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

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Clockwise: Fertilizer deep placement applicator; Maria Mateus, a farmer in Bandua who hosted an on-farm groundnut trial, Buzi, Mozambique; Bangladesh agro-dealer micronutrient survey; comparison of LCC products from the SoilGrids digital soil product, the field data from this study, and the FAO HWSD soil map; and greenhouse trial on teff.

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List of Acronyms

AAPFCO	Association of American Plant Food Control Officials
AFAP	African Fertilizer and Agribusiness Partnership
AFO	AfricaFertilizer.org
Africa RISING	Africa Research in Sustainable Intensification for Next Generation
AFU	Agriculture and Forestry University
AgMIP	Agricultural Model Intercomparison and Improvement Project
AGRA	Alliance for a Green Revolution in Africa
AGRODIA	Association of Wholesalers and Retailers of Agricultural Inputs
ANCAR	Agence Nationale de Conseil Agricole et Rural
APEX	Agricultural Policy/Environmental eXtender
API	Application Program Interface
APR	activated phosphate rock
ARS	Agricultural Research Service
As	arsenic
ASABE	American Society of Agricultural and Biological Engineers
AU	African Union
B	boron
BAME	Bureau of Macroeconomic Analysis
BINA	Bangladesh Institute of Nuclear Agriculture
BRRI	Bangladesh Rice Research Institute
C	carbon
Ca	calcium
CA	conservation agriculture
CABI	Centre for Agriculture and Biosciences International
CASC	Conservation Agriculture Service Center
CASCAPE	Capacity building for scaling up of evidence-based best practices in agricultural production in Ethiopia
CE SAIN	Center of Excellence on Sustainable Agriculture Intensification and Nutrition
CIAT	International Center for Tropical Agriculture
CIMMYT	International Maize and Wheat Improvement Center
CIRAD	Centre de Coopération Internationale en Recherche Agronomique pour le Développement
Cl	chlorine
CNRA	Centre National de Recherches Agronomiques
Co	cobalt
CoE	Center of Excellence
CORAF	West and Central African Council for Agricultural Research and Development
Cr	chromium
CSM	Cropping System Model
Cu	copper
DALRM	Department of Agricultural Land Resources Management
DAP	diammonium phosphate
DAT	days after transplanting
DLEC	Developing Local Extension Capacity
DSSAT	Decision Support System for Agrotechnology Transfer
EAC	East African Community
EARCS	Ethiopian Agriculture Research Council Secretariat
EAS	extension and advisory services
ECOWAS	Economic Community of West African States
EiA	Excellency in Agronomy
EIAR	Ethiopian Institute of Agricultural Research
EnGRAIS	Feed the Future Enhancing Growth through Regional Agricultural Input Systems in West Africa Project
ES	elemental sulfur
EthioSIS	Ethiopian Soil Information System

FAK	Fertilizer Association of Kenya
FAO	Food and Agriculture Organization of the United Nations
FAR	Food security through climate Adaptation and Resilience in Mozambique project
FDP	fertilizer deep placement
Fe	iron
FGD	Focus Group Discussion
FTF	Feed the Future
FY	fiscal year
GAP	good agricultural practice
GB	Groundnut Basin
GDA	General Directorate of Agriculture
GHG	greenhouse gas
GIS	Geographic Information System
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GSSAT	Geo-Spatial Decision Support System for Agrotechnology Transfer
Hg	mercury
HQ	Headquarters
HYV	high-yielding variety
ICRAF	World Agroforestry
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFA	International Fertilizer Association
IFDC	International Fertilizer Development Center
INERA	Institut de l'Environnement et Recherches Agricoles
INFA	International Network on Fertilizer Analysis
INRAN	Institut National de la Recherche Agronomique du Niger
iREACH	Research, Extension and Advisory Coordination Hub
ISFM	integrated soil fertility management
ISO	International Organization for Standardization
ISP	input and service provider
ISRA	Institut Senegalais de Recherches Agricoles
ITA	Institut de Technologie Alimentaire
IZA	International Zinc Association
K	potassium
KeFERT	Kenya Fertilizer Platform
KMT	Kenya Markets Trust
KSU	Kansas State University
LCC	Land Capability Classification
LOD	limits of detection
LSMS-ISA	Living Standards Measurement Study – Integrated Surveys on Agriculture
MAP	monoammonium phosphate
MCA	Millennium Challenge Account
MCC	Millennium Challenge Corporation
Mg	magnesium
Mn	manganese
Mo	molybdenum
MoALD	Ministry of Agriculture and Livestock Development
MoALF	Ministry of Agriculture, Livestock and Fisheries
MoFA	Ministry of Food and Agriculture
N	nitrogen
NAC	N-acetyl cysteine
NARC	Nepal Agricultural Research Council
NARCS	National Agricultural Research Council Secretariat
NARES	National Agricultural Research and Extension Systems
NARS	National Agricultural Research Systems
NAS	National Academy of Sciences
Ni	nickel
NIR	near-infrared

NSAF	Feed the Future Nepal Seed and Fertilizer Project
NSDL	National Soil Dynamics Lab
P	phosphorus
PARSEN	Fertilizer Sector Reform Support Project in Niger
Pb	lead
PCU	polymer-coated urea
PEER	Partnerships for Enhanced Engagement in Research
PFAG	Peasant Farmers Association of Ghana
PNT	Tahoua natural phosphate rock
PPRSD	Plant Protection and Regulatory Services Directorate
PR	phosphate rock
PRDSS	Phosphate Rock Decision Support System
PTWG	Policy Technical Working Group
QA/QC	quality assurance/quality control
QUEFTS	Quantitative Evaluation of Fertility in the Tropical Soils
RAB	Rwanda Agriculture and Animal Resources Development Board
RAE	relative agronomic effectiveness
RARI	regional agricultural research institute
REC	Regional Economic Community
RECA	National Network of Chambers of Agriculture
RELC	Research Extension Linkage Committee
RESOPP	Réseau des Organisations Paysannes et Pastorales du Sénégal
RFS	Bureau for Resilience and Food Security
RHEAS	Regional Hydrologic Extremes Assessment System
RUA	Royal University of Agriculture
S	sulfur
SARI	Savanna Agricultural Research Institute
Se	selenium
SFT	Soil Fertility Technology Adoption, Policy Reform, and Knowledge Management
SIL	Soybean Innovation Lab
SIIL	Feed the Future Innovation Lab for Collaborative Research on Sustainable Intensification
SMaRT	Soil testing, Mapping, Recommendations development, and Technology transfer
SMN	Secondary and Micronutrients
SNCA	National Agricultural Advisory System
SNNPR	Southern Nations, Nationalities, and Peoples' Region
SOILS	Sustainable Opportunities for Improving Livelihoods with Soils
SRI	System of Rice Intensification
SRV	Senegal River Valley
SSA	sub-Saharan Africa
SWAT	Soil and Water Assessment Tool
TERI	The Energy and Resources Institute
TPR	Togo phosphate rock
TSP	triple superphosphate
UB	urea briquette
UCF	University of Central Florida
UDP	urea deep placement
UDS	University for Development Studies
USAID	U.S. Agency for International Development
USDA	U.S. Department of Agriculture
VIFAA	Visualizing Insights on Fertilizer for African Agriculture
WECARD	West and Central Africa Council for Agricultural Research and Development
WRB	World Reference
WS	Workstream
WSP	water-soluble phosphorus
XRF	X-ray fluorescence
Zn	zinc

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

Semi-Annual Report FY2021
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Executive Summary

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. Since 2015, USAID and IFDC entered into a cooperative agreement to support the strategic objectives of the Bureau for Resilience and Food Security (RFS), particularly in relation to Feed the Future (FTF), through a global project on "Soil Fertility Technology (SFT) Adoption, Policy Reform, and Knowledge Management." The RFS-SFT project focuses on **bridging the gap between scientific research and technology dissemination** to smallholder farmers in FTF countries by developing more nutrient-efficient, profitable soil fertility technologies, supported by influencing markets and policies, and local capacity strengthening capacities, leading to improved livelihoods. Under the agreement, IFDC has conducted a range of activities and interventions, prioritized from each annual work plan, for the three agreed-upon workstreams (Table 1). The activities under the RFS-SFT project focus on the key result areas described below and continue to contribute to major intermediate outcomes, i.e., different phases of research and peer-reviewed publications. More information can be found at the following link: [Feed the Future Soil Fertility Technology (SFT) Adoption, Policy Reform and Knowledge Management Project - IFDC]

Table 1. FTF Soil Fertility Technologies (RFS-SFT) Adoption, Policy Reform, and Knowledge Management Project Workstreams

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

*****_From March 2019 onward_

Basic principles of engagement under RFS-SFT: The research activities and technologies developed and disseminated through the SFT project are inclusive and effectively engage women, youth, and other minority people. Other key features include (i) strong partnership and engagement with the private sector – from soil fertility research aspects, especially during the advanced stages of research, i.e., piloting and preparation for scaling, to creating enabling environments for better policy and regulatory uptake among stakeholders; and (ii) engagement of national and local partners through capacity development and implementation of activities for better and long-lasting results.

Focus Countries for FY21: Activities are implemented in the following countries to generate technologies, practices, and policies with broader geographic coverage, suitability, and scalability. As part of engagement with the country-level missions, concurrences have been obtained for the following set of countries except Senegal.

Asia: Bangladesh, Nepal

East and Southern Africa: Kenya, Uganda, Rwanda, Ethiopia, Mozambique

West Africa: Ghana, Senegal, Niger, Nigeria

Activity Highlights during the October 2020-March 2021 Reporting Period

Number of publications during the reporting period	6 published, 4 under review, and 5 policy briefs 1 webinar on Kenya Soil Mapping was conducted.
EG.3.2-7 Number of technologies, practices, and approaches under various phases of research, development, and uptake as a result of USG assistance [IM-level]	Production systems research: Soil Fertility Technologies Phase 1: 9 research activities. Phase 2: 17 research activities Phase 3: 4 research activities

The ongoing research on improving N use efficiency are at various research phases using urea as coated or granulated with secondary and micronutrients, nano- and bulk material, inhibitors, and control-release polymers or deep placement application.

- Field trials completed in Nepal with rice, applying 80% of recommended N rate with polymer-coated urea gave similar or higher yields than urea at full application rate.
- Maize trials in Bangladesh also highlighted the combined effect of increased N use efficiency and improved sulfur nutrition, where significantly higher yield and protein content was obtained with elemental S enriched urea than conventional N and S fertilizers.
- Field trials in Burkina Faso under rainfed condition gave up to 1 mt/ha higher rice yield with urea deep placement than conventional N application. Under irrigated conditions with improved water management, conventional split application of urea was as effective as deep placement.

Ongoing greenhouse and field activities have confirmed that activated phosphate rock (PR) – combining PR with water-soluble P (WSP) fertilizers – improves bioavailability of P by 2-3 times vs. PR and is as effective as WSP. In addition, activated PR particularly when combined with residual response has significantly higher P recovery efficiency than conventional WSP fertilizers.

The Phosphate Rock Decision Support System (PRDSS) is a web-based tool used to predict the relative agronomic effectiveness of phosphate rock compared to water-soluble phosphate fertilizers jointly created by FAO/IAEA and IFDC. This tool has been redesigned to providing a better user experience and new features and the new PRDSS is currently available at https://prdss2.ifdc.org.

Balanced fertilization field trials with various Zn products were completed in Ghana (maize), Nepal (rice), and Rwanda (wheat, maize).

Field trials to quantify conservation agricultural practices, crop diversification, and integrated soil fertility management on crop yield, nutrient use efficiency, and soil health were conducted in Bangladesh and Cambodia. Besides substitution values of recycled wastes and organic amendments were evaluated under greenhouse conditions.

Mapping of Land Capability Classification (LCC) for Dosso Region using map products and field data collected by IFDC in Niger has been completed. Compared field data based to LCC assessments through global soil maps, derived a regional spatial evaluation of land capability for future use in land planning activities in Niger has been recommended (journal *Land* https://doi.org/10.3390/land10050458).

