry manure, and the evaluation of biofertilizers, will be conducted with private sector and university partners. This activity will also involve a partnership with Auburn and Tuskegee universities to evaluate soil health parameters. Protocols for the above activity have been developed, with field and laboratory studies starting in late May.

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

Assessing Changes in Soil Organic C and N Stocks and Soil Functions of Sandy Paddy Fields under Conventional Tillage and Conservation Agriculture Production Systems

Partners involved in this activity include the following:

- Royal University of Agriculture (RUA): Center of Excellence on Sustainable Agricultural Intensification and Nutrition (CE SAIN) and Faculty of Agronomy, Phnom Penh, Cambodia.
- General Directorate of Agriculture (GDA), Department of Agricultural Land Resources Management (DALRM), Conservation Agriculture Service Center (CASC), Cambodia.
- Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD), Cambodia.
- Sustainable Intensification Innovation Lab (SIIL), Kansas State University, Manhattan, Kansas, USA.

The intensification of rice farming over the last 10 years in Cambodia has generated significant increases in rice productivity, but it has also raised several questions related to economic profitability, food quality, and environmental sustainability. Among several factors, the improvement of soil health should be a central element of the sustainable intensification process. Rice farming is based on the principles of the green revolution, with an increasing use of inorganic fertilizers, pesticides, and conventional tillage management (plough, rotovator, harrowing) inducing a continuous depletion of soil fertility.

A diversity of soils exists, depending on their position in the toposequence, with a gradient from the upper sandy terraces to the clayey soils of the hydromorphic plains of the Tonle Sap Lake. Since 2011, a paired-plot design has been implemented in the Stung Chinit irrigation scheme (Santuk district, Kampong Thom province) to assess the performances of conventional tillage (CT) and conservation agriculture (CA) production systems using legume cover crops. The field experiment is located at Kampong Thom province (12°32’55” N and 105°08’47” E). The soil is characterized as sandy soil that is more than 70% sand at a depth of 0-40 cm. The soil is classified as Prey Khmer group in the Cambodian Agronomic Soil Classification System (White et al., 1997) or Fluvisols/Arenosols in FAO-soil taxonomy (FAO 2006). The objectives of the study are:

i. To quantify the soil organic C (SOC) and N storage using a diachronic approach based on a paired-plot comparison of paddy fields under CT and CA during different years (2014 and 2018).
ii. To assess the changes of three main soil functions (Biofunctool® approach: C transformation, soil structure, and nutrient cycling) between CT and CA. For the diachronic analysis, two soil sampling periods were used, December 2014 and December 2018 (0-5, 5-10, 10-20, and 20-40 cm depth). The Biofunctool® approach was conducted on the soil samples collected in December 2018 at 0-10 cm depth.

Figure 30. Vira Leng (left), Cambodian Conservation Agriculture scientist, explaining the benefits of conservation agriculture with soil blocks taken from the forest, a conservation agriculture farmer field, and a conventional tilled field (Photo courtesy of Swisscontact). A closer look at the soil blocks from different soil management practices (right).

Soil Sampling and Analysis Progress

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

- 592 bulk soil samples collected from four soil depths (0-5, 5-10, 10-20, and 20-40 cm) were air-dried, sieved, and ground. These soil samples will be used for the analysis of total N, SOC, and SOC fractions (hot-water extractable organic C and permanganate oxidizable organic C). SOC fractions are being analyzed in the Soil Lab of the Royal University of Agriculture.
- 52 soil samples collected from one depth (0-10 cm) were analyzed using The Biofunctool® approach, including soil respiration, available N, available P, permanganate-oxidizable C (POXC), pH, Lamina bait, litter index, water infiltration, and aggregate stability. All variables have been analyzed except the aggregate stability.

Summarizing Data for Long-Term Predictions of Soil Health

The team is planning to collect and parameterize the data from the plots for long-term modeling using either the SWAT, APEX, or DSSAT models. The hiring of graduate students who will do the modeling is still being arranged.

Cover Crop and Mechanization

Activities on aspects of cover crop seed production and use of mechanization for effective soil preparation are in progress and will be included in the next report.

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

Since most farmers in the target areas have no access to water for cultivation of vegetables as an off-season option, the cultivation of chickpea as an alternative crop in rotation with rice is being evaluated in Mozambique. Chickpea is a new crop for farmers; thus, its cultivation requires close collaboration with extension and research services. This activity will complement the ongoing IFDC FAR project in Mozambique. However, because chickpea is a winter crop, the planned activity will start in late April or early May 2019. Apart from chickpea, groundnut has also been included as an additional legume crop for smallholder farmers. Working with Yara and the USAID-funded FTF project, Improved Seeds for Better Agriculture (SEMEAR), 20 on-farm demonstration trials were established in January in Chibabava district. This was done in collaboration with smallholder farmers, agro-dealers, and government extension officers in order to evaluate groundnut varieties (*CG7* and Chitala), fertilizer application, and rhizobial inoculation effects as well as the interaction between fertilizer and inoculation. In these demonstrations, SEMEAR provided seeds, Yara provided fertilizer, and IFDC provided the human resource, including implementation, farmers with land and labor, and extension officers to assist with field monitoring.

Figure 31. Groundnut Fields in Chibabava District

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

The synergistic effect of CA practices in combination with an activated PR amendment as a component of ISFM was evaluated as a means to alleviate drought and soil acidity stress on maize in northern Ghana using a drought-tolerant variety. The research will compare the performance of maize under CA versus non-CA (main plot) and activated PR and DAP rates (subplot). It is envisaged that the soil amendment with activated PR as a nutrient source will improve rooting and drought-tolerance while reducing soil acidity. This activity will be carried out in partnership with the Africa Rising project, commencing during the onset of the main farming season in northern Ghana. Sites for the trials are being selected and demarcated, and all soil amendments have already been acquired to establish the trials.

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

IFDC has lost expertise in database management and programming during the past few years due to budget reductions. Given the large amount and types of biophysical and socioeconomic data, IFDC is planning 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.

The partnership with the University of Florida will also be used to improve the existing soil dynamics model in the DSSAT Cropping System Model using the soils and agronomic data generated by IFDC over past years. The geospatial addition to the DSSAT software, GSSAT, originally developed by IFDC, will be refined and evaluated using spatial soil data from Ghana and Burkina Faso. The database and decision support tools will help in making timely and reliable recommendations on fertilizers, sowing dates, and other management inputs covering a wide range of biophysical and socioeconomic conditions.

Status of Deliverables – September 30, 2019

Task	Activity	Deliverable	Status on 2019-02-28
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.	See detail below.
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.	See detail below.
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 3 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-CSM with at least one of the priority rice model improvement 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 include 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, US 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

Task	Activity	Deliverable	Status on 2019-02-28
C. Improvements to the GSSAT spatial modeling platform			
C.1. *	Complete input data reading and file generation, link with the latest DSSAT version, and generate recommendation maps merging input and simulated data	GSSAT with completed input data reading and file generation.	See detail below.
		GSSAT linked with latest DSSAT-CSM version.	No action this reporting period
C.2.	Expand applications to other countries, explore buy-in opportunities, conduct training program	GSSAT version which generates recommendation maps merging input and simulated data.	No action this reporting period
		Resources to expand GSSAT applications to other countries identified.	No action this reporting period
D. Development of IFDC database for biophysical and socioeconomic modeling			
D.1 *	Install database at IFDC, including authentication system for user access	AgMIP Crop Site Database installed at IFDC.	No action this reporting period
		Functional user authentication system for IFDC Crop Site Database.	No action this reporting period
D.2. *	Develop searchable metadata definitions to harmonize with CGIAR data system	Searchable metadata to allow harmonization with CGIAR data system identified.	No action this reporting period
D.3. **	Develop database interface to allow users to access the database	Database user interface conceptually designed.	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	

1.5.1 Activity A1 – Soil C balance

Figure 32 presents the components to consider in the soil C balance report for the CERES soil organic matter module in the DSSAT Cropping System Model. If the "system boundary" is drawn around the soil column, the state variables are the soil C stored in each soil layer. These are compartmentalized into SOM (soil organic matter) and FOM (fresh organic matter). FOM is increased in the system by the application of organic matter amendments, senescence of roots and other plant matter, and any crop residues that are not removed from the field at harvest. FOM is reduced by decomposition, which moves C into SOM pools and CO_2 released into the atmosphere. SOM is also reduced by decomposition accompanied by the equivalent release of CO_2 into the atmosphere. A tillage event can redistribute and mix the organic matter within the soil profile.