A unified fertilizer trial protocol for targeting fertilizer source and rate in Ethiopia was developed by IFDC, ICRISAT, and EIAR and 362 field trials were implemented for teff (183), wheat (119), and sorghum (60) across Amhara, Oromia, SNNPR, and Tigray regions. Except for Tigray, crops were harvested from 290 sites. Initial results indicate:

- Yields of wheat and teff were significantly increased over 300% vs. control, up to 8% relative to the NP treatment only, and over 25% compared to treatment with half of all the nutrients (50% of all nutrients + K) due to application of 150% all K treatment.
- Sorghum yield increments of about 37% and 21% were achieved at foot slope position compared to hill and mid-slope positions, respectively.

COVID-19 Fertilizer Watch Updates in SSA: RFS-SFT supported a collaborative initiative toward informing fertilizer value chain stakeholders through weekly fertilizer bulletin across SSA on the impact of COVID-19 on fertilizer markets and the agro-input supply from April to December 2020 (https://ifdc.org/tag/fertilizer-watch/). Since January 2021, this has been published as a monthly bulletin https://africafertilizerwatch.org/#/en/about through IFDC's AfricaFertilizer.Org

Influencing Fertilizer Policy Reforms in Kenya: With KeFERT and OCP, collaboratively conducted a webinar on Kenya soil mapping aspects and disseminated the new Kenya soil map site: https://mapping.cropnuts.com/projects/ifdc/kenya. The dissemination activity on new fertilizer regulations, followed by feedback surveys among fertilizer stakeholders in Niger, found face-to-face meetings and person-to-person exchanges were the most effective methods in disseminating the policy regulations. Of the five regulations passed, fertilizer actors valued more on regulations related to licensing, sales, and sanctions.

Economic studies to understand the micronutrient fertilizers (zinc/boron/manganese) uptake in rice farming in Bangladesh shows private sector is the sole source of supply of micronutrient fertilizers, technologies, and knowledge. Preliminary survey results from input retailers (45) and agricultural extension officers (15) in rice growing south-western Bangladesh indicate the need for close monitoring of micronutrient fertilizers quality available in the market, with multiplicity of brands being imported and supplied by private firms for consumption.

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

A summary of research activities and accomplishments for the four focus areas under Workstream 1 follows.

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

The major focus of this activity is improving nitrogen (N) use efficiency by minimizing N losses while increasing productivity. This can be accomplished by developing/using alternatives to urea, modified and coated urea products, synthetic and natural coatings, additives/amendments (organic, biofertilizers, biostimulants), as well as nanomaterials/nano-micronutrients (phosphate rock [PR], elemental sulfur [ES], zinc [Zn], boron [B]), and implementing innovative practices, such as mechanized fertilizer deep placement (FDP). The proposed activities will be conducted under field, greenhouse, and laboratory conditions, targeting:

1.1.1. Development of enhanced efficiency N fertilizers.

1.1.2. Field evaluation of existing enhanced efficiency N fertilizers and technologies for improved yield and reduced N pollution.

1.1.3. Resolution of technology dissemination/scaling constraints to FDP.

1.1.4 Promotion of climate resilience and minimization of greenhouse gas (GHG) emissions from N fertilizers.

1.1.1 Development of Enhanced Efficiency N Fertilizers ***(Ongoing)***

The objective of the activity is to develop enhanced efficiency N fertilizers using agricultural wastes, alternative renewable and biodegradable materials, plant biostimulants, and alternative slower release fertilizers and amendments, such as PR, ES, Zn, B, and urea polymers, as coating material. The coatings may include bulk or nano-sized material, such as capped zinc oxide nanoparticles.

Activity: Continued to work on development of new products (inhibitors, plant biostimulants) using active ingredients in the formulations to improve nutrient efficiency. Specific activities included product formulation, nutrient release in water, nutrient transformation in soils, and quantification of volatilization and leaching losses.

Partnership: University of Central Florida

Location/Timeline: HQ/Ongoing-December 2021

Progress:

Zn, copper (Cu), and magnesium (Mg)-based nanomaterials were used to coat urea fertilizers for improved nutrient use efficiency. Due to their small particle size, nanomaterials showed different physical and chemical properties compared to their conventional analogues. It has been reported that nanomaterials show improved apparent solubility, controlled release, target delivery, and bioavailability. Zn, Cu, and Mg are vital plant nutrients. Additionally, studies suggest that Cu and Zn can inhibit urease activities, thereby limiting the transformation of urea to ammonium and slowing ammonia volatilization. Therefore, five coating products based on Zn, Cu, and Mg were synthesized through the co-precipitation method. Magnesium nitrate, copper nitrate, and zinc nitrate were selected as metal sources. Sodium citrate and N-acetyl cysteine (NAC) were each used as capping agents to control particle formation, size, and surface charge.

Table 2. Particle size analysis results (LA-950 Particle Size Analyzer).

Sample	Mg-Sol	Mg-Cu	Cu-Mg	Zn-Mg-Cu	NAC-ZnO
Size (dia. nm)	251	344	68	266	67

Nano-Micronutrient Coated Urea

Table 3. Targeted metal concentration for the urea coated with each synthesized material.

Product	Zn Content (%)	Mg Content (%)	Cu Content (%)
Mg-Sol	-	5.0	-
Mg-Cu	-	1.7	0.4
Cu-Mg	-	0.1	0.4
Zn-Cu-Mg	1.5	0.2	0.2
NAC-ZnO, low rate	1.5	-	-
NAC-ZnO, high rate	3.0	-	-

Granular urea was coated with each of the coating materials using a rotary coating drum at a temperature of no more than 70°C and spraying each product onto the fertilizer bed. The white or colorless coating materials were dyed with food coloring to observe the uniformity of the coating. In each case, the urea was coated to a targeted micronutrient concentration, depending on the limiting nutrient (Table 2). Photos of the final products – Urea coated with Mg-Sol (5% Mg), Mg-Cu (1.7% Mg, 0.4% Cu), Cu-Mg (0.1% Mg, 0.4% Cu), Zn-Cu-Mg (1.5% Zn, 0.2% Cu, 0.2% Mg), NAC-ZnO (1.5 % Zn), and NAC-ZnO (3% Zn) – are shown Figure 1.

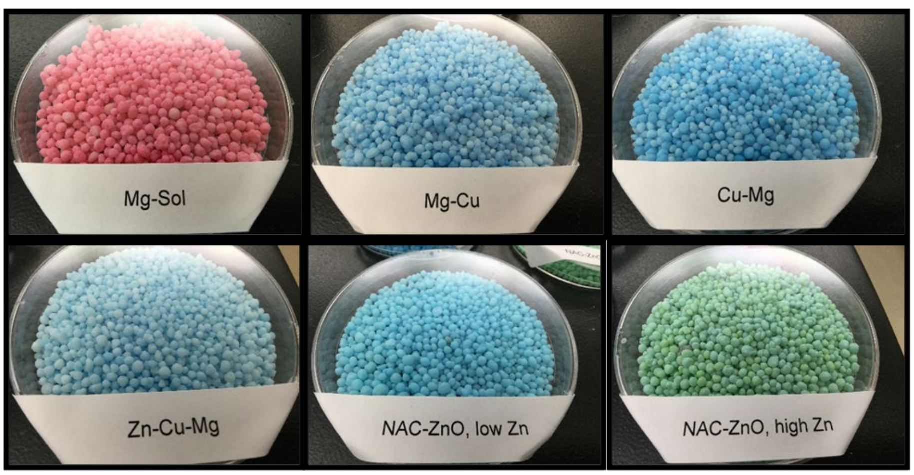


Figure 1. Various urea products coated with micronutrients.

Greenhouse Evaluation to Quantify the Performance of Synthesized Products

In this study, uptake of N, Zn, Cu, and Mg from coated urea will be evaluated using sorghum plants. We will quantify the effect of urea-metal hydroxide/oxide products compared to conventional analogues, such as zinc oxide, copper hydroxide, and magnesium hydroxide, on sorghum yield and Zn, Cu, Mg, and N uptake (Table 4). Plant biomass, uptake, and grain translocation of Zn, Cu, Mg, P, and N will be measured as sorghum reaches maturity. Planting is targeted for the first week of June on Brownfield soil.

Table 4. Treatments for the greenhouse study of sorghum performance.

1	Mg-Sol	5	Nac-ZnO (1.5% Zn)	9	Cu-Mg & NBPT	13	Bulk ZnO *	17	Bulk $Zn(OH)_2$ *
2	Mg-Cu	6	Nac-ZnO (3% Zn)	10	Zn-Cu-Mg & NBPT	14	$ZnSO_4$ *	18	Bulk $Cu(OH)_2$ *
3	Cu-Mg	7	Mg-Sol & NBPT	11	NAC-ZnO (1.5% Zn) & NBPT	15	$CuSO_4$ *	19	Bulk $Mg(OH)_2$ *
4	Zn-Cu-Mg	8	Mg-Cu & NBPT	12	NAC-ZnO (3% Zn) & NBPT	16	$MgSO_4$ *	20	Urea-control

* indicates the testing material was not coated in urea.

Quantification of Nutrient Transformation

The objective of this study is to evaluate the 12 coated products and urea for N transformation. The 12-week incubation study is designed to quantify the effect of coating ingredients on N transformation (urea-N, ammonium-N, and nitrate-N) over time. This study is planned for late August 2021 onwards.

*1.1.2 Field Evaluation of Existing Enhanced Efficiency N Fertilizers and Technologies for Improved Yield and Reduced N Pollution **(New FY21)***

N use efficiency of conventional urea is very low, particularly when applied with the surface broadcast method. Enhanced efficiency products, such slow or controlled release, not only increase crop productivity, but also increase N use efficiency and reduce environmental pollution related to N losses. Several modified urea products, including urea-ammonium sulfate, urea-S, urea-Zn, urea-B, various forms of inhibitor-coated urea (such as Agrotain, neem-coated), and controlled-release urea products (such as polymer-coated urea [PCU], S-coated urea) are already available in international markets, including those in Africa and Asia. These enhanced efficiency fertilizers are ideally suited for farmers in the focus countries since they face greater climatic vulnerability than their counterparts in developed countries. IFDC's findings under laboratory and greenhouse conditions have shown that these products do not require briquetting or special applicators and can be applied at one time.

Activities: Evaluation of polymer-coated urea, urea deep placement (UDP), and neem-coated urea in wheat, maize, and vegetables. Wheat trials established in November 2020 and validation trials for maize and rice in 2021.

Partnership: Input and service providers (ISPs), farmers, and local universities, with cost-sharing from the Feed the Future Nepal Seed and Fertilizer (NSAF) project and the private sector.

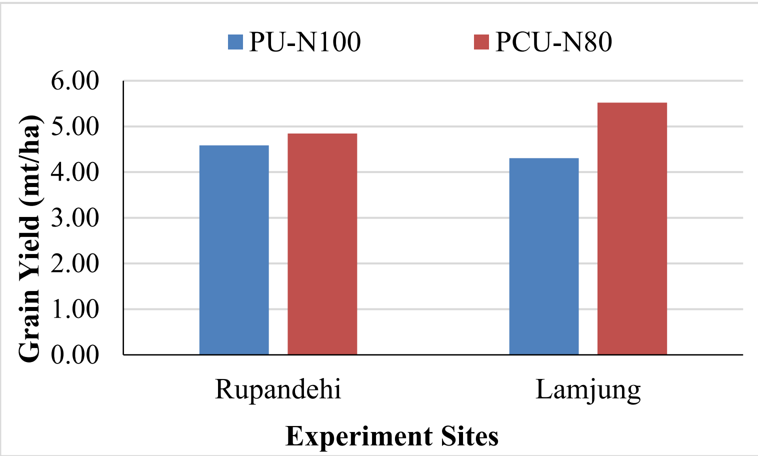
Location/Timeline: Nepal and Bangladesh/October 2020-June 2021

Progress:

Nepal

Two field trials were conducted in rice across two agroecologies – the central terai district bordering India (Rupandehi) and the mid-hill district (Lamjung) – during the 2020 monsoon season to compare the effects of PCU against the variable N rates of conventional urea (variable N results presented separately). Results confirmed that the use of PCU reduced N input by 20% without any yield penalty (Figure 2).