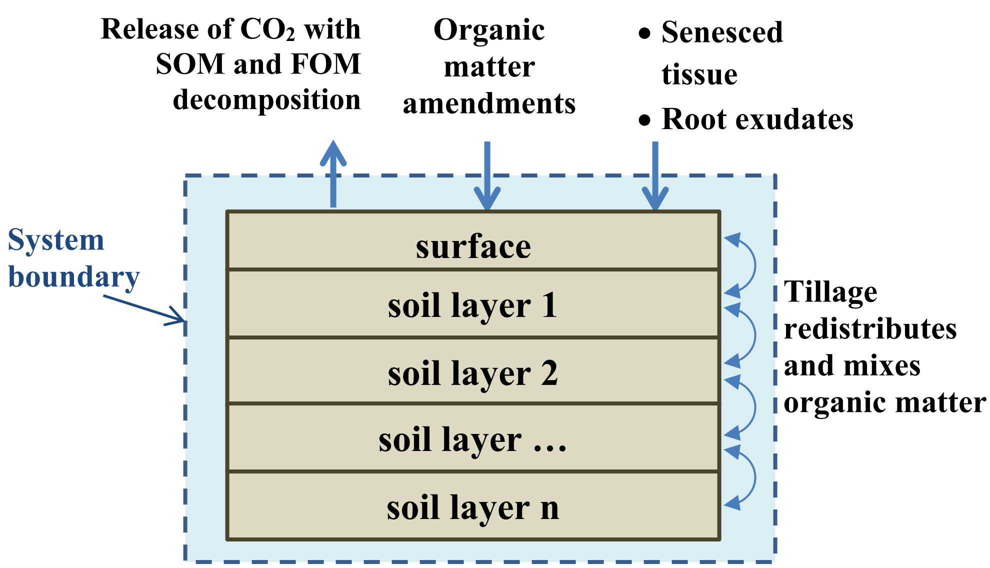


Figure 32. Components of a Soil C Balance Routine

Eq. 1 presents a simple mass balance equation.

$$\Delta OC = Inputs - Outputs \qquad \text{Eq. 1}$$

Where ΔOC is the sum of the change in mass of all state variables, $Inputs$ represents the sum of all inputs, and $Outputs$ represents the sum of all outputs from the system. This mass balance is based on soil components only and does not include plant processes, except as they influence the soil organic matter.

The additions to the system are organic matter amendments, senesced plant tissue to surface and soil, and harvest residues left in the field after harvest. The removal of C from the system comes from the release of CO_2 with SOM and FOM decomposition. There is some difficulty involved with defining these additions of C from plant components because each crop model in DSSAT will handle these differently. There has been some standardization through the use of the variables SENESCE and HARV_RES. However, some models, such as CERES-Maize, also produce root exudates which may not be captured in these variables.

The state variables to track in the balance are soil and surface organic SOM-C and soil and surface FOM-C.

A seasonal soil C balance was added to the model, producing an output as shown in Box 1. A daily balance has also been added (with switch IDETL = "D") for debugging and detailed analysis. For six crops tested, plus for a fallow simulation, the balance is within tolerable limits (all balances less than 0.02 kg/ha per season).

Box 1. Seasonal Soil C Balance

```
!                                                 Initial              Final
!                                                Year/DOY            Year/DOY
!                                                1978-165            1978-293
! SOIL C BALANCE                                 --------- kg[C]/ha ---------
!  SOIL & SURFACE ORGANIC C
!   Soil Organic C                               38919.00            38807.24
!   Surface Organic C                                0.00                0.00
!   Soil Litter C                                   40.00              280.55
!   Surface Litter C                                 0.00             1087.10
!                                                --------            --------
!   Total C in Soil and Surface Layers           38959.00            40174.89
!  ADDITIONS AND REMOVALS:
!   C in Harvest Residues from Previous              0.00
!   C from Organic Applications                    400.00
!   C in returned senesced material               1557.14
!   CO2-C emitted                                                      741.25
!                                                --------            --------
!     TOTAL C BALANCE                            40916.14            40916.14
!   Balance                                                            -0.001
```

However, testing with a wider set of data revealed that the soil C balance is not zero for all datasets. Further investigation is needed to determine what conditions cause the imbalance and to fix the issue.

1.5.2 Activity A2 – N_2O Emissions Module

The N_2O emissions module has been fully implemented in DSSAT-CSM. There are currently four options to run the greenhouse gas emissions simulation:

1. Godwin soil organic matter module with CERES-based denitrification routine
2. Parton soil organic matter module with CERES-based denitrification routine
3. Godwin soil organic matter module with DayCent-based denitrification routine
4. Parton soil organic matter module with DayCent-based denitrification routine

Both of the soil organic matter modules export soil C in fresh organic matter (LitC in Figure 33), soil C in humic matter (SSOMC), and the CO_2 released as a byproduct of the decomposition (newCO_2). The DayCent denitrification routine accepts the new CO_2 as a measure of the decomposition of organic matter, and this variable is used in further calculations of denitrification and N-gas losses.

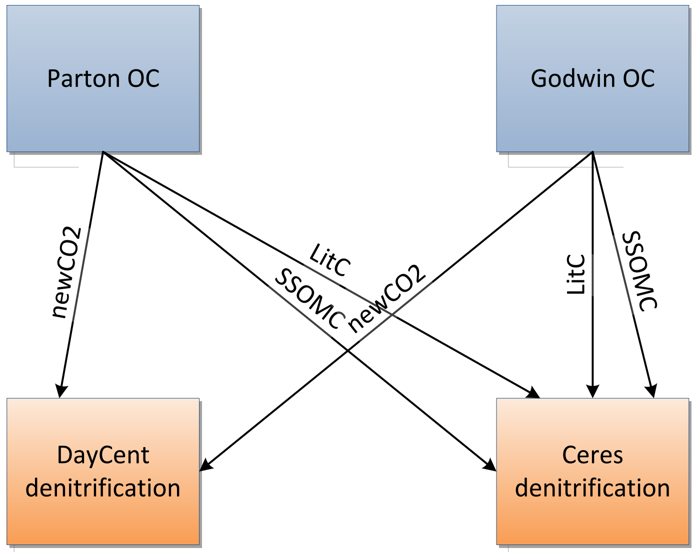


Figure 33. Simplified Schematic of Variables Used in N_2O Emissions Routines

The CERES denitrification routine has not been modified from the original, and it still accepts the soil organic matter pools to estimate denitrification, as previously. Total N from denitrification is proportioned between N_2O and N_2. New code has been added to estimate the proportions of N_2 and N_2O gases generated. Two methods of calculating the ratio of N_2:N_2O are provided: one based on NO_3 only and the other based on the water-filled pore space and the number of previous wet days. The maximum of the two ratios is used to compute N_2O and N_2 gases. Box 2 presents the new code.

Box 2. Determination of N2O and N2 gases from denitrification in CERES-based denitrification routine.

```
!         N2:N2O Ratio METHOD 1
!         Calculation of n2odenit based on ratio (N2O/total denit) determined from
!           original DayCent dataset of DelGrosso (PG) assuming denitrif = N2O + N2
          Rn2odenit = NO3(L)/(NO3(L)+30.)
          ratio1(L) = 1./Rn2odenit - 1.

!         N2:N2O Ratio METHOD 2
!         Count the number of days that water filled pore space is above 0.80
          if (wfps(L) >= 0.80) then
            ndays_wet(L) = min(7, ndays_wet(L) + 1)
          else
            ndays_wet(L) = 0
          endif

!         modify Rn2n2o based on number of wet days
          if (ndays_wet(L) > 0) then
            ratio2(L) = -330. + 334 * wfps(L) + 18.4 * ndays_wet(L)
            ratio2(L) = max(ratio2(L),0.0)
          else
            ratio2(L) = 0.0
          endif

          Rn2n2o(L) = max(ratio1(L), ratio2(L))
          n2odenit(L) = denitrif(L) / (Rn2n2o(L) + 1.0)
          N2FLUX(L) = DENITRIF(L) - n2odenit(L)    ! PG
```

Both daily and seasonal emissions of N_2O, N_2, and CO_2 from soil organic matter decomposition are simulated. Additional testing must be done to evaluate the performance of the model.

1.5.3 Activity C1 – GSSAT – DSSAT linkage

After installing the latest Delphi compiler 10.3 and supporting libraries, existing GSSAT sources were compiled and tested. Several issues related to updated libraries were resolved. Current work involves integrating CSM v4.7.5 to replace CSM v4.5. This includes generating updated *.SNX files containing data on various inputs and simulation settings as well as updating the *.DRV4 file (DSSAT batch file) used to run CSM from a command line. Most of the work for generating both files is done, but there are still several errors to be resolved.

1.5.4 Advance DSSAT Rice Model Training

The Decision Support System for Agrotechnology Transfer (DSSAT) crop productivity model is in use at SERVIR-Mekong by staff involved in regional crop yield and drought information systems. Droughts in the Lower Mekong region negatively impact ecosystem services, food and water security, and biodiversity. The DSSAT has been used in combination with Asian Disaster Preparedness Center (ADPC) Regional Hydrologic Extremes Assessment System (RHEAS), using a Variable Infiltration Capacity Model (VIC) developed by NASA, to predict rice yields in the different environmental conditions. This training helped the ADPC / SERVIR-Mekong staff better understand the science and the DSSAT tools to more adequately interpret the outcomes of the crop modeling.

The weeklong training program at ADPC in Bangkok, Thailand, Nov 26 - 30, 2018, was attended by five SEVIR-Mekong Hub staff from Thailand, Vietnam, and Cambodia.

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

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

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

2.1 Document Policy Reforms and Market Development

Workstream 2 activities on policy processes support efforts that provide the necessary impetus to catalyze reforms to existing policies. The aim is to create an environment that encourages private sector investments that will result in increased access to input markets by smallholder farm households. With BFS support, IFDC is partnering with organizations and stakeholders at various levels in countries that show high potential for policy change to: (a) support the reform processes utilizing evidence-based approaches and (b) build the capacity of stakeholders toward effective implementation of reforms. In FY2019, IFDC is engaging in the following set of sub-activities with associated deliverables.

2.1.1 Support for Kenya Fertilizer Roundtable Meeting and Policy Reform Processes

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

A detailed agenda for the proceedings and the presentations can be found at www.ifdc.org/KeFERT.

The presentations can be downloaded at https://ifdc.org/presentations-given-at-the-2018-kenya-fertilizer-round-table/.

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

2.1.2 Capacity-Building Activities: Policy Reforms

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

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

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

2.1.3 Documenting Global and SSA Fertilizer Market Trends and Outlook

IFDC is a member of the International Fertilizer Experts Working (IFEW) group, a World Bank initiative that has been carried out by the Food and Agriculture Organization (FAO) of the United Nations for the past 20 years, with participation from the private global industry and IFDC. During 2018, IFDC personnel collected/updated, validated, and analyzed data for projections on fertilizer consumption and demand, with a focus on SSA. The outputs of the annual IFEW group meeting are joint projections of fertilizer supply, demand, and supply-demand balances to be published in an IFEW joint World Fertilizer Trends and Outlook (WFTO) report, issued annually by FAO. Projections were presented, discussed, and further validated with the IFEW group, and in some cases, the projections were replaced based on group consensus. According to an FAO representative, although all data have been validated by the group, the WFTO is still in the revision process among the IFEW group members before its final publication by June 2019.

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

This is an ongoing activity initiated in 2015, when IFDC joined the Partnership for Enabling Market Environments for Fertilizer in Africa (PEMEFA), a Michigan State University (MSU)-led "consortium" of five organizations to undertake policy research in Africa for advocating reforms. The five members of the consortium are MSU, AFAP, the Regional Network of Agricultural Policy Research Institute (ReNAPRI), the New Markets Lab (NML), and IFDC. The main objective of PEMEFA is to bring together relevant organizations that can facilitate fertilizer-related policy changes by engaging with policymakers. PEMEFA received a $200,000 grant to initiate the process and start developing joint proposals. The initial activities were partly funded under a grant from MSU, but further work will depend on additional institutional contributions or successful joint fundraising opportunities.

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

- A policy brief on "ECOWAS Fertilizer Regulatory Framework: Implications for the Development of Private Sector-Led Supply of Quality Fertilizers in West Africa" by Bocar Diagana, Emmanuel Alognikou, Porfirio Fuentes, Joaquin Sanabria and Latha Nagarajan
- A concept note on proposed research activities for the ECOWAS fertilizer regulatory and policy framework.

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

- Five-year PEMEFA technical proposal: Some of the proposed research activities under the concept note mentioned above were selected and integrated into a proposal developed by PEMEFA to seek additional funding beyond the AAP grant. One of the targeted sources is the Bill and Melinda Gates Foundation. For this reason, the PEMEFA group held preliminary discussions to identify key potential themes in line with the Gates Foundation's current agenda.
- AAP final report: IFDC thoroughly reviewed and suggested revisions.

Finally, upon request from *Fertilizer Focus*, a leading magazine in the fertilizer industry, an article titled "Beyond subsidies: How else can African governments support private sector investment in fertilizer value chains?" was submitted by PEMEFA for publication in a forthcoming edition of the magazine. Bocar Diagana, IFDC regional economist for North and West Africa, co-authored the article. Diagana is also presenting the article at the West Africa Fertilizer Forum held in Lomè, Togo, during April 24-26, 2019.

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

2.1.5 Policy Briefs on Fertilizer Policies and Market Development

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

IFDC anticipates producing two country-level policy briefs that detail fertilizer market conditions, the role of private and public sectors, and policy reform processes documented for Bangladesh and Ghana near the end of the FY2019 workplan period. A brief is being assembled based on the USAID-funded Enhancing Growth through Regional Agricultural Input Systems (EnGRAIS) program, "Ghana Fertilizer Value Chain Optimization Study," carried out during September 2018. The brief will be incorporated in the next report.

2.2 Impact Assessment Studies

To support policy reforms for the development of input markets and value chains, IFDC is implementing the following sub-activities: (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. These two activities are being implemented through extensive consultations and surveys with relevant stakeholders in Kenya and Rwanda, and in partnership with donor organizations, such as AGRA and the Ministry of Agriculture, policy research institutions at the national level (Tegemeo Institute of Agricultural Policy and Development), the Kenya Agricultural and Livestock Research Organization (KALRO), and community service organizations (CSOs), on a cost-sharing basis.

2.2.1 Impact Assessment Study on the Kenya Fertilizer Subsidy Program

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

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

2.2.1.1 Technical Assistance Towards Designing Existing Input Vouchers in Kenya

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

The short-term technical assessment was conducted during March 14-28, and a debriefing was made to the Cabinet Minister, along with recommendations and a suggested way forward. Key stakeholders from across the public and private sectors were included during the consultations; an extensive field trip was also taken to assess the existing situation on the ground. Based on the technical assessment, a modified input subsidy design, along with key recommendations, was presented to the Ministry for further adoption and implementation, along with key steps and a required timeline. The Ministry has to finalize several steps before a technically sound voucher program can be implemented. It is unlikely that such a program will be ready for the next year (2020). Steps that need to be undertaken by the Ministry include the following:

- Define the purpose and goals of the program, target farmers and crops, and establish government policies to support this.
- Finalize farmer database and registration to target farmers.

- Define the role of the national government versus the counties in the program.
- Target crops and input recommendations.
- Establish training and accreditation for agro-dealers.
- Create a detailed design of the system and tendering of various components.
- Establish a training and communication program to accompany the rollout.

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

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

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

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

In 2016, this activity was launched to assess the effectiveness of agro-dealer development programs in documenting the impact of the donor's investment in such initiatives (e.g., are they narrowing the "last-mile gap" between farmers and input access) and the sustainability of such input networks in the developing country context. During FY2018, it was further proposed to continue the field-level impact assessment of the Rwanda Agro-Dealer Development (RADD) programs implemented in two phases, 2010-13 and 2014-16. This activity will be initiated with the Agribusiness-Focused Partnership Organization (AGRIFOP), a local Rwandan CSO involved in the capacity building of agro-dealer programs in Rwanda. Furthermore, partnering with AGRA will also be beneficial for the assessment, since AGRA is actively engaged in agro-dealer development programs in Rwanda and elsewhere in Africa.

Progress has been made toward finalizing the contractual as well as the technical aspects (including study areas, sampling, broad questions, and specific outputs, etc.) of the proposed evaluation work in Rwanda. A field trip has been planned during the month of April to finalize the ToR and meet with other stakeholders and the Mission representative in Rwanda to seek support for such an assessment. It is expected that, upon getting concurrence from the Rwanda Mission in April, the survey activities are expected to begin during May-June. We expect to produce a draft based on preliminary analysis of the survey results near the end of the FY2019 workplan period.

2.3 Economic and Market Studies

IFDC's FY2019 work in this sub-activity involves the following key areas: (a) supporting policy efforts to harmonize fertilizer quality regulations based on evidence-based scientific analysis; (b) documenting data on fertilizer cost buildups and market margins across different countries in SSA; (c) initiating an African Fertilizer Access Index for Kenya; (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; (e) supporting an economic analysis of fertilization methods for rice paddy in Bangladesh; (f) enhancing M&E capacities of soil fertility research projects; (g) documenting gender data on access to and use of fertilizers across IFDC projects, with a specific focus on Bangladesh; (h) initiating activities to improve fertilizer use, access, and market development in Honduras and Guatemala; and (i) identifying select indicators of fertilizer use and access in SSA.

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

This sub-activity complements the FQA work carried out during FY2016-18 under Workstreams 1 and 2 in Kenya, Zambia, and Uganda. Disparate fertilizer quality and regulatory frameworks across countries contribute to: (a) marketing of poor-quality fertilizer products; (b) reduced farm productivity and incomes; and (c) limited fertilizer trade within and between countries resulting from restrictions and, thus, low aggregate supply and consumption nationally and regionally.