In addition, two field trials for wheat are being conducted to evaluate yield response and economic returns of these products in comparison to urea and FDP across two districts in Nepal. Treatments include PCU, UDP, neem-coated urea, real-time N management using a leaf color chart, and conventional urea. In each location, treatments were laid out in a randomized complete block design. Trials are in progress and will be harvested in the first week of April. The detailed results, including yield, nitrogen use efficiency, and economic return, will be presented in the next report.



The number following N represents kilograms of nitrogen per hectare.

Figure 2. Comparison of rice grain yields obtained with prilled urea and polymer-coated urea across two districts in Nepal.

Figure 3. Evaluation of wheat yield and nitrogen use efficiency obtained with various enhanced efficiency nitrogen fertilizers in Rupandehi District, Nepal

Bangladesh

Following the evaluation the prior season, two more trials were conducted on maize in rabi seasons in December 2019 using S-rich urea fertilizer in an S-deficient area in Bangladesh. The treatments included S omission, different S sources applied at 50 kg S/ha – Thiogro ES 13%, Thiogro ES 75%, gypsum, Thiogro ESS 13%, and ammonium sulfate (AS) – recommended practice with straight fertilizers and blended fertilizer (NPKSB), and farmer's practice.

Two additional treatments – Thiogro ES 13% at 25 kg and 75 kg S/ha – were also added to determine the optimal S rate for maize cultivation. N fertilizers (both urea and urea-S) were applied in three equal splits at final land preparation, 6-8 leaf, and tasseling stages, and farmer fertilization was followed in the farmer practice treatment. At maturity during the end of May 2020, trials were harvested, and crop biomass yields (grain and straw) and yield attribute data were recorded from each plot. Nutrient content of plant samples (grain and straw) was determined to calculate N and S use efficiency.

The salient results of plant samples of the 2020 trials, in brief, are stated. Among the different S sources, Thiogro ES 13% produced the highest yield compared to the other sources, i.e., gypsum, Thiogro ESS 13%, Thiogro ES 75%, and ammonium sulfate (AS), whereas Thiogro ES 75% performed best in 2019.

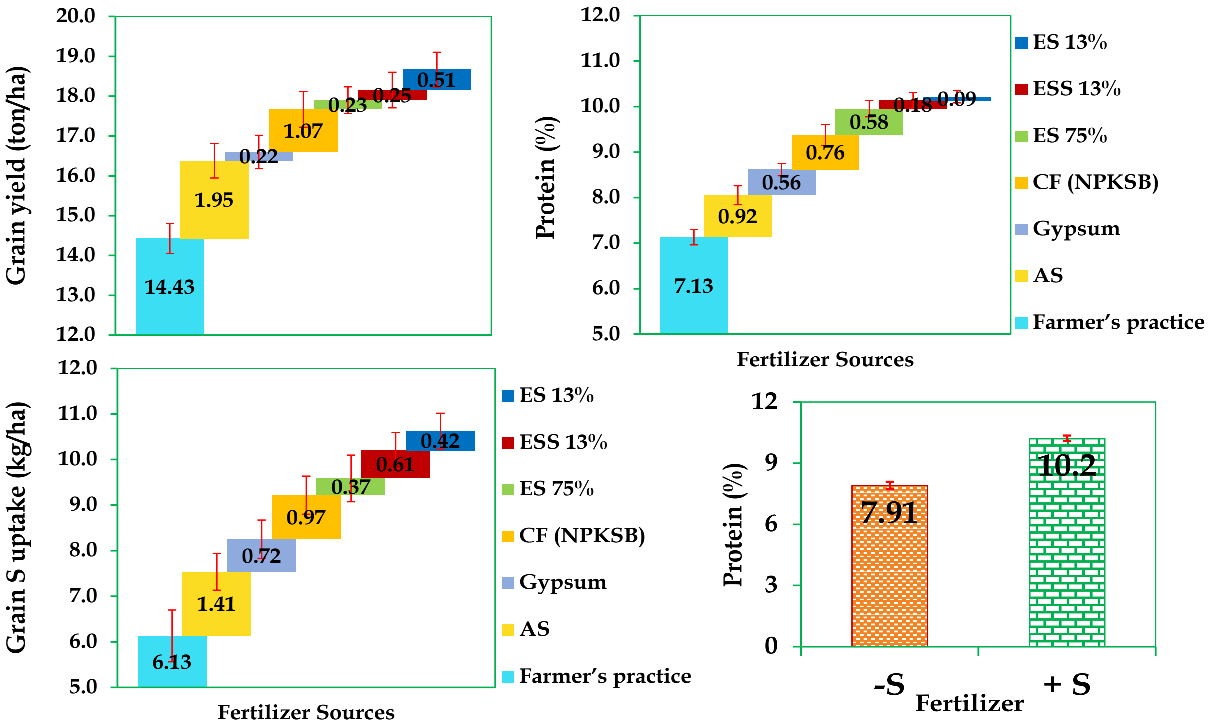


Figure 4. Effect of sulfur-enriched urea fertilizers on maize grain yield, protein (%), and S content across two locations in Northern Bangladesh.

Results indicate that S fertilizers had an additive effect on the grain yield, protein content, and S concentration, with an increase of up to 29%, 43% and 73%, respectively, over farmer practice and management (Figure 4). Concerning grain protein response to S fertilization, S fertilization increased protein content by 29% (Figure 4).

1.1.3 Resolution of Technology Dissemination/Scaling Constraints to Fertilizer Deep Placement (FDP) (Ongoing)

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

1. Development of a high-capacity briquetting machine: Uganda

The current Bangladesh briquetter model was designed to be placed with agro-dealers who produce a low volume of briquettes at the point of sale of urea. This model does not work well for Africa, where agro-dealers are handling multiple crops other than rice.

Outcome: Development of a high-capacity briquetting machine that can be placed with a fertilizer distributor, who would then distribute briquettes to multiple cooperatives or rice schemes.

Lead Researcher(s): John Wendt.

The briquetter is in the final stages of development. We anticipate that final modifications, blueprints, and data on trial runs will be available by December 2021. The large-scale briquetting machine was built in Kampala, and briquettes have been produced during the test runs in early 2021 (Figure 5). Based on the results from preliminary tests, additional modifications will be made in the next couple of months. Results on the operational efficiency of the machine along with output capacity with blueprints will be included during the next reporting period.

Figure 5. **Large-scale briquetter machine built in Kampala.**

2. Transplanter/FDP applicator development: USA

The work was initiated under a university partnership grant with Mississippi State University (MSU) began in February 2018-19. Due to delays in the importation of the transplanter from India and then the on-set of COVID-19, progress has been slow. Expected completion date is September 30, 2021.

Outcome: Greater adoption and scaling of FDP along with seeds.

Progress:

The objective of this activity is to develop an automated, mechanical FDP device as an attachment to a rice transplanter. This will facilitate the combined deep placement of urea or NPK briquettes along with the transplanting of rice seedlings. A Yanji Shakti 8 Row Rice Transplanter (manufactured by VST Tillers Tractors Ltd., Bangalore) was imported from India. Initially, the FDP applicator was designed and fabricated so that two tank hoppers were supplying briquettes to four-row applicators (two rows per hopper). The transplanter plants eight rows while the briquettes are placed in four rows (between two rice plants rows), as shown in Figure 6.

Figure 6. **FDP application device, with the hopper attached to the transplanter (side view).**

Following the initial tests, major changes were made to the rice transplanter/FDP applicator, with installation of a single self-contained unit to meter, place, and cover the briquettes. Four Chapin planter units were modified and attached to the rice transplanter utilizing a parallel link-mounting system to allow the individual units to float independently and follow the contour of the ground, maintaining the desired urea briquette placement depth. Additionally, the parallel link-mounting configuration allows the wheel driving the metering plate to remain in constant contact with the soil, a crucial component of controlling urea briquette metering. A unified lifting mechanism was installed to create a means for the transplanter operator to lift the planter units simultaneously at a single point of contact, a feature necessary to facilitate turns at the end of rows and prevent damage to the parallel link and planter assemblies.

The FDP applicator consists of urea briquette-metering disks designed to select an individual briquette and place it into the tubular passage that delivers the briquette into an adjustable piercing attachment opening. The knife-like leading-edge piercing attachment creates a passage for the briquette to be placed at depth. A spring-loaded, winged device affixed to the trailing edge of the piercing attachment is responsible for covering the passage around the briquette with soil to be pressed into place by trailing packing wheels, effectively sealing the briquette into the soil for use by the plants (Figure 7).

Figure 7. ***FDP applicator: (A) raised with unified lifting mechanism; (B) metering disk singulating urea briquettes; and (C) packing wheels sealing the soil over the briquettes.***

With the current modifications, the FDP applicator technology could be developed in a universal configuration, creating the opportunity for the applicator to be easily attached to any rice transplanter via a universal hitch. Also, this decoupled configuration would open the door to utilizing this technology in upland crops as an add-on implement to combine the seeding/fertilizing process into a single-pass operation. Hence with the fewest passes in the field, efficiency is improved while minimizing "footprints." During the coming season, the transplanter/applicator will be evaluated under puddled field conditions.

1.1.4 Climate Resilience and Mitigating GHG Emissions

Fertilizers play a unique role in both emitting and sequestering GHGs and improving crop resilience to abiotic and biotic stresses. The proposed activities highlight the resilience and GHG mitigation features of FDP technology in improving crop yields under unfavorable environments.

1.1.4 (A) Increasing fertilizer use efficiency and resilience in saline soils in Bangladesh (Ongoing)

More than 30% of the cultivable lands and about 0.223 million hectares (26.7%) of new land has been affected by various degrees of salinity during the last four decades. Two field trials were conducted in the Southwest part of Bangladesh (saline soil areas) by using soil amendment (cow dung and ash) and customized compound fertilizers to reduce the impact of salinity on rice yield (December 2019-September 2020). To confirm the positive effect of the proposed technology, validation trials are being conducted.

Activity: Two validation trials are conducted during Boro season 2021 (December 2020-May 2021) in saline soil areas on the effect of rice varieties and nutrient management.

Location/Timeline: Bangladesh/October 2020-September 2021

Partnership: Soil Science Division, Bangladesh Rice Research Institute (BRRI)

Outcome: Saline soil management data and information will be validated, and recommendations shared with NARS and farmers.

Progress:

Two validation field experiments have been established in saline soils at the BRRI farm, Shatkhira, and at a farmer's field, Kaligong (agroecological zone 13: non-calcareous gray floodplain soils and alkaline in nature) (Figure 8).

Figure 8. ***Saline soil management trials established in the Southwest part of Bangladesh (saline soil areas).***

In these field experiments, two varieties of Boro rice (BRRI dhan67 [salinity resistant] and BRRI dhan88 [farmer's choice]) were used with seven treatment combinations: nitrogen control (N0), UDP, customized fertilizers, gypsum, and organic amendments (ash and cow dung). The experiment was laid out in a split-plot design, distributing the variety to the main plots and treatments to the sub-plots, with three replications. N, P, K, S and Zn were applied at a soil test-based recommended rate to all plots as per the *National Fertilizer Recommendation Guide* (FRG 2018); the rates were 120 kg N/ha, 28 kg P/ha, 100 kg K/ha, 18 kg S/ha, and 2.6 kg Zn/ha. Farmer fertilization was followed in the farmer's treatment. Soil amendments (cow dung and ash) were applied three days prior to transplanting. For the UDP treatment, urea briquettes (UB) were placed at a depth of 10 cm at the center of 4 rice hills 10 days after transplanting (DAT). Prilled urea was applied in three equal splits at 7, 35, and 55 DAT, respectively. Crop management and plant protection measures were done when needed to keep the crop free from any insect or pathogen attack. In both experiments, rice crops are in the grain-filling phase. The tentative harvest date is the end of April 2021. During harvest, all yield parameters (number of tillers, panicles, effectively filled grains, and 1,000-grain weight) will be recorded. Grain and straw will be collected for determining the nutrient content, and soil samples will be analyzed to understanding the reclamation status. However, due to COVID-19 restrictions in Bangladesh, harvesting and processing will be hampered; plant and soil samples analysis may be delayed if the restrictions continue beyond May 2021.

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

Fertilizer application in the widely promoted System of Rice Intensification (SRI) does not differ from the classical broadcast method, which includes basal application of nitrogen, phosphorus, and potassium (NPK) fertilizers and topdressing with urea; this induces significant nutrient loss and low nutrient use efficiency. The objective of this study was to test the effectiveness of a single application of NPK fertilizer briquette in the SRI cropping systems in Burkina Faso. A one-time application of multi-nutrient fertilizer briquettes was compared with the recommended practice of basal diammonium phosphate (DAP) application plus urea topdressing and to the conventional urea briquette application after a basal DAP or NPK application in both irrigated and rainfed lowland rice systems.

Location/Timeline: Burkina Faso; trials started in June 2020 and were completed by December 2020. Analysis of results and final reporting toward the end of FY21.

Partnership: This activity is being conducted in partnership with the NARES (Institut de l'Environnement et de Recherches Agricoles [INERA]) and farmer-based organizations in Burkina Faso.

Lead Researcher(s): Ekwe Dossa

Outcome: Efficient fertilizer recommendations made available to NARES and scaled out to farmers.

Progress:

In cooperation with INERA, FDP (deep-placed NPK and urea briquette) treatments were demonstrated in Burkina Faso for rice in rainfed lowland systems at Koumbia, Sabou, and Kombissiri sites and in irrigated rice systems at Bagre, Zoungou, and Bama. In the lowland systems, the FDP technology resulted in about 1 mt of surplus paddy rice yield compared to the recommended practice of basal NPK plus broadcast urea. However, yield differences were significant only at Sabou. The one-time deep placement application of two NPK briquettes did not perform better than the conventional treatment.

Figure 9. Demonstration of multi-nutrient fertilizer briquettes in lowland (left) and irrigated (right) rice production systems in Burkina Faso.

Table 5. Paddy grain yield and biomass as affected by different fertilizer treatments in rainfed lowland rice systems in Burkina Faso.

Traitements	Koumbia		Sabou		Kombissiri	
	Rendement grains (kg/ha)	Rendement paille (kg/ha)	Rendement grains (kg/ha)	Rendement paille (kg/ha)	Rendement grains (kg/ha)	Rendement paille (kg/ha)
Témoin	833[b]	7167	2889[d]	3500[b]	1417[b]	1133[b]
150 kg / ha de NPK+100 Kg / ha d'urée	2250[a]	8900	4728[b]	3564[b]	2750[a]	2467[ab]
150 kg / ha de NPK+PPU	2625[a]	9067	6764[a]	7278[a]	3333[a]	3117[a]
2granules de NPK	2375[a]	8283	3667[c]	4728[b]	2850[a]	2200[ab]
Probabilité	**<0.001**	**0.28**	**<0.001**	**0.002**	**0.02**	**0.04**
Signification	**THS**	**NS**	**THS**	**HS**	**S**	**S**
Coefficient de variation (%)	**10.2**	**14.1**	**8.4**	**14.2**	**20.9**	**27.7**

Note: PPU = deep placement of urea briquette (UDP), 2 granules de NPK = deep placement of NPK briquette

In the irrigated rice systems, paddy grain yield and straw biomass were very site dependent. One-time NPK briquette application did not perform well at Bama and Bagre; however, it yielded 945 kg/ha higher grain yield, a 25% increase in yield from the conventional recommendation practice (Figure 10).

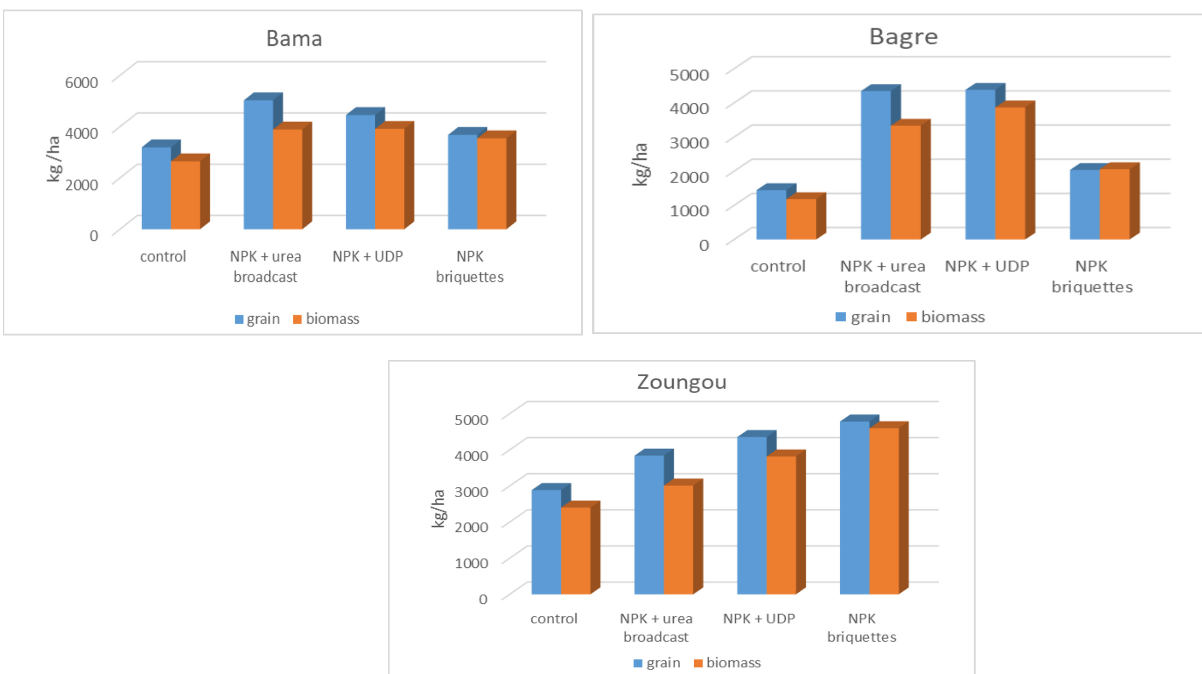


Figure 10. Paddy grain and straw biomass as affected by different fertilizer treatments in irrigated rice systems in Burkina Faso.

1.2 Improving Phosphate Availability and Use Efficiency

Highlights of Activated Phosphate Rock Research

Activated PR is an innovative method to: (i) provide plant-available P with reduced P losses (fixation, runoff, and leaching); (ii) increase P use efficiency; (iii) utilize PR deposits that are economically not viable for production of conventional P fertilizers; and (iv) promote decentralization and greater accessibility of P fertilizers. Our greenhouse and field trials have shown that activated PR containing as little as 20-25% of its P content as water-soluble MAP or DAP is 65-90% as effective as conventional P fertilizers. The activated PR continues to provide plant available P to the following crop, further improving its efficiency relative to water-soluble P fertilizers. Unlike PR, which is suitable for direct application only on acidic soils (pH < 5.5), activated PR can be applied like conventional fertilizers on a wide range of soils. As shown below, recovery efficiency of activated PR was like, if not better than, WSP sources (MAP and DAP) on both Hiwassee soil (pH 5.3) and Greenville soil (pH 6.2).

Hiwassee Soil (pH 5.3)

P Applied 1st Crop mg P/kg		P Applied 2nd Crop mg P/kg		P Uptake Total	Recovery Efficiency (%) P applied as	
WSP	PR	WSP	PR	mg/ pot	WSP	Total P
0	0	0	0	11.9		
25	0	25	0	109.7	24.5	24.5
25	75	0	0	172.4	80.3	16.0
50	0	50	0	165.6	19.2	19.2
50	150	0	0	328.5	79.2	17.8
50	50	0	0	184.1	43.1	17.5
100	0	100	0	285.8	17.1	17.1
100	100	0	0	362.0	43.8	19.9
200	0	200	0	480.5	14.6	14.6

Greenville Soil (pH 6.2)

P Applied 1st Crop mg P/kg		P Applied 2nd Crop mg P/kg		P Uptake Total	Recovery Efficiency (%) P applied as	
WSP	PR	WSP	PR	mg/pot	WSP	Total P
0	0	0	0	44.4		
25	0	25	0	213.9	42.4	42.4
25	75	0	0	297.7	126.7	31.7
50	0	50	0	303.6	32.4	32.4
50	150	0	0	457.0	103.1	25.8
50	50	0	0	335.6	72.8	36.4
100	0	100	0	456.2	25.7	25.7
100	100	0	0	555.6	63.9	31.9
200	0	200	0	702.6	20.6	20.6

In summary:

- Greater accessibility of phosphatic fertilizers to farmers in sub-Saharan Africa (SSA), where soil P deficiency is widespread and large amounts of P must be applied to get crop response due to high P adsorption by soils.
- Utilizes local PR deposits in SSA for production of activated PR.

1.2.1 *Activated Phosphate Rock Trials under Greenhouse Conditions* (Ongoing)

Ongoing greenhouse residual trials on the performance of activated phosphate rock against conventional P fertilizers, such as diammonium phosphate (DAP), monoammonium phosphate (MAP), and triple superphosphate (TSP), will be completed by September 2021. This activity is done on cost-sharing basis.

Partnership: Private sector (Minbos, Australia)

Location/ Timeline: HQ/October 2019-September 2021

Outcome: Activated PR performance verified under greenhouse conditions

Progress:

Greenhouse studies at IFDC HQ with Cabinda PR (Angola) are ongoing with soybean, comparing the application of (i) Cabinda PR alone; (ii) compacted Cabinda PR with MAP; and (iii) MAP alone. The ongoing trials are evaluating a wide range of MAP:Cabinda PR blends, tableted (compacted) product versus granulated, and the residual effect of Cabinda PR on grain yield and P uptake with crops grown to maturity. There are many reasons MAP was used in the blends: (i) It serves as a starter to help early plant growth with better root development that, in turn, results in more effective utilization of PR than the use of PR alone at planting; (ii) non-granular MAP is cheaper than granular TSP or DAP as a water-soluble P source; (iii) MAP is an acidic fertilizer (pH 4.8) that may help PR dissolution; and (iv) nitrification of NH_4^+ of MAP to NO_3^- and H^+ ions in soils further enhances PR dissolution.

Figure 11. Soybean grown using activated PR.

The main objectives of the ongoing trials are to evaluate the agronomic effectiveness of Cabinda PR as mined, MAP, and various MAP:Cabinda PR products (ratios, rates, and method of production – granulation vs tableting) for soybean-wheat-sorghum cropping. The first soybean crop did not perform well in greenhouse conditions on Hiwassee soil (pH 5.3). However, grain, straw, and total biomass showed a response to an increasing P rate from all P sources (Figure 12). PR dissolution was more effective for legumes than cereals, with 200 mg P/kg of Cabinda PR giving similar soybean grain and total dry matter yields as 25 mg P/kg of MAP.