The results from fertilizer quality analyses will be utilized to draw economic and policy-level implications for the agriculture sectors in these countries. The FQAs in East and Southern Africa have benefited from the lessons learned during Economic Community of West African States (ECOWAS) assessments. In addition, this sub-activity may also initiate the preparatory work required to conduct a detailed assessment of the status and impact of the fertilizer regulatory framework that was signed by ECOWAS in 2012 and was being carried out in countries with support from the USAID-funded West Africa Fertilizer Program (WAFP) implemented by IFDC. The EnGRAIS program will continue supporting the ECOWAS regulatory system implementation during 2019.

Zambia FQA data is under statistical analysis, and a draft report will be issued in May 2019.

2.3.1.1 FQAs in Benin, Burkina Faso, and Liberia

FQAs were conducted in Benin, Burkina Faso, and Liberia between 2015 and 2017 under the USAID-funded West Africa Fertilizer Program (WAFP). A manuscript on the assessments is being finalized. A summary of the assessments is presented below.

The objective of the FQAs in these three ECOWAS Member States was to develop a fertilizer quality diagnostic to provide the countries, and the ECOWAS Commission, with the information needed to develop and implement policies and regulations associated with the domestication and harmonization of the regulatory systems in the countries assessed.

The main fertilizer quality problem found in Benin and Burkina Faso was the low quality of bulk blends. The problem is generalized to all blends commercialized in these two countries, but it is particularly pronounced, in terms of frequency and severity of shortages, in regard to P_2O_5, K_2O, secondary nutrients, and micronutrients. Segregation of the bulk blends may explain some of the nutrient shortages, but the main origin of the problem seems to be insufficient nutrient inputs at the time of blending. Solving the quality problems of bulk-blended fertilizers in West Africa is urgent, considering that bulk blends will be the dominant way to deliver the balanced fertilizer formulation needed for increased crop productivity, which will lead to improvements in smallholders' livelihoods, regional food security, and economic development. This objective can be achieved through the reinforcement of components in the ECOWAS regulatory framework that relate to the manufacture and trade of bulk blends.

Some of the imported NPK compounds traded in the three surveyed countries are of good quality, such as the NPK 15-15-15 traded in Benin and Burkina Faso and the NPK 23-10-5+3S+2MgO+0.3Zn that is highly commercialized in Burkina Faso. Some of the imported NPK compounds are of low quality, like the NPK 14-23-14+5S+1B used in Benin and the NPK 15-15-15+6S+1B commercialized in Burkina Faso. No fillers or foreign substances that suggest adulteration by nutrient dilution were found, not even in re-bagged fertilizers. The only plausible explanation that remains for the nutrients that are out of compliance in these imported products is that the nutrient deficiencies originated during the manufacture. Therefore, effective inspection of imported products in ports is necessary.

Cadmium content in phosphate fertilizers from Benin, Burkina Faso, and Liberia, expressed as mg of Cd per kg of P_2O_5, falls under the safety limits established by Europe and USA regulations.

Thirty-one percent of the bags weighed in Benin and 23% of the bags weighed in Burkina Faso were underweight by at least 0.5 kg. There were no underweight bags among the 31 bags weighed in Liberia.

External factors not directly associated with the characteristics of fertilizer products, such as rural markets, isolated dealers, periodic markets, and lack of dealers' knowledge about fertilizers, have been found to have a significant association with nutrient contents being out of compliance.

Fertilizer caking has a significant association with management factors; this indicates that chances of fertilizer caking increase when storage conditions do not reduce relative humidity, when bag stacks have 20 or more bags, and when pallets are not used. Similarly, the chances of adequate fertilizer moisture content increase when fertilizer bags are impermeable, either through a plastic inner and a woven outer double layer or using plastic laminated bags.

Laboratories in West Africa have demonstrated low accuracy and precision of their analytical outputs; therefore, personnel training and equipment updates are urgent for the implementation of the ECOWAS fertilizer quality framework to be effective.

2.3.1.2 Fertilizer Quality Problems in Developing Countries

A manuscript titled "Fertilizer Quality Problems in Developing Countries: An Obstacle for Food Security and Economic Growth", by Joaquin Sanabria, Emmanuel Alognikou, Georges Dimithe, and Dennis Mose, was submitted for publication in the *Agronomy Journal*. A summary is presented below.

Low fertilizer use by smallholder farmers and poor fertilizer quality in the markets of developing markets constrain food security, limit the prosperity of farmers and their countries, and prevent remediation of soil nutrient depletion. Studies conducted in nine ECOWAS countries, two countries in East Africa, and Myanmar identified quality issues that vary between regions. Bulk blends make up most of the fertilizer traded in ECOWAS countries. These bulk blends had serious nutrient shortages and physical problems associated with inappropriate blending technology and deliberate use of insufficient input nutrients during manufacturing.

Kenya and Uganda had severe nutrient shortages in locally manufactured, foliar application fertilizers. There were also nutrient shortages in imported granulated products that originated in deficient manufacture. Inspections in local manufacturing plants and in ports of entrance are needed. The main cause of quality problems in Kenya is the limited implementation of regulations. In Uganda, the quality problems are explained by the absence of a regulatory system in the country. The most serious problem in Myanmar is the contamination of imported fertilizers from China with arsenic and nickel. This is caused by inadequate port inspections and registrations of new fertilizer products that originate in the weak legal and implementation components of the regulatory system.

Data do not support the concept that adulteration was a major source of the quality problems in any of the countries studied; it is apparent that several quality problems are misinterpreted as adulteration. Bag weight shortages beyond tolerance limits were found in all countries. The generalized shortage of secondary and micronutrients across fertilizer products and countries is an obstacle for the application of the balanced crop nutrition principles.

The solution to all of the fertilizer quality problems identified in this study must come from effective regulatory systems working in coordination with a self-regulated fertilizer private sector. The existing regulatory systems – in ECOWAS countries, Kenya, and Myanmar – need to be introduced to legislative and administrative measures to correct relatively new problems, such as the difficulties with the manufacture of bulk blends, the contamination of fertilizers with heavy metals, and the need for secondary and micronutrients at very specific concentrations in fertilizers. Countries, like Uganda, with no fertilizer quality regulation in place have the opportunity to initiate regulatory systems to address the present quality problems, taking advantage of their neighbor countries' experiences. The regional fertilizer quality regulatory systems, in a world of unlimited trade across international borders, play a very important role in the economic growth of individual countries and entire regions. These quality regulatory systems must be the objective of every group of countries with heavy trade between them. Findings from the fertilizer quality situation in Kenya and Uganda, and from other East African countries, are expected to be studied in the near future and will be the foundation for forming a regional regulatory system for the East African Community (EAC).

2.3.2 Fertilizer Cost Buildup Studies and Marketing Margin Analysis

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

A discussion paper based on data, information, and completed reports from Mali and Ghana, "Changes in Cost of Supplying Fertilizer in West Africa: A Historical Perspective," was finalized in January 2019 (see Annex 4).

2.3.3 The African Fertilizer Access Index

The proposed African Fertilizer Access Index for Kenya (TAFAI-Ke) will be a consolidated measure of various factors (policy, market, research, and development) that influence and are responsible for creating an enabling environment. Along with the initiation of the fertilizer sector platform in Kenya in October 2018, this would be an important contribution for the decision makers as well as other stakeholders. Through AfricaFertilizer.org (AFO), the AFO network would further validate the concept in discussion with stakeholders and potential users by designing an online survey to obtain feedback from stakeholders in Kenya. These are being initiated and a draft report regarding the progress of TAFAI-Ke will be be presented during the second half of the FY2019 workplan period.

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

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

The proposed work in Workstreams 1 and 2 is being carried out by a graduate student from Rutgers University, in order to fulfill dissertation requirements, with data support from a field-level project in Bangladesh. The Rutgers graduate student visited IFDC Headquarters in Muscle Shoals during February 20-22, 2019, and worked toward accessing the necessary scientific data for further analysis. During the trip, the student also set up the parameters needed for estimating the GHG emissions from UDP application versus the regular application process under different agronomic and irrigation regimes.

The graduate student is further expected to identify and complete the necessary list of both scientific and economic parameters required to estimate the GHG emissions between different fertilization strategies and conduct the life cycle assessment during the second half of the FY2019.

A draft of the assessment report, along with the analytical approach, will be presented during the end of the FY2019 workplan period.

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

Using the data from the uptake of UDP by farmer households in Bangladesh through the USAID-funded Accelerating Agriculture Productivity Improvement (AAPI) project, an economic analysis was conducted by a graduate student from Rutgers University to assess the agricultural productivity and climate-smart solutions for using the UDP method in southwestern Bangladesh. The graduate student defended the dissertation toward his M.S. in January 2019. The dissertation research was guided by Rutgers University professors and an economist from IFDC. The following is a summary of the research undertaken by the graduate student.

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

The surveyed population is divided into two treatment groups: (i) fully adopted FDP and (ii) mixed users using both fertilizer practices. Their yields, revenues, fertilizer productivity, and average fertilizer inputs were analyzed through ordinary least squares (OLS) fixed effects regressions. The results show a significant positive relationship between FDP use and yields, total revenues, net revenues, and fertilizer productivity. There is a significant negative relationship between FDP technology and average fertilizer input. The farmers that fully adopted FDP had higher yields, revenues, and fertilizer productivity and less fertilizer input than the mixed and broadcast users. In addition, the adoption behavior of surveyed households in the 2015 treatment group is compared to the behavior of those in the 2016 group. Our study shows that deep-placement technology can be a climate-smart practice in helping farmers mitigate greenhouse gas emissions and slow climate change; however, it continues to face adoption barriers for farmers in Bangladesh.

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

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

Under BFS, we are building the internal capacity of field operations staff on monitoring, evaluation, learning and sharing (MELS) systems. An IFDC M&E specialist from Togo was identified and has secured admission for the Ph. D program at the University of Georgia. He started academic sessions in January 2019 to specialize in qualitative research and evaluation methodologies and gain comprehensive knowledge on various tools and techniques to be applied in field situations. He is working as a research associate in the UGA Impact Evaluation Unit to improve his theoretical knowledge and skills in evaluation.

As a part of the MELS initiative, data on soil- and fertilizer-related outcomes, i.e., indicators from different projects within IFDC, are being generated for a presentation toward annual reporting purposes. Significant progress has also been made toward defining and collecting information on specific outcomes regarding fertilizer use and yields, nutrient use efficiency, and capacity building for women, and other indicators under new technologies in the area are also being undertaken.

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

For various reasons, women farmers use less fertilizer than male farmers. Studies show that female farmers are as efficient as male farmers, but they produce less because they control less land, use fewer inputs, and have less access to important services, such as extension advice. According to the FAO, closing the gender gap could increase agricultural output in the developing world by 2.5-4% and reduce the number of undernourished people by 12-17%.

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

As part of this initiative, a detailed research paper is in progress documenting the experiences of the Accelerating Vegetable Productivity Improvement (AVPI) project in Bangladesh. This project was funded by the Walmart Foundation (Phase 1 and 2) and operated in the FTF districts of Bangladesh from 2013 to 2018. The paper will document the benefits of expanding the use of FDP technologies in vegetables by women farmers and also assess the knowledge gained by women in rural households on various fertilizer and crop management technologies and markets. The draft research paper will be submitted during the end of the FY2019 workplan period.

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

In early 2017, IFDC, in coordination with Honduras Outreach Inc. (HOI), a private NGO based in Georgia (U.S.A.), 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 were identified. Future opportunities for collaboration with HOI were also discussed. During 2018, IFDC also established contact and initiated discussions with DISAGRO in Guatemala for potential collaboration related to fertilizer markets in the Central American region. Prospective activities would be related to training and other technical assistance programs for the industry and farmers, market expansion, and policies. DISAGRO is one of the main suppliers of fertilizer in Central America, and its reach spans to some countries in South America.

The proposed activities for Honduras include an assessment of the fertilizer market in the context of the FTF Global Food Security Strategy-Honduras Country Plan (GFSS-HCP) zones of influence (GFCC-HCP ZOI). The focus is on smallholder and coffee producers, which comprise 90% of the coffee farming population and face production issues and food insecurity between coffee-harvesting seasons. A scope of work has been developed for the following two activities to be carried out in Honduras starting in June 2019.

2.3.8.1 Assessment of the Fertilizer/Agro-Input and Output Markets in Honduras

The overall objective is to assess the fertilizer/agro-input and output markets in Honduras. We will document the issues facing the agribusiness and agriculture sectors in the context of the GFSS-HCP and envision ways to better support GFSS-HCP goals and objectives. The specific objectives are:

- To identify issues constraining markets and, therefore, the development of the agriculture sector in the context of the GFSS-HCP ZOI.
- To propose recommendations based on identified issues and:
  - To effectively and efficiently deliver fertilizer and other agro-inputs where and when they are needed in rural areas.
  - To promote efficient utilization of nutrient sources (organic and mineral fertilizers) throughout the country with a major focus on the GFSS-HCP ZOI.
  - To contribute to solving the problems of low-quality diets, child stunting, and pervasive malnutrition through improved soil and nutrient management for better plant nutrition.
  - To propose policy reforms or encourage the implementation of new policies and alternative or complementary programs to improve markets and bolster agricultural productivity for lifting rural families out of extreme poverty

The assessment field work is expected to take at least four weeks and is scheduled to take place between June and July 2019, led and conducted by an IFDC senior specialist and local consultants. The output of the activity will be a full report with a detailed narrative of findings and recommendations. The expected outcomes are better informed stakeholders on issues facing the agro-input/fertilizer sector that constrain market development and agriculture sector growth and recommendations to address and contribute to solving the identified issues and other socio-economic problems facing the country and the FTF GFSS-HCP ZOI.

2.3.8.2 Public-Private Partnership for Experimentation and Scaling Out of Soil Fertility Management Technologies

In collaboration with local and regional partners, this activity will initiate experiments and demonstrations of fertilizer and fertilization technologies on key crops grown by smallholder and subsistence farmers in the FTF GFSS-HCP ZOI and as determined by the market assessment. Discussions are ongoing with Honduras Outreach Inc. and DISAGRO in Guatemala to collaborate on leveraging funding to implement projects that will contribute to the experimentation and scale out of soil fertility management technologies. This will aid in the development of agro-input markets and the agriculture sector and contribute to the respective governments' agricultural development plans. The partnership will take advantage of HOI's establishment of an experimental and demonstration farm in the central region of Honduras for tested technologies and potential dissemination and scale out.

An IFDC senior economist attended a conference on "Advanced Technologies for the Development of the Agricultural Sector in Honduras," sponsored by the Inter-American Development Bank (IADB), March 28-29, 2019. Visits were also made to key government institutions, USAID offices in Honduras, and current projects funded by USAID and other donors. The purpose of these visits was to introduce IFDC, give a brief explanation of our work in Africa and Asia, and express interest in contributing to the development of the agriculture sector in Honduras through partnerships and collaborations. The visited institutions and projects include the following:

- USAID-Honduras (USAID-H) office
- USAID "Access to Markets" Project, implemented by Fintrac
- Honduras Coffee Institute (IHCAFE)
- USAID "Transforming Market Systems" Project, implemented by ACDI/VOCA
- Directorate of Agricultural Science and Technologies (DICTA) of the Ministry of Agriculture

The USAID Agriculture Development Officer and FTF Initiative Coordinator in Honduras and the USAID-H Project Manager Specialist - Agriculture both welcomed the initiative. The USAID-H Project Manager was particularly interested in the fertilizer sector assessment, since he is not aware of any such assessment being done in the past. The assessment will shed light on the issues facing the sector, which could be addressed with current or future projects. They were also interested in the initiative to introduce innovative fertilization technologies that could improve soil and plant nutrition and productivity. USAID-H projects, "Access to Markets" and "Transforming Market Systems," also welcomed the initiative. The Access to Markets project works to identify fertilizer formulations that are appropriate for crops and micro-environmental conditions and to improve soil pH in the project zone of influence. The objective of these efforts is to address low human nutrition. The Transforming Market Systems project, which is in its first year of operation, is very interested in the fertilizer sector assessment, which will help them better program their activities for Years 2 through 5 of the project. They also welcomed any future collaboration, especially on activities that will create added value in agriculture, leading to rural job creation and reducing migration.

The Honduras Coffee Institute (IHCAFE) Technical Manager also welcomed the initiative to start experimentation and demonstrations plots to introduce innovative technologies in the coffee sector. Considering the precarious situation currently facing the sector, their key interest is on technologies that will help reduce the cost of fertilization while increasing productivity, improving coffee quality, and inducing crop resilience under climate change conditions. The Directorate of Agricultural Science and Technologies (DICTA) of the Ministry of Agriculture also welcomed the initiative to establish experiments and trials congruent with their objective of supporting family gardens in the rural sector to increase vegetable production and help diversify diets and improve human nutrition. Their key interest is in reducing the cost of fertilizer and fertilization while increasing nutrient use efficiency.

In general, we believe that there is substantial interest in the proposed activities and in the work that IFDC does in other regions of the world that could meaningfully contribute to development of the agriculture sector in Honduras.

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

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

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

Toward the end of FY2019, we expect to select the FTF country for conducting the study. We also plan to have the hypotheses and objectives defined and detailed outcomes identified from the research study.