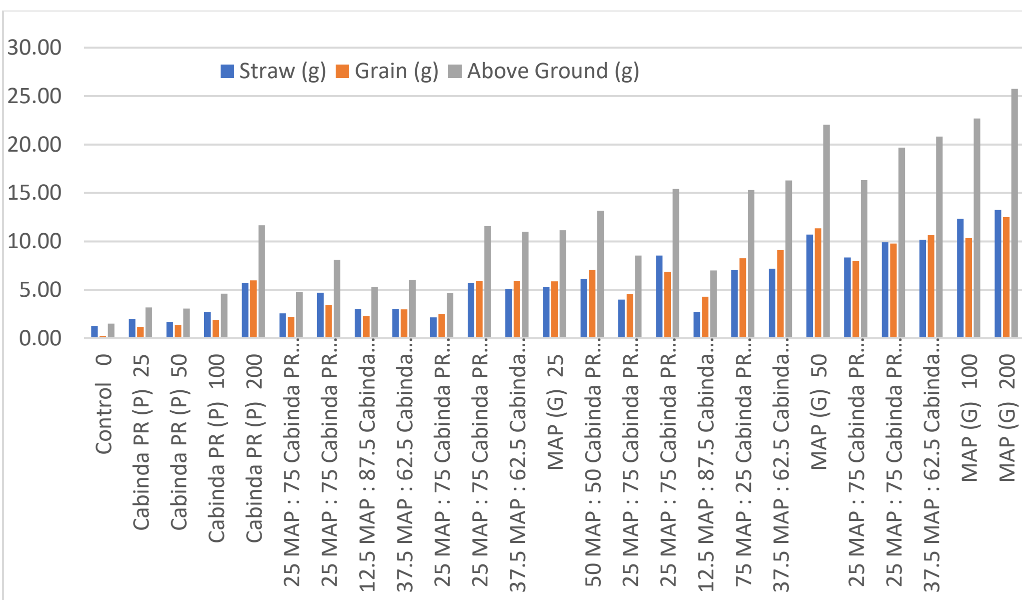


Figure 12. Overall dry matter yield of soybean grown in greenhouse conditions.

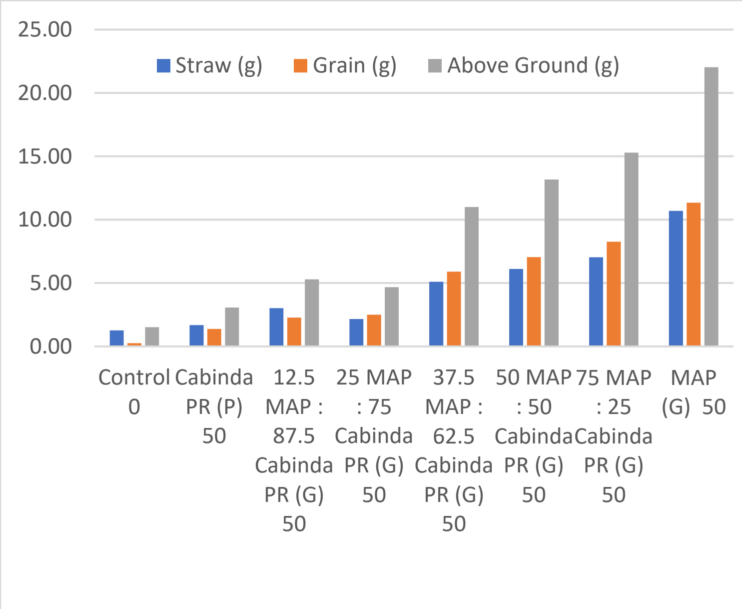


Figure 13. Response curve for P at a rate of 50 mg.

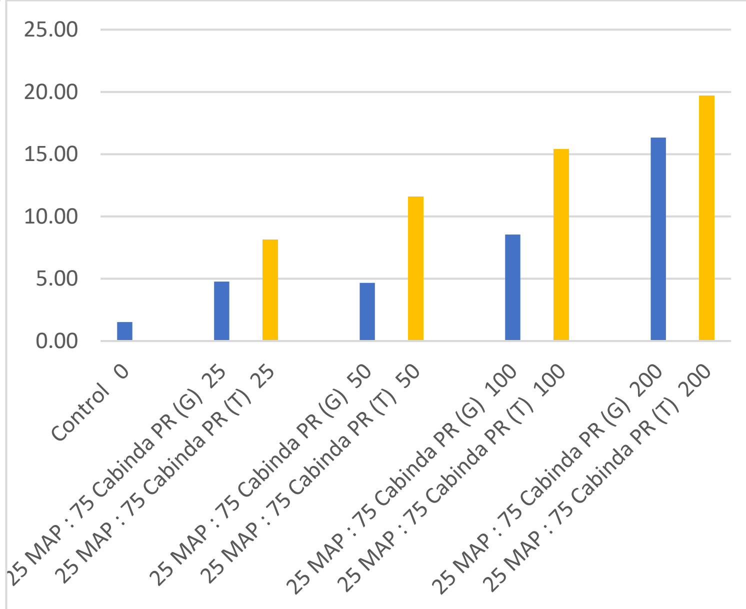


Figure 14. Effect of granular versus tableted MAP:Cabinda PR on total aboveground dry matter yield of soybean.

Overall, the effectiveness of the activated PR products increased with an increasing proportion of MAP for application at a rate of 50 mg P/kg, as shown in Figure 13. Compacted (tablet) activated PR was found to be more effective than a granulated mixture, giving higher total dry matter yield (Figure 14). However, the differences were not significant for seed yield. A residual wheat experiment comparing activated PR with MAP and PR is in progress with wheat at heading stage. After the wheat experiment is completed, this research will conclude with sorghum as the final residual crop in the summer of 2021.

1.2.2 Alternative Activation Process for Enhanced Efficiency P Fertilizers (New FY21)

This research will also provide opportunities to remediate heavy metals from phosphatic fertilizers besides providing alternatives to current P fertilizer production, which are inefficient. Expanding on our activated PR findings, laboratory and greenhouse research will investigate alternative "activation" processes using bio-organic acids, biofertilizers, and bio-nanotechnology.

Progress:

This activity will be concluded with the greenhouse trial results on wheat and soybean in the next semi-annual report. Due to COVID-19, the private sector partner working on nano PR and calcination has filed for bankruptcy and the interactions and progress with other partners was restricted. **The progress will be reported during September 2021**.

1.2.3 Quantifying P Use Efficiency of Liquid P Fertilizers in Mozambique (New FY21)

Since the efficiency of granular P fertilizers from initial application is only 10-20%, the proposed activity evaluates whether a liquid P fertilizer applied once as a foliar can meet the P requirement of a crop cost-effectively. A major outcome of this activity is to assess the performance of liquid phosphatic and activated PR (APR) fertilizers with TSP on groundnut and soybean crops in Mozambique.

Activity: Compare performance of liquid "Super Phos" with triple superphosphate (TSP) on groundnut and activated PR on soybean. Trial sites will be fully characterized with collection of minimum data set, including data on labor, input costs, etc.

rops/location/timeline: Groundnut (October-November) and soybean (December); Mozambique; October 2020-September 2021

Partnership: Private sector (Phoenix Seed and Agrodata), Swiss-funded Food security through climate Adaptation and Resilience in Mozambique (FAR) project

Progress:

This study focuses on investigating the response of groundnut and soybean to inorganic sources of P from granular and liquid fertilizers, with emphasis on yield and profitability. The study is being conducted in Bandua, Buzi District, located at 26 meters below sea level. The area is situated at the basin of the Buzi River, an area heavily devasted by recent cyclones and tropical storms that hit central Mozambique: Idai, Chalane, and Eloise. The climate is sub-humid, characterized by a uni-modal rainfall pattern, with rains from November to April. The rainfall distribution is irregular and unreliable. The general objective was to identify appropriate fertilizers and the rate of P from TSP 45% P_2O_5), activated phosphate rock (APR; 32.8% P_2O_5), and liquid fertilizers.

Groundnut: The rates of the fertilizers applied are presented in Table 6. Despite the heavy rains due to Tropical Storm Chalane, followed by Cyclone Eloise, which severely devasted the area, the groundnut showed resistance to these events (planted in the uplands to avoid flooding damage) and farmers are very enthusiastic about crop performance. Harvesting has been completed and threshing and yield measurements will be performed.

Harvesting of groundnut plots in Bandua combined with a field day on post-harvesting

Table 6. Rates of nutrients applied in groundnut trials in Mozambique.

Treament No.	Treament Description	P Rate kg P2O5/ha	K Rate K2O/ha	S Rate S/ha
1	Control-full	0	0	0
2	Control-P	0	50	18
3	3 L SuperPhos	20	50	18
4	6 L SuperPhos	40	50	18
5	TSP	40	50	18
6	TSP-2	80	50	18

TSP = 89 kg/ha, TSP-2 = 178 kg/ha. The source of K and S is potassium sulfate at 100 kg/ha. TSP is triple superphosphate. SuperPhos refers to liquid fertilizer.

Soybean

While farmers in Bandua have cultivated soybean for many years, it has been largely without any associated crop management practices. Therefore, apart from investigating the response of soybean to inorganic sources of P, a second objective was to assess the adaptability of this crop under farmers' conditions in the area. Table 7 shows the fertilizers applied and their rates. Inoculants and APR were included as part of the treatments. Unlike the groundnut, the soybean suffered from both biotic (damaged due to grasshoppers) and abiotic (floods) stress-related issues. The initial planting, which was done in late December, was severely affected by grasshoppers. After the assessment in January 2021, the soybean was replanted. Unfortunately, nine of the 16 replanted plots were flooded again due to Cyclone Eloise, and only six plots (also planted upland) could be recovered. These plots are showing very good performance, and visual differences between the treatments can be observed.

The six plots will be harvested in the coming month for analysis. Given that this is the first time that these farmers in Bandua have been exposed to soybean, we continued monitoring the remaining plots and organized field days with farmers and the private sector to share knowledge. A total of 140 smallholder farmers (105 female) attended the field days.

Table 7. Nutrients applied in soybean trials in Mozambique.

Treament No.	Treament Description	P Rate kg P2O5/ha	K Rate K2O/ha	S Rate S/ha	
1	Control-full	0	0	0	Innoc
2	Control-P	0	50	18	Innoc
3	3 L SuperPhos	20	50	18	Innoc
4	6 L SuperPhos	40	50	18	Innoc
5	Act PR	40	50	18	Innoc
6	Act PR-2	80	50	18	Innoc
7	TSP	40	50	18	Innoc
8	TSP-2	80	50	18	Innoc

TSP = 89 kg/ha, TSP-2 = 178 kg/ha, Act PR = 125 kg/ha, and Act PR-2 = 258 kg/ha. Act PR is activated phosphate rock; TSP is triple superphosphate. SuperPhos refers to liquid fertilizer.

1.3 Balanced Crop Nutrition for Site-Specific Fertilizer Recommendations

The proposed activities will 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 will be defined by a 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

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

Zn, S, Cu, and iron (Fe) deficiencies are widespread, affecting both crop yields and human nutrition. 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. S, a macronutrient, plays an important role in enhancing the methionine and cysteine (S-containing amino acids) content in legumes and has been shown to increase the nutritional quality of protein and increase the proportion of legume protein that can be utilized by humans and nonruminant livestock. Deficiencies of micronutrients, such as Zn and Cu, also increase the susceptibility of crops to infectious disease. Little definitive information is available on efficient ways of incorporating micronutrients, such as Zn, into fertilizers.

Activities: Laboratory, greenhouse, and field evaluations of various rates, sources, and methods of nutrient delivery under a wide range of soil pH and soil organic matter content. The efficiency of Zn, S, Cu, and B on crop yield, crop performance, and nutrient uptake will be quantified as affected by: (a) their delivery using N-, NP-, and NPK-based fertilizers; (b) crops (soybean, rice, wheat, and maize); and (c) soils. The efficacy of S-based fertilizers applied as urea+ES, urea+ES+SO_4-S, and urea+SO_4-S will also be quantified. Since balanced fertilization can also improve the quality of produce for human nutrition, grain samples from selected trials will be analyzed for methionine and cysteine, Zn, Cu, P, and phytate content.

Location/Timeline: Ghana (data for grain quality analysis); HQ-Ongoing-September 2021

Partnership: Tennessee State University and other industry partners (cost-share)

Outcomes: Increased use and availability (efficiency) of multi-nutrient (balanced) fertilizers

Progress:

Starting in FY19, S trials have been conducted in northern Ghana, in partnership with a private client (Shell International Petroleum Company), to evaluate the agronomic effectiveness of a new S fertilizer product (Thiogro ES-13). This product contains micronized urea with 13% ES. Results from the field validation studies showed that Thiogro ES-13 was as effective as the locally available S in the season of application in terms of enhancing maize biomass and yield, grain nutrient (N and S) concentration, and total aboveground nutrient uptake. However, despite the increased S and N uptake with increasing S application rate from the Thiogro ES-13, the proportion of the applied S taken up by plants decreased with increasing S application rates. At an S application rate of >50 kg S/ha across all locations, the proportion of applied S taken up by the plants was <25%, suggesting that substantial quantities of the applied S were not taken up by the plants. Post-harvest soil analysis showed that large amounts of S in the plots receiving Thiogro ES-13 at an application rate of >50 kg S/ha remained in the soil after crop harvest.

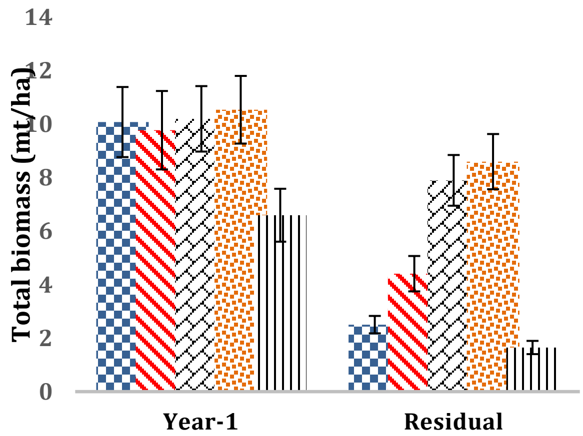


Figure 15. *Maize total biomass resulting from one-time application of Thiogro ES-13.*

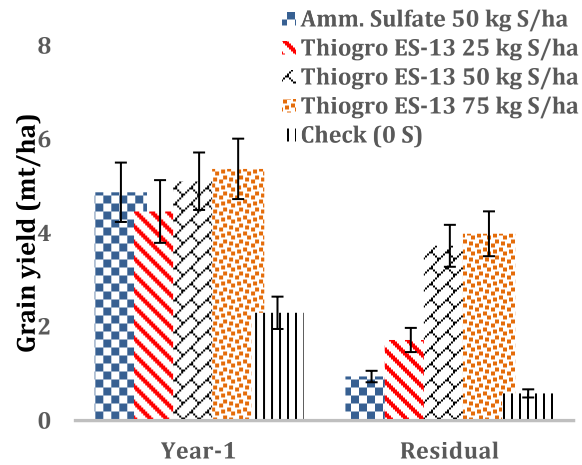
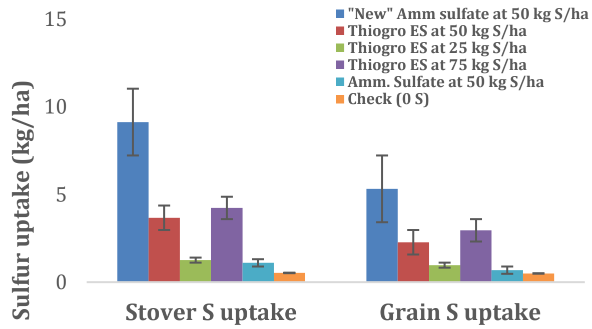


Figure 16. *Maize grain yield resulting from one-time application of Thiogro ES-13.*

During the FY20 reporting period, we presented the biomass and grain yields from the residual S trials. To recap, the residual S trial showed that no application of "new" S fertilizer to the follow-up maize crops resulted in a near total crop loss from the plots previously applied with conventional S fertilizer (ammonium sulfate), with resulting yields not significantly different from the check plots that did not receive any S in the previous cropping. However, plots that received Thiogro ES-13, at an S rate of at least 50 kg/ha, during the previous cropping produced grain yield of ≥50% of expected grain yield (yields obtained from the plots receiving fresh S fertilizer application).

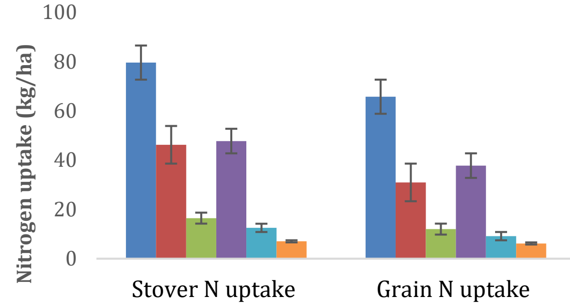
Maize grown with residual Thiogro ES-13 initially applied at 50 kg S/ha (left) and residual ammonium sulfate initially applied at 50 kg/ha (right)

Analysis of the samples for plant tissue and grain S and N uptake of the residual S field validation trials was conducted during the current FY21 workplan period. Across the 12 experimental sites, new application of S and N fertilizer (ammonium sulfate) resulted in the highest S and N uptake (Figure 17 and Figure 18).



Each bar represents average of 48 replicates (12 sites x 4 reps/site).

Figure 17. Effects of residual S compared to new application of S fertilizer on S uptake.



Each bar represents average of 48 replicates (12 sites x 4 reps/site).

Figure 18. Effects of residual S compared to new application of S fertilizer on N uptake.

This was not surprising, because it shows increased availability of S and N to the plants through fresh supply. Consistent with the grain and stover yields reported previously, the lowest S and N uptake among the residual S sources from the S fertilizer treatments occurred with the previously applied ammonium sulfate treatment, suggesting that a substantial amount of the unused S and N was lost from the soil. Also, as observed with the stover and grain yields from the residual S study (averaged across the 12 study sites), S uptake with Thiogro ES-13 applied at 50 kg S/ha was 43% of the S uptake with the newly supplied S and N uptake was 35% of the new ammonium sulfate application. At a Thiogro ES-13 application rate of 75 kg S/ha, residual S recovered by the maize plant was 55% of that observed with new application, and N uptake was 46% of that with the fresh fertilizer supply). In general, S availability within the depth of the radical and seminal root and the drainage of water through the soil profile influence S uptake in maize, and studies have shown that S uptake by grain and stalk increases significantly with increasing S availability in the root zone. Thus, the residual field data confirm the previous suggestion that, due to slow oxidation and mineralization with Thiogro ES-13, succeeding crops could benefit from the unused S. In such instances, the residual S from Thiogro ES-13 fertilizer application should be considered when making S recommendations for subsequent crops.

To sum up, the combined results, including stover yield, grain nutrient (N and S) concentration, and total aboveground N and S uptake highlight that the Thiogro ES-13 was as effective an S source as the locally available sulfate (ammonium sulfate) fertilizer in the season of application. However, the residual S study shows that Thiogro ES-13 could supply substantial amounts of S and N in residual form to succeeding crops. The agronomic effectiveness of the new S fertilizer product when combined with its residual effects is higher than the locally available S product, which could easily be lost from the soil with heavy rains. Thiogro ES-13 (using recycled ES) could also be economically more favorable, given its cost could be like ammonium sulfate or even cheaper when computed with respect to nutrient value.

1.3.1 (B) Improving crop performance through balanced fertilization using customized compound fertilizers in maize-legume-rice system (Ongoing)

In ***Nepal,*** existing fertilizer recommendations for most crops including cereals and vegetables are blanket type – the same rate for a particular crop across different agroecological zones despite spatial variation in soils and agro-climate. The fertilizer requirement varies by soil type and agroecological zone. To increase fertilizer use efficiency and maximize farm income, fertilizers should be applied based on soil fertility status and crop nutrient demand. This problem is being addressed through the development of a domain-specific fertilizer recommendation. Field trials conducted over past three years in partnership with the Feed the Future Nepal Seed and Fertilizer (NSAF) project have shown that N is the most limiting nutrient for cereals and vegetables.

Activity: Field trials on a maize-legume-rice system to evaluate integrated balanced fertilization

Partnership: Agriculture and Forestry University (AFU), Tribhuvan University, and NARC

Location/Timeline: Nepal/October 2019-September 2021

Progress:

To complement the results of the NSAF project, two field trials were conducted across two agroecological zones (terai and mid-hill) to determine the optimal N rate for irrigated rice. Six N rates – 0, 100, 120, 140, 160, and 180 kg N/ha⁻ were laid out in a randomized complete block design. All other agronomic practices, except for N rate, were similar for all treatments.

Figure 19. Determination of the optimal N rate for irrigated rice at Paklihawa Campus, Rupandehi District, Nepal.

Results show that the optimal N rate varies by agroecology. Although increasing the N rate beyond the current recommended rate, i.e., 100 kg/ha, did not increase yields significantly across both sites, addition of 20 kg N/ha produced about a 22% higher yield compared to the existing recommendations (Figure 20). These data are being used to calibrate the Quantitative Evaluation of Fertility in the Tropical Soils (QUEFTS) model. NARC has adopted this approach to extrapolate the fertilizer recommendation from trial sites to a larger domain.

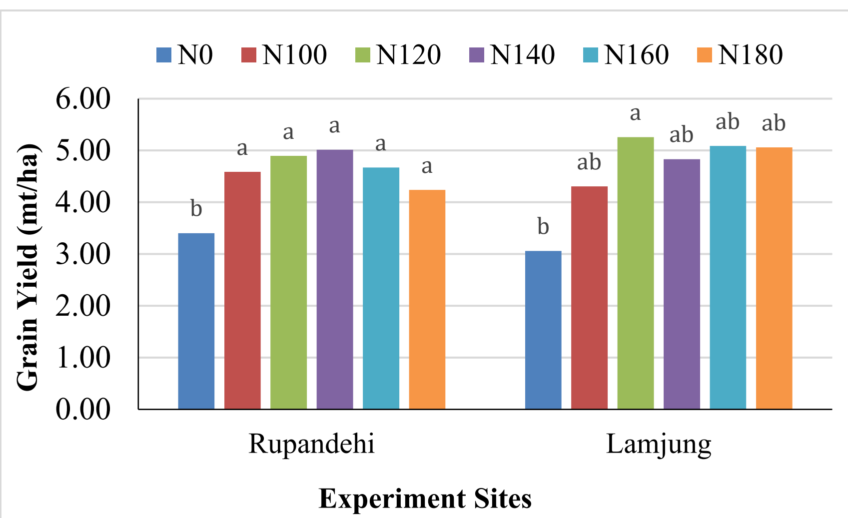


Figure 20. Comparison of rice grain yields with different N rates in Rupandehi (terai, plains bordering India) and Lamjung (mid-hill) districts.

Results of total number of tillers, total biomass yields, and agronomic efficiency also confirm that the existing recommended rate (100 kg N/ha) is optimum for this variety and locations (Table 8).

RFS-SFT Project Builds Capacity of Nepal Agricultural Research Council (NARC) on Improving Nitrogen Use Efficiency

Deep placement of briquetted urea in rice grown under rainfed conditions in Nepal.

After enrolling as a doctoral student in Soil Science at the Agriculture and Forestry University (AFU), Nepal, Mr. Bandhu Raj Baral, Senior Soil Scientist of Nepal Agricultural Research Council (NARC), was eager to conduct research on increasing nitrogen use efficiency (NUE) through urea deep placement (UDP). His aim was to determine the appropriate source and application method to increase NUE of rice under both irrigated and rainfed regimes and for both high yielding improved and hybrid varieties. While UDP is proven to increase nitrogen use efficiency, crop yields, and farm profits for a range of crop across different countries, it had not been tested in Nepal, as briquetted urea was not available. The project supported Baral in conducting his research by providing a sub-grant through AFU. The briquetted urea was introduced in Nepal in 2017.

Mr. Baral conducted field trials in both irrigated and rainfed rice during two cropping seasons and measured NUE, N losses, and crop yields. Trial results confirmed that UDP in rice is suitable under both rainfed and irrigated conditions and for both improved and hybrid varieties. It increased grain yields by 15-20% while using about 20% less urea than the broadcast method. UDP produced the best grain yields as compared with other real-time nitrogen management practices, including the SPAD meter, leaf color chart, and GreenSeeker. These findings have already been published.