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

IFDC, FTF Innovation Lab for Collaborative Research on Sustainable Intensification (SIIL) at Kansas State University, and USAID jointly committed to the creation and support of a consortium called the Sustainable Opportunities for Increasing Livelihoods with Soils (SOILS). The primary goal of the SOILS Consortium is to improve soil fertility in the most vulnerable regions of sub-Saharan Africa.

The consortium will bring together important national and international partners in developing and implementing soil health and fertility-enhancing innovations across large geographical regions. Through innovative research, coordination, capacity building, networking, data sharing, and communication approaches, the SOILS Consortium will work to provide sustainable solutions to build resilient households with access to nutritious food.

Key Accomplishments

1. Organizational Structure Establishment and Planning:
    a. Goals and Objectives: Develop the organizational structure and management plan for the SOILS Consortium.
    b. Key Accomplishments:
        i. The Soils Leadership Team was formed (i.e., Jerry Glover, John Peters, Upendra Singh, and Vara Prasad)
        ii. Core Partners were selected (i.e., Auburn: Dr. Beth Guertal & Dr. Joey Shaw; Michigan State University: Dr. Sieg Snapp & Dr. Nicole Mason; University of Colorado – Boulder: Dr. Jeff Herrick; USDA-ARS: Dr. Jason Neff; University of Nebraska: Dr. Charlie Wortmann & Dr. Patricio Grassini)
        iii. Advisory Members were selected (i.e., Africa RISING: Bernard Vanlauwe and Fred Kizito)
        iv. Program Manager was identified and confirmed by the Leadership Team (i.e., Zach Stewart)
        v. The Management Plan and Organizational Structure was drafted and confirmed by the SOILS Leadership Team. The document outlines the roles and responsibilities of each member and institution.
        vi. The Terms of Reference has been developed and confirmed by the Leadership Team for a Post-Doctoral Fellow to support the research needs of the Consortium. The search process has begun but the position has not been filled.
        vii. A SOILS promotional flyer has been developed and a website is under development.

2. Core-Partner Meeting: American Society of Agronomy (ASA) and Crop Science Society of America (CSSA) Annual Meeting: Baltimore, MD (Date: November 5, 2018)
    a. Goals and Objectives: To bring the Core Partners together to share the structure and vision of the SOILS Consortium, identify and cross-share Core Partner strengths, and share findings from the foundational SSA Soil Fertility Prioritization Studies.
    b. Key Accomplishments: Core Partners gathered at the ASA/CSSA meeting and cross-shared their strengths relevant to the SOILS Consortium. Following the meeting, Core

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

3. Soft-Launch and Core Partner Strategic Planning Meeting: Soil Science Society of America (SSSA) Annual Meeting: San Diego, CA (Date: January 9, 2019)
    a. Goals and Objectives: To develop a strategic plan and draft activities for the SOILS Consortium to achieve in the near-term and long-term, to publicly share the foundational studies leading to the SOILS Consortium, and to share the goals of the SOILS Consortium with the soil science research community.
    b. Key Accomplishments: Through a facilitated process using the strengths, weaknesses, opportunities, and threats (SWOT) approach, Core Partners developed a strategic plan for the SOILS Consortium's near-term and long-term activities. This has been a guiding document leading to the planned activities for the current year. IFDC and SIIL shared the goals of SOILS Consortium and the SSA Soil Fertility Prioritization Survey and Summit results to highlight the need for the SOILS Consortium to the soil science research community and gained their feedback. Approximately 45 SSSA members attended.
    c. Issues encountered: Due to a federal government "shutdown" during the planned event, USAID and federal employees were not allowed to participate in the public ceremony nor the facilitated planning meeting. The outputs of the facilitated planning meeting were documented and shared with members that were not able to attend to gain their input. A subsequent launch was conducted in Washington, D.C., with USAID.

4. USAID Formal Launch in Washington, D.C. (Date: March 15, 2019)
    a. Goals and Objectives: To formally launch the SOILS Consortium showing USAID and IFDC's leadership and to solidify activities for the first year of the consortium.
    b. Key Accomplishments: The formal launch was held at USAID headquarters with Rob Bertram and Albin Hubscher formally announcing the launch of the SOILS Consortium. A public press release was developed and published following the event. The USAID meeting garnered the support of USAID and IFDC leadership. A SOILS team meeting was held after the launch to plan specific activities for the coming year, building from the previous soil studies, strengths of the Core Partners identified at the ASA meeting, and the strategic plan developed during the SSSA meeting. The SOILS team identified three core activities for near-term activities: (i) Release a call for concept notes (CN) to bring together the research activities of the Core Partners for year one activities; (ii) organize a summit in Niger to partner with MCC and The World Bank on a Presidential Level Initiative to Improve Soil Fertility; and (iii) organize an Ethiopian Summit to bring together leading soil fertility institutions and people to reinforce the Ethiopian government's effort on scaling soil fertility recommendations.

5. Core Partner Concept Note Release
    a. Goals and Objectives: To aid in co-designing Core Partner activities that bring together the strengths of the Core Partners to scale regionally applicable soil fertility recommendations.
    b. Key Accomplishments: The CN has been developed and shared with the Core Partners for a competitive and co-developed initiative that has clear outcomes and is achievable in under one year. The CN was released to Core Partners on March 19, 2019, and CNs are due for review and co-development on April 15. Following submission, the SOILS Leadership Team and Core Partners will co-design the year one activities, integrating the CNs and the outcomes of the Niger Summit. Due to the recent momentum and country-led support in Niger, the CN will be Niger focused with regional applicability. This work will be foundational for future long-term soil fertility improving activities of the SOILS Consortium.

Near-Term Events and Progress:

1. Niger Soil Fertility Summit (May 2-3, 2019)
    a. Goals and Objectives: There is a Presidential-level initiative calling for improving the soil fertility of Niger. MCC, The World Bank, and USAID are keen to develop and support activities that lead to improved soil fertility in Niger. However, lead institutions are not coordinated, integrated, or aligned. The SOILS Consortium will bring together leading soil health activities across major production zones in SSA, and through synergies with these key partners, co-develop unified regional strategies to improve soil health and fertility. Through a facilitated process with these soil fertility leaders, we will: (i) identify what needs to be done (i.e., agronomically and regulatory), (ii) map ongoing activities, (iii) identify partners, and (iv) develop an agenda as a way forward.
    b. Key Accomplishments: The venue has been set for the Grand Hotel in Niamey, and invitations have been sent to bring together lead soil fertility institutions and participants working in Niger and the region. MCC, The World Bank, and SOILS Consortium have agreed to co-brand the summit as a joint initiative. Ministerial-level government officials have been invited to open the event and to maintain their support. An agenda for the event has been drafted and is in development.

2. Ethiopia Joint Soil Fertility Summit (May 23-24, 2019)
    a. Goals and Objectives: There are numerous soil fertility investments, limited in scale and time, occurring in Ethiopia. Each soil fertility initiative uses different methods, does not share data, and has no coordination for sharing and scaling their results. Current recommendations are only appropriate for a specific region, and recommendations are often differing. A national, site-specific fertilizer recommendation must be created to consolidate multiple studies across regions/topography and crops. The Ethiopian Government is committed to investing in scaling fertilizer recommendations, but there is little coordination and alignment among soil fertility activities. The SOILS Consortium is working to bring lead Ethiopian soil fertility institutions together to develop a framework for developing and scaling suitable soil fertility recommendations as aligned with the Ethiopian Government's vision.
    b. Key Accomplishments: Planning meetings have been held with the ICRISAT/EIAR team and the IFDC team to develop an agenda for the summit. These are two leading

institutions where conflicting fertilizer recommendations have emerged. Previous national fertilizer frameworks have also been shared to provide guidance for the summit and to ensure continuity and responsiveness to previous frameworks. A draft agenda has been co-developed following these calls and building from previous soil fertility frameworks. Government officials are being invited to deliver opening remarks and to show alignment with their initiatives. The summit date, venue (i.e., ILRA Campus), and invitation list have also been arranged.