Testing of UDP was also done through the Ftf-NSAF project for rice, maize, cauliflower, and tomato. Multilocation field trials conducted across different project districts showed that UDP reduced the amount of N required by 35% on maize, 33% on cauliflower, and 25% on tomato while maintaining or increasing yields as compared with the government-recommended practice. After getting these results, the Ministry of Agriculture and Livestock Development (MoALD) registered briquetted urea as a new fertilizer, and it is being produced within the country by the private sector. Mr. Chandra Kanta Dallakoti, a briquetting machine owner, says, “Demand for briquetted urea is ever increasing, particularly for vegetable crops, as it has considerably increased yields.” Dallakoti noted that several local entrepreneurs are now interested in installing briquetting machines, as they see the business potential.

Baral said, “UDP is a promising technique for Nepal, as it increases crop yields with less urea compared to conventional surface broadcast, and NARC will continue this study for other crops across different agroecological zones. If this technology is widely adopted, it will help the Government of Nepal cut the subsidy budget allocated to urea and help to cut nitrogen pollution in the environment.”

Table 8. Comparison of tillers, total plant biomass yield, and agronomic nitrogen use efficiency with different N rates across Rupandehi and Lamjung districts in Nepal.

Treatments	Tiller Hill^{-1}		Total Biomass (mt/ha)		NUE (kg grain/kg N)	
Paklihawa, Rupandeshi (central terai district)						
Control (N0)	14.40	a	7.88	a		
100 kg N/ha (N100)	18.00	a	11.15	b	11.84	a
120 kg N/ha (N120)	15.60	a	12.57	b	12.43	a
140 kg N/ha (N140)	15.47	a	12.48	b	11.50	a
160 kg N/ha (N160)	15.80	a	12.14	b	7.93	ab
180 kg N/ha (N180)	14.07	a	12.56	b	6.17	a
Lamjung (hill district)						
Control (N0)	7.63	a	7.13	a		
100 kg N/ha (N100)	7.83	a	11.09	b	12.47	a
120 kg N/ha (N120)	9.33	a	10.44	b	18.32	a
140 kg N/ha (N140)	8.40	a	11.01	b	12.66	a
160 kg N/ha (N160)	9.13	a	12.18	b	12.67	a
180 kg N/ha (N180)	8.53	a	14.09	b	16.14	a

Other trials on smart balanced fertilizer products using local resources, improved genotypes, and cereal-legume rotations within the context of integrated soil fertility management (ISFM) and conservation agriculture (CA) were originally planned. This activity could not be conducted in winter maize, as fertilizers could not be imported due to COVID-19 restrictions. Trials are now planned for summer maize and monsoon rice and will be reported in the next report. The "smart" fertilizers/technologies, including customized compound fertilizers, subsurface fertilization/FDP, and slow-release N fertilizers, in combination with locally available organic amendments will be evaluated for climate resilience and sustainable intensification.

1.3.1 (C) Evaluation of zinc sources for coated fertilizer blends in Rwanda (New FY21)

While coating fertilizers with Zn and/or B is increasingly employed as a way of addressing deficiencies of these nutrients, the most economical way to do this has not been investigated. Although we have made considerable progress using a mixture of zinc oxide and zinc sulfate (also known as zinc oxysulfate) at a rate of 0.5 to 1 kg Zn/ha, this mixture is not commercially available at a reasonable cost. In this activity, we will compare zinc oxide and zinc sulfate with zinc oxysulfate. We will also include zinc borate in these trials, as B deficiency often accompanies Zn deficiency in Africa.

*Activit*ies: The objective of this activity is to determine the most economical source of Zn to apply to coated blends. Field trials were conducted using a no-Zn control, zinc oxide, zinc sulfate, zinc oxysulfate, and zinc borate (two finenesses) as coatings. All crops were fertilized with 0.5 kg/ha Zn from each source, with other nutrients balanced. Sites are located on acidic sites known to be Zn-responsive from past trials. To contrast broadcast vs. point placement of fertilizer sources, we used wheat and maize as test crops, with 20 sites for each crop, replicated three times. The outcome will determine of the most effective coating product, considering both cost and yield response. This is one of our first tests of Zn borate, which has better handling characteristics compared to applying Zn and B sources separately.

Outcome: Increased use and availability of efficient multi-nutrient Zn-coated fertilizers; cost-effective way for blenders to incorporate Zn into their products.

Location/Timeline: Rwanda/October 2020-September 2021

Partnership: Rwanda Agriculture and Animal Resources Development Board (RAB)

Progress:

The trial was planted in October 2020 at 40 on-farm sites (20 in maize and 20 in wheat) in various provinces of Rwanda. Yield response to the various treatments is shown in Table 9. There were only minor statistically significant differences between zinc sources, and all Zn+B combinations outperformed the control containing no Zn and no B. The greatest yield average was achieved with Zn sulfate powder, which is coated onto granules together with Solubor®, the boron source. Of all Zn sources, Zn sulfate is the most soluble.

Results:

Zinc sulfate was the best performer for both crops, increasing yields (in combination with Solubor®) by 24% and 22% for wheat and maize, respectively. The order of response differed for the other Zn treatments, which may reflect the different nutrient placement (broadcast in wheat, point-placed in maize) and the different Zn and B demands and efficiencies of wheat and maize in absorbing these nutrients.

Zinc sulfate is the best Zn source in terms of both yield and consistency of response. However, other factors related to cost and ease of production may not make it the best choice when both Zn and B are required. When applied with boron, the two product streams complicate procurement. In addition, the most employed boron coating product, disodium octaborate tetrahydrate (used in this trial under the brand name Solubor), has a very low density and does not flow well, which can complicate its coating onto granules.


Wheat trials with the zinc + boron fertilization

This was the justification for testing Zn borate (used under the brand name Firebrake® ZB). As a single Zn-B source, only one product needs to be procured, and problems with B product caking are avoided. The two Firebrake® ZB powders performed equally, indicating that fineness was not a factor in crop response in this trial.

Yields with Firebrake® ZB were statistically equivalent to ZnO, Zn oxysulfate, and granular Zn for both crops, making it a viable Zn and B source. Both Firebrake ZB treatments were statistically similar to Zn sulfate in wheat, but underperformed Zn sulfate in maize by some 0.5 mt/ha, which is of practical consequence.

In summary, all the Zn fertilizer sources offered similar yield response, except in maize, where Zn sulfate powder coated onto fertilizer granules was superior. Firebrake® ZB shows potential as a single product to replace Zn and B sources, and this trial indicates that the finer product may not be required. Since the Zn borate in Firebrake ZB is of low solubility, this product is not likely to induce B toxicity. It would be useful to further evaluate FireBrake ZB on other crops and of soils with higher soil pH, where its solubility will be lower. The acceptance of FireBrake ZB will depend on its cost-competitiveness with other Zn and B sources.

Table 9. Wheat and maize response to various Zn and B sources.

	Wheat Yield		Maize Yield		Zn Rate	B Rate
	mt/ha		mt/ha		kg/ha	kg/ha
$ZnSO_4$ (powder) + Solubor®	4.72	a	6.08	a	0.5	0.25
Zn oxysulate + Solubor®	4.35	b	5.89	ab	0.5	0.25
Firebrake® ZB	4.55	ab	5.62	ab	0.5	0.25
Firebrake® ZB Fine	4.56	ab	5.55	b	0.5	0.25
$ZnSO_4$ (granular) + Solubor®	4.62	a	5.54	b	1	0.25
ZnO + Solubor®	4.66	a	5.53	b	0.5	0.25
No Zn or B (Control)	3.81	c	4.99	c	0	0

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

Under this activity, data from the Feed the Future Zone of Influence and IFDC programs are used to evaluate the Soil SMaRT (Soil testing, Mapping, Recommendations development, and Technology transfer) framework for delivering balanced fertilizers to smallholder farmers. This also links with the cross-cutting Geo-Spatial Decision Support System for Agrotechnology Transfer (GSSAT) activity in Section 1.5. Based on soil analyses results and maps, nutrient deficiencies and soil acidity constraints are identified. In the recommendations development step, balanced fertilizers and lime formulations that are appropriate to farmers' purchasing power are developed and evaluated on-farm and compared to current fertilizer recommendations. Once superior formulations have been validated, they become recommendations. In the technology transfer step, coordinated plans are implemented for manufacturing or blending the fertilizers and exposing farmers to them.

1.3.2 (A) Generate site- and crop-specific balanced fertilizer recommendations and nutrient omission trials in Ghana (*Trials Completed, Analysis Ongoing)*

Two years of nutrient omission trials conducted in northern Ghana showed that S, Zn, and B are often required to enhance crop productivity. For maize, grain yield increased at least 60% compared to the recommended NPK fertilization with addition of these secondary and micronutrients. By adding only S and Zn (minus-B treatment) to the blanket NPK, an average increase of ~49% in maize yields were observed. Also, by adding Zn and B to the blanket NPK (minus-S treatment), maize yields increased an average of ~23%, and addition of S and B (minus-Zn treatment) to the NPK resulted in an average yield increase of ~29% compared to the NPK-only treatment.

Activity: Established two years of trials in the savanna agroecological zones of northern Ghana to determine the economically optimal rates of secondary and micronutrients that could be added to the NPK-based recommendation to result in increased productivity and profitability for smallholder farmers.

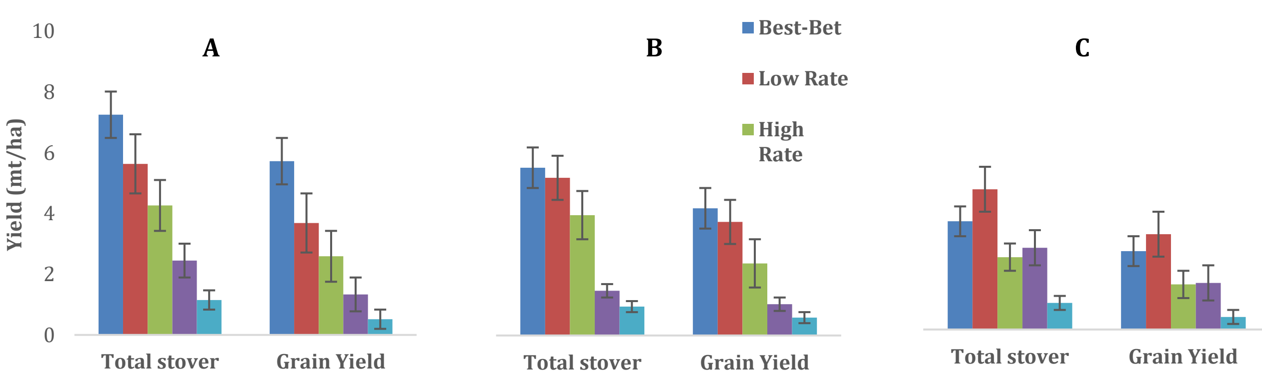
Partnership: Ministry of Food and Agriculture (MoFA); agro-input dealers, Peasant Farmers Association of Ghana (PFAG); University for Development Studies (UDS); Soil Research Institute; Savanna Agricultural Research Institute (SARI); Research Extension Linkage Committee (RELC); Plant Protection and Regulatory Services Directorate (PPRSD); African Fertilizer and Agribusiness Partnership (AFAP); Centre for Agriculture and Biosciences International (CABI)

Progress:

During FY20, we established 15 trials in the savanna zones of northern Ghana to determine the economically optimal rates of secondary and micronutrients that could be added to the NPK-based recommendation to result in increased productivity and profitability for smallholder farmers. The trials were designed to have one treatment with identical fertilizer application rates for the "balanced" treatment of the nutrient omission trials, one with lower rates, and one with higher rates of the secondary and micronutrient addition to the NPK-based fertilizer recommendation. Thus, at all locations, five treatments were compared: (i) control (no fertilizer application); (ii) locally recommended fertilizer application; (iii) best-bet fertilizer application (using the balanced application rates of the nutrient omission trials, i.e., 30 kg S, 5 kg Zn, and 1 kg B per hectare); (iv) "low" best-bet application (same NPK rates, but 50% of the Zn, S, and B rates); and (v) "high" best-bet application (same NPK rates, but 125% of Zn, S, and B rates). All basal fertilizers (initial N, P, K, and micronutrients) were applied at blanket (uniform) rates, following the local extension recommendation, and based on the results of soil analysis for all treatments.