Annex 1. Workstream Summary Tables

Activity	Country	Description	Partnership	Funding
1.1 Technologies Developed, Refined, and Adapted for Improving Nitrogen Use Efficiency				
1.1.1 Development and Evaluation of Enhanced Efficiency N Fertilizers	SSA, Bangladesh, Nepal, USA	Developing and evaluating enhanced efficiency products that are climate-resilient, require one-time application, have high N use efficiency, and reduce reactive N to the environment.	University of Florida (UF) and University of Central Florida (UCF)	BFS - university partnership grant
1.1.2 Disseminating Fertilizer Deep Placement Technology	Bangladesh, Myanmar, SSA, USA	Fast and flexible applicator that will work under a wide range of lowland and upland water regime conditions.	Mississippi State University, private sector	BFS
	Kenya	A prototype high capacity, robust briquette machine will be produced by a private sector partner in Kenya starting in May 2019.	Private sector	BFS
1.1.3 Climate Resilience and Mitigating GHG Emissions	Global	The reported activities highlight the resilience feature of fertilizer deep placement technology in improving crop yields under unfavorable environments and mitigating GHG emissions	Agricultural and Forestry University (AFU), Rutgers University, University of Florida	BFS
1.2 Activated Phosphate Rock				
1.2.1 Complete and Analyze Ongoing Field Trials	Ghana, Kenya	Ongoing field tests are evaluating the performance of activated PR vs. conventional P fertilizers.		BFS
1.2.2 Conduct PR and Activated PR Demonstrations on Soils of Varying pH with Prominent PR Producers to Capture Their Interest in Activated PR	SSA	In these trials, we will use activated PR from PR producers to judge the efficacy of the activation process using their own PR source. The results should be enough to make a go/no-go decision as it concerns developing business plans for producing activated PR commercially.	Private sector	BFS

	Activity	Country	Description	Partnership	Funding
1.3	**Balanced Crop Nutrition (Cross-Cutting with Workstream 2.3)**				
1.3.1	Efficient Incorporation of Micronutrients into NPK Fertilizers and Evaluation of Multi-Nutrient Fertilizers	Global	Activities focus on the improved delivery, distribution, and efficiency of nutrients (N, P, K, Zn) supplied from multi-nutrient fertilizer granules. The effect of improved nutrient efficiency will be quantified.	UCF	BFS – university partnership
1.3.2	Facilitate Site- and Crop-Specific Fertilizer Recommendations for Increased Economic and Environmental Benefits from Fertilizer Use	Ghana	Trials were conducted to use the SMaRT concept and develop fertilizer recommendations for the northern regions of Ghana.	ATT project, Soybean Innov Lab, MOFA, and UDS	BFS
		SSA, Global	Wet chemistry-spectral analysis relationship to plant nutrient response. Provide options to partners and development agencies for rapid and reliable techniques for fertilizer, soil, and plant analyses	ATT project, MOFA, UDS, and private sector	BFS, private sector
		Global	The objective of this research is to create the opportunity to use low-cost spectral capabilities and, eventually, set up "laboratories" in countries or regions lacking good quality analytical laboratories for fertilizer testing.	Private sector, ICRAF	BFS, private sector
		Beira Corridor, Mozambique	Maps are being developed to help identify areas of nutrient and pH constraints in the soil.	AFAP, ISPM, Yara	BFS
		Mozambique	In support of the FAR project, field trials have been conducted to evaluate the yield response and economic returns to sulfur, zinc, boron, copper, and lime products.	Yara	BFS
		Senegal	The aims of this activity are to conduct nutrient omission and rate trials to quantify the effect of key nutrients, including secondary and micronutrients, on millet and peanut yields and economic returns in Senegal.	NARES	BFS
1.4	**Sustainable Intensification Practices: Integrated Soil Fertility Management**				
1.4.1	Nutrient Recycling	Global	Effective recycling of nutrients using black soldier fly larvae to enhance shelf-life and use efficiency of poultry manure, and the evaluation of biofertilizers, will be conducted.	Private sector, Auburn University, Tuskegee University	BFS, Private sector

Activity	Country	Description	Partnership	Funding
1.4.2 Developing a Highly Productive and Sustainable Conservation Agriculture Production Systems for Cambodia and Myanmar	Cambodia, Myanmar (from August 2019)	Assessing changes in soil organic C and N stocks and soil functions of sandy paddy fields under conventional tillage and conservation agriculture production systems	RUA-CE SAIN, GDA, DALRM, CASC, CIRAD, SIIL KSU, Africa Rising	BFS - university partnership grant
1.4.3 Evaluation of the role of Legumes in Rice-Based Farming Systems in Mozambique for Nutrient Improvement, Soil Health, and Income Generation	Mozambique	The cultivation of chickpea as an alternative crop in rotation with rice is being evaluated.	FAR project, SEMEAR project, Yara	BFS
1.4.4 Evaluation of the Synergistic Effect of CA Practices in Combination with an Activated PR Amendment as a Component of ISFM in Northern Ghana	Ghana	Trials to compare the performance of maize under CA versus non-CA (main plot) and activated PR and DAP rates (subplot).	Africa Rising	BFS
1.5 Improving the DSSAT Cropping System Model for Soil Sustainability Processes – Cross-Cutting with Workstream 2				
1.5.1-3 Model Improvement	United States	IFDC will be implementing the AgMIP database and improving DSSAT Cropping System Model to help in making timely and reliable recommendations on fertilizers, sowing dates, and other management inputs	University of Florida	BFS - university partnership grant
1.5.4 Advance DSSAT Rice Model Training	Thailand	Conduct a one-week training program at the Asian Disaster Preparedness Center (ADPC) in Bangkok, Thailand from Nov 26 to 30, 2018	SERVIR-Mekong Hub	SERVIR-Mekong Hub

Activity		Country	Description	Partnership	Funding
2.1	**Documenting Policy Reforms and Market Development**				
2.1.1	Support for Kenya Fertilizer Roundtable (KeFERT)	Kenya	KeFERT resulted in the formation of the Kenya Fertilizer Platform, a public-private mechanism composed of key stakeholders involved in fertilizer access, quality, and use.	Kenya's MoALF&I, private sector	BFS MoA/AFAP - 60%
2.1.2	Capacity-Building Activities: Policy Reforms	Global	A presentation was given on the importance and impact of agricultural input policies during the USAID BFS-sponsored agriculture core course for staff from inter- and intra-agencies involved in U.S. Government. A poster was also created.	BFS/Rutgers Consortium	BFS Rutgers Consortium - 90%
2.1.3	Documenting Global and SSA Fertilizer Market Trends and Outlook	Global/SSA	Data from meetings with the IFEW group is being revised for publication in the IFEW joint World Fertilizer Trends and Outlook report.	IFA/FAO, World Bank	BFS
2.1.4	Partnership for Enabling Market Environments for Fertilizer in Africa	SSA	Efforts are being made to continue to support the PEMEFA. The AAP grant has been closed, and the PEMEFA is searching for new funding to continue collaboration between the partner institutions.	MSU-led Alliance for African Partnerships (AAP) consortium (MSU-IFDC-New Market Lab-AFAP)	BFS
2.1.5	Policy Briefs on Fertilizer Policies and Market Development	SSA/Asia/ LAC	The overall purpose of these briefs is to contribute to influencing policy reforms through active engagement with stakeholders, such as research institutions, private and public sectors, and in-country missions, through wider dissemination forums.	Rutgers University, EnGRAIS project	BFS, EnGRAIS project Rutgers - 10%
2.2	**Impact Assessment Studies**				
2.2.1	Impact Assessment Study on the Kenya Fertilizer Subsidy Program	Kenya	The Government of Kenya requested that IFDC and other policy think-tanks in Kenya assess the government's existing subsidy program to help them better target farmers for improved crop and soil productivity.	MoA, KALRO, Tegemeo, CSO	BFS MoA/Tegemeo - 50%

Activity	Country	Description	Partnership	Funding
2.2.2 Effectiveness of Agro-Dealer Development Programs Toward Sustainable Input Supply and Technology Transfer in SSA	Rwanda	Field-level impact assessments of RADD will continue, and a report will be produced.	AGRIFOP/AGRA	BFS AGRA - 10%
2.3 Economic and Market Studies				
2.3.1 Fertilizer Quality Assessments: Support Policy Efforts to Harmonize Fertilizer Regulations (with Workstream 1)	Zambia, Kenya, Uganda	Fertilizer quality analyses will be produced to help draw economic and policy-level implications for the agriculture sectors in these countries.	EnGRAIS, WAFP	BFS
2.3.2 Fertilizer Cost Buildup Studies and Marketing Margin Analysis	Ghana, Mali, Kenya, Tanzania	Reports will be produced to encourage improvements within the fertilizer/agriculture market.		BFS
2.3.3 The African Fertilizer Access Index	Kenya	Efforts are being put forth to establish the Africa Fertilizer Access Index (TAFAI-Ke), and a draft report on said progress is underway.	AFO-IFDC	BFS
2.3.4 Economic and Environmental Implications of Fertilizer Technologies Using Life Cycle Analysis Approach	Bangladesh	A graduate student from Rutgers University is conducting research to analyze GHG emissions to help farmers and policymakers gain carbon credits.	Rutgers University	BFS Rutgers - 40%
2.3.5 Economic Estimation of Fertilization Methods for Rice Paddy in Bangladesh – A Production Function Analysis	Bangladesh	A summary of a Rutgers University graduate student's research to assess the agricultural productivity and climate smart solutions for using the UDP method in southwestern Bangladesh.	IFDC-Dhaka field office, Rutgers University	BFS Rutgers - 25%
2.3.6 Enhancing M&E Capacities of Soil Fertility Research Systems in IFDC	Global	An IFDC M&E specialist from Togo is working with the University of Georgia to obtain his Ph. D. and ultimately help build on IFDC's MELS systems.	University of Georgia	BFS

Activity	Country	Description	Partnership	Funding
2.3.7 Women's Access to and Use of Fertilizers in Field Crops and Vegetables	Global/ Bangladesh	Efforts are being made to offer best practices for IFDC and others that incorporate technologies that are "gender neutral", to those that are "gender aware", and eventually "gender transformative."	IFDC – Bangladesh office IFDC – HQ (MELS)	BFS Walmart - 10%
2.3.8 Improving Fertilizer Use, Access, and Market Development: Case of the Coffee Sector and Other Food Security Crops in Honduras and Guatemala	Honduras, Guatemala	Collaborations are being established to aid the agricultural sectors in Honduras and Guatemala.	Honduras Outreach Inc., DISAGRO	BFS
2.3.9 Determining Factors Affecting Fertilizer Supply and Demand Among Supply Chain Stakeholders and Farmers in West Africa	West Africa	Efforts are being made to determine why fertilizer is not being used by smallholder farmers in West Africa, despite its availability on the market.	EnGRAIS	BFS

Activity	Country	Description	Partnership	Funding
3 Sustainable Opportunities to Improve Livelihoods with SOILS Consortium				
3.1 Establishment of the SOILS Consortium	Global	The consortium has been established to promote national and international partnerships to develop and implement soil health and fertility-enhancing innovations.	IFDC, KSU, World Bank	BFS

Annex 2. University Partnerships

Theme/Activities	Countries	Partnership
I. Collaboration with U.S. Land-Grant Universities*		
1.1.1.1 Development of Modified Urea Products – Developing Hydrophobic and Controlled-Release Fertilizer – Pg. 5 1.5 Improving the DSSAT Cropping System Model for Soil Sustainability Processes – Cross-Cutting with Workstream 2 – Pg. 54	Global	University of Florida
1.1.1.1 Development of Modified Urea Products - Improving Nano-Zinc Coated Urea – Pg. 8 1.3.1 Efficient Incorporation of Micronutrients into NPK Fertilizers and Evaluation of Multi-Nutrient Fertilizers – Pg. 38.	Global	University of Central Florida
1.1.2.1 Mechanized Applicators – Pg. 18	Global	Mississippi State University
1.3.1 Efficient Incorporation of Micronutrients into NPK Fertilizers and Evaluation of Multi-Nutrient Fertilizers – Nutritional Quality (no update during this reporting period) – Pg. 37	Global	Tennessee State University
1.3.2 Facilitate Site- and Crop-Specific Fertilizer Recommendations for Increased Economic and Environmental Benefits from Fertilizer Use – Pg. 41	Northern Ghana	Soybean Innovation Lab, University of Illinois
1.4.1 Nutrient Recycling – Pg. 50	Global	Auburn University, Tuskegee University
1.4.2 Developing a Highly Productive and Sustainable Conservation Agriculture Production Systems for Cambodia and Myanmar – Pg. 51	Cambodia	Kansas State University (KSU)
2.1.2 Capacity-Building Activities: Policy Reforms - USAID BFS Agriculture Core Course: Policy, Governance, and Standards – Agriculture Input Policy Analysis – Pg. 62 2.3.4 Economic and Environmental Implications of Fertilizer Technologies Using Life Cycle Analysis Approach – Pg. 69	Bangladesh	Rutgers University
2.1.4 Partnership for Enabling Market Environments for Fertilizer in Africa – Pg. 62	SSA	Michigan State University
2.3.6 Enhancing the M&E Capacities of Soil Fertility Research Projects in IFDC – Pg. 70	Global	University of Georgia
Workstream 3 SOILS Consortium – Pg. 75	SSA	KSU, Auburn, Michigan State, University of Nebraska, University of Colorado

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

Annex 3. List of Publications and Presentations for FY2019

Publications:

Adisa, I.O., V.L.R. Pullagurala, J.R. Peralta-Videa, C.O. Dimkpa, W.H. Elmer, J.L. Gardea-Torresdey, and J.C. White. "Nano-Enabled Fertilizers and Pesticides: Enhanced Efficacy with Lower Environmental Impacts" (under revision, *Environmental Science: Nano*).

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.

Bindraban, P.S., C.O. Dimkpa, and R. Pandey. "Exploring Phosphorus Fertilizers and Fertilization Strategies for Improved Human and Environmental Health" (under review, *Biology and Fertility of Soils*).

Bindraban, P.S., J.C. White, F.A. Franklin, A. Melse-Boonstra, N. Koele, R. Pandey, C.O. Dimkpa, J Rodenburg, K. Senthilkumar, P. Demokritou, and S. Schmidt. "The Great Food Transformation Demands Fertilizer Transformation to Safeguard Human and Planetary Health" (under review, *Materials Today Sustainability*).

Comer, B.A., P. Fuentes, C.O. Dimkpa, Y-H. Liu, C. Fernandez, P. Arora, M. Realff, U. Singh, M.C. Hatzell, and A.J. Medford. Prospects and Challenges for Solar Fertilizers (under review, *Joule*).

Diagana, B. "Beyond Subsidies: How Else Can African Governments Support Private Sector Investment in Fertilizer Value Chains?" (under review, *Fertilizer Focus*).

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

Islam, S.M.M., Y.K. Gaihre, J.C. Biswas, U. Singh, Md.N. Ahmed, J. Sanabria, and M.A. Saleque. 2018. "Nitrous Oxide and Nitric Oxide Emissions from Lowland Rice Cultivation with Urea Deep Placement and Alternate Wetting and Drying Irrigation," *Scientific Reports*, 8:17623.

Sanabria, J., and J. Wendt. 2019. "Statistical Analysis of Non-Replicated Experiments in Farmers' Fields. A Case of Balanced Fertilization of Bean in Burundi," *Agronomy Journal* (in print).

Sanabria, J., J. Ariga and D. Mose. 2018. *Fertilizer Quality Assessment in Markets of Kenya*, IFDC.

Sanabria, J., J. Ariga and D. Mose. 2018. *Fertilizer Quality Assessment in Markets of Uganda*, IFDC.

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

Presentations:

Agyin-Birikorang, S., Nuhu, S.A., Fuseini A-R.A, Dawuda, H.W., Fugice J., Bible W., Sylvester C., Mobley A., Singh U. 2019. "Does blanket fertilizer recommendation still work? a case study of maize production in Northern Ghana" Presented at the Soil Science Society of America Annual Meeting, San Diego, CA, 6-9 January 2019.

Singh, U, Fugice, J., Agyin-Birikorang,

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

Dimkpa, C.O. 2018. "Micronutrient fertilizers as a one-stop shop for improving crop production: from conventional to nano-scale," Presented at the Materials Innovation for Sustainable Agriculture Symposium, University of Central Florida, Orlando, October 2018.

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

Sanabria, J. 2018. "Fertilizer Quality Problems in Markets of Developing Countries," Oral presentation at the American Society of Agronomy Annual Meeting, ASA in Baltimore, MD, November 2018.

Sanabria, J. 2018. "Kenya Fertilizer Quality Assessment," Oral presentation at Kenya Fertilizer Roundtable. Nairobi, October 2018.

Sanabria, J. 2018. “Uganda Fertilizer Quality,” Workshop for Government and Private Sector, Kampala, June 2018.

Sanabria, J. 2018. “Kenya Fertilizer Quality Assessment,” Workshop for Government and Private Sector, June 2018.

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

Singh, U., Porter, C, Gaihre, Y, Fugice, J. 2018. “Do existing crop models simulate soil processes adequately for soil health and climate change mitigation applications?,” Paper presented at 5th International Rice Congress, October 15-17, 2018, Singapore.

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

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

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

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

Annex 4. List of Reports Referenced in Annual Report

- Agronomic Effectiveness of the Urea Deep Placement (UDP) Technology for Upland Maize Production in the Northern Regions of Ghana
- Changes in Cost of Supplying Fertilizer in West Africa
- ECOWAS Fertilizer Regulatory Framework Implications for the Development of Private Sector-Led Supply of Quality Fertilizers in West Africa
- Exploring farmers' knowledge gap on fertilizer management practices in a rice-based cropping system in Nepal
- Fertilizer Quality Assessments in Benin, Burkina Faso and Liberia
- Fertilizer Quality Problems in Developing Countries An Obstacle for Food Security and Economic Growth
- Mitigating nitrous oxide emissions from rice-wheat cropping systems with nitrogen fertilizer and irrigation management
- Mitigating N2O and NO Emissions from Direct-Seeded Rice with Nitrification Inhibitor and Urea Deep Placement
- Nutrient Leaching from One-Time Application of Briquetted Multi-Nutrient Fertilizer
- One-Time Application of Multi-Nutrient Fertilizer Briquettes for Maize (Zea mays L.) Production
- Quantifying nitric oxide emissions under rice-wheat cropping systems

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