During this period, we repeated trials to validate the results obtained from the Year 1 trials. The trials were harvested in September 2020 and the results were collated and analyzed during the first quarter of FY21. Based on Year 1 results and statistical analyses, sites were grouped as having near-neutral soils (pH 6.2-6.8), moderately acid soils (pH 5.5-6.1), and strongly acid soils (pH 5.1-5.4). In all, soils at six sites fell within the near-neutral classification, five in the moderately acid classification, and four in the strongly acid classification. The effects of the fertilization treatments on maize grain yield from the near-neutral soils are presented in Figure 21A, moderately acid sites in Figure 21B, and strongly acid soils in Figure 21C. Consistent with Year 1 results (irrespective of the experimental site), yields from the control treatment produced low yields, but fertilizer application (irrespective of the fertilizer treatment) increased yield. This confirms the "very low" native soil fertility designation of the selected sites. Consistent with the previous results and that of the nutrient omission trials, S, Zn, and B addition to the locally recommended NPK fertilizer significantly increased maize yields. However, the effects of S, Zn, and B application rates on maize yield were significantly different among sites with different soil acidity levels.

Across the sites with a near-neutral soil pH level, applying S, Zn, and B at rates of 30 kg S/ha, 5 kg Zn/ha, and 1 kg B/ ha, respectively, to the recommended rate of NPK consistently produced the greatest yield. Increasing the S, Zn, and B application rates by 50%, however, resulted in a significant decrease in grain yield. Although halving the S, Zn, and B rate of the best-bet rates resulted in yield decrease, the magnitude of the yield decrease was <50% (Figure 21A).



Each bar in (A) represents average of 24 replicates (6 sites x 4 blocks), (B) 20 replicates (5 sites x 4 blocks), and (C) 16 replicates (4 sites x 4 blocks).

Figure 21. ***Maize stover and grain yields from (A) near-neutral, (B) moderately acid, and (C) strongly acid soils.***

Across the sites with moderately acid pH level, applying S, Zn, and B rates at the estimated best-bet rates consistently resulted in maize yields that were not significantly different from yields observed with 15 kg S/ha, 2.5 kg Zn/ha, and 0.5 kg B/ha (low rate), and both treatments resulted in the greatest maize yields (Figure 21B). Like the observation from the near-neutral soil, among the treatments receiving secondary and micronutrients, the "high rate" treatment (45 kg S/ha, 7.5 kg Zn/ha, and 1.5 kg B/ha) consistently produced the least yield, with yields not significantly different from the NPK-only treatments in some locations Figure 21B).

Contrary to the observation of treatment effects on maize yield at the sites having near-neutral soil pH, across the sites with a strongly acid soil pH level, applying S, Zn, and B at low rates (15 kg S/ha, 2.5 kg Zn/ha, and 0.5 kg B/ha consistently produced the greatest yields, followed by the best-best rates. Thus, across the sites with strongly acid soil, maize yield followed the order: low rate > best-bet > NPK-only = high rate > control (Figure 21C). This suggests that, in the acid soils, micronutrients became more soluble, resulting in more availability to the plant, consequently resulting in sufficiency from the low rate and more toxicity with the high-rate treatments, with the best-bet rate in between the two extremes.

In conclusion, addition of the secondary and micronutrients to the NPK fertilizer resulted in an average increase in maize yield compared to the blanket application of NPK fertilizer only. The combined data suggest that, even though secondary and micronutrients are only needed in small quantities by plants relative to N, P, and K, they have an enormous effect on crop productivity. Therefore, to ensure increased productivity, fertilizer recommendations should not be restricted to only NPK fertilizers, but essential limiting secondary and micronutrients must also be accounted for in a holistic and balanced fertilization. This notwithstanding, application rates of secondary and particularly micronutrients should be based on the acidity level of the soil since micronutrients become more soluble in acid soils and could lead to toxicity if high rates of micronutrients are applied to such soil. Our results clearly show that, to ensure increased maize production in the savanna agroecological regions of northern Ghana and SSA, inclusion of limiting nutrients to NPK fertilizers is critical. Such recommendations, however, need to be justified by an economic analysis to determine potential losses in revenue due to the omission of limiting nutrients.

Next Steps: Three papers have been drafted and submitted for journals for review (see Appendix) Nutrient uptake data are being collated for statistical analyses and reporting.

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

These activities will utilize IFDC's global soil, plant, and fertilizer analyses data and crop responses to develop reliable spectral analytical procedures that correlate well to crop response and/or wet chemistry. It will be conducted in partnership with the private sector (labs and equipment suppliers).

1.3.3 (A) Wet chemistry-spectral analysis relationship to crop yield and nutrient response (Ongoing)

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 so that the value of ongoing soil mapping by IFDC and others is valorised to its maximum potential, and its accuracy is understood. This work forms the evidentiary basis for farm-specific data interpretation as well.

Activity: Using omission trials to determine individual nutrient response, we will directly correlate wet chemistry and spectral scans of soils from research plots. Multivariate analysis will be employed to understand which soil variables should be included in interpretations. For spectral analyses, machine learning algorithms will be employed to identify the spectral signals that lead to best correlations of response for individual nutrients. A low-cost near-infrared (NIR) instrument and X-ray fluorescence (XRF) will be used to quantify nutrients in soil, plant, and fertilizer samples. Review of statistical methodologies for obtaining the wet chemistry-spectral calibration curves will be done to ensure appropriate regression techniques are used.

Partnership: Bruker (private sector), providing instrument and support data sharing for this activity

Location/Timeline: HQ – analyzing samples from Senegal and work with the SOILS Consortium in Niger and Ethiopia/ongoing-September 2021

Progress:

The continued effort to provide different methodologies to improve fertilizer analysis and provide better tools for fertilizer recommendations has been an ongoing activity between IFDC and Bruker Instrumentation scientists. The team is developing calibration curves to be used in fertilizer analysis.

Using fertilizers to optimize plant nutrient supply can improve yield, which will lead to more efficient food production and more people being fed per acre. IFDC has partnered with Bruker to create a calibration for the handheld XRF spectrometer that will help identify the composition of fertilizers being used to treat soils. This identification can be done in or out of the laboratory with minimal sample preparation. Although the handheld XRF is not able to detect N, the other important matrix elements, such as Mg, P, K, and Ca can be measured, as well as additives such as Zn and Cu. Toxic contaminants like lead (Pb) can also be identified and quantified.

Table 10. Limit of detection (LOD) and standard deviation (Std) for analyses by XRF

Element	LOD (ppm)	High Std (wt%)
Mg	2000	11.4
P	100	20.4
S	90	32.1
Cl	80	47.6
K	30	52.5
Ca	32	71.5
Cr	12	0.07
Mn	12	7.5
Fe	35	14.9
Co	12	0.053
Ni	15	0.54
Cu	21	12.6
Zn	14	80.4
As	5	0.017
Se	10	0.025
Mo	12	0.058
Pb	20	0.05

The fertilizer calibration is a dual-phase calibration, with a 30 kV phase to measure heavy elements and chlorine (Cl) and a 15 kV phase to measure the lighter matrix elements. Both phases must be measured to get quantitative results. The samples should be prepared as powders packed into a sample cup, with the measurement surface covered with a 4-micron Prolene foil. The elements covered in the calibration are Mg, P, S, Cl, K, Ca, chromium (Cr), manganese (Mn), Fe, cobalt (Co), nickel (Ni), Cu, Zn, arsenic (As), selenium (Se), molybdenum (Mo), and Pb. Mercury (Hg) can also be added if customized samples are provided. The ranges and limits of detection (LOD) for each element are shown in Table 10. Because the calibration is empirical, elements outside the calibrated range will have more errors. It is important that the analyzed samples be homogeneous and representative of the material from which they are taken.

Performance was checked by recalculating the calibration samples. Two of the samples are certified reference materials, and the agreement of the calibration with these was noted. Figure 22 represents the recalculated calibration samples. There are a few outliers in which the expected values are known to be suspect. The calculated values were compared with the spectral intensity and found to agree with the spectra. The error in the calculated concentrations is believed to be due to sample inhomogeneity or other sample preparation problem.

Further improvements need to be done related to different sources of different materials. More testing with commercial samples with varied matrices, especially for important and matrix-sensitive elements, such as P, K, and Ca, would be valuable. IFDC and Bruker will continue their cooperation in optimizing this calibration as more data becomes available.

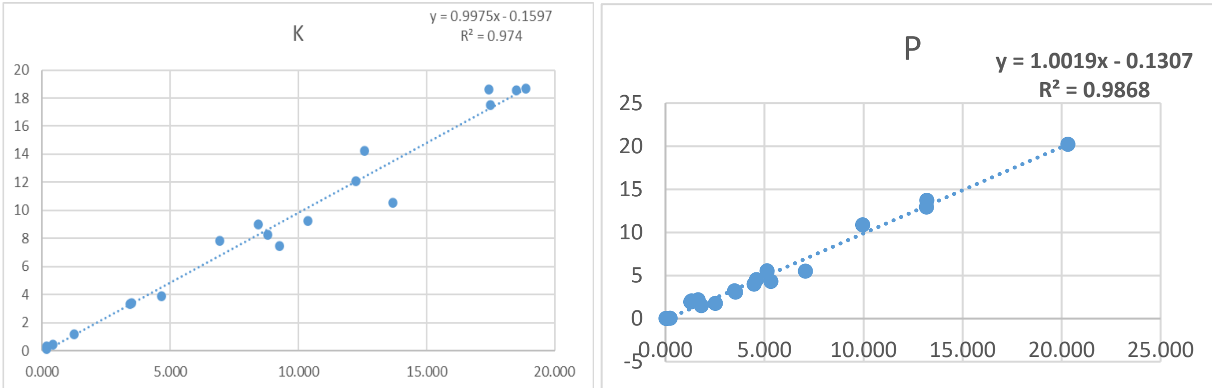


Figure 22. Updated response curve comparing wet chemistry analysis (Y axis) with XRF (X axis) for P and K.

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

While spectral analysis of soils is gaining widespread use, it does not accurately determine the availability of some soil nutrients – for example, N and P. Further, spectral methods rely on algorithms that take several related soil properties and estimate nutrient availability. With fertilizer application, those related variables might not change when a nutrient is added. A fundamental demand of a soil test is that it can recognize when a nutrient is applied. If spectral methods cannot recognize an increase in nutrient availability due to nutrient application, then the test is not useful to a farmer, who risks applying nutrients that are not necessary.

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

Progress:

As an initial step, we supplemented a soil with known quantities of P (15 ppm), K (20 ppm), S (10 ppm), Zn (2 ppm), B (1 ppm), and Cu (1 ppm) and measured nutrient concentration before and after addition, using wet chemistry methods only, to establish that changes due to nutrient addition would be detectable with wet chemistry methods before assessing the changes using spectral methods.

Our initial results were unexpected, as we had poor recovery of applied P and B and excessive recovery of applied K and Cu (i.e., recovered several times more than applied). We will repeat the experiment, taking extra care to eliminate sources of contamination (Cu) and also applying an additional higher nutrient rate, as we may expect some irreversible absorption of elements, especially P. Once we are confident that results from the wet chemistry samples are consistent, we will forward the samples to a spectral laboratory. Currently, there is only one reliable spectral laboratory in the region (AgroCares) willing to accept the samples. The World Agroforestry (ICRAF) laboratory will not run spectral analyses without first developing an independent calibration model.

1.3.3 (C) Laboratory standards and standardized methodologies for fertilizers and amendments (Ongoing)

Critical for fertilizer recommendation are reliable soil and plant analyses. Laboratories in many developing countries do not have reliable access to parts, services, and maintenance. Also, standard protocols, and quality assurance/quality control (QA/QC) is seldom followed or implemented by many laboratories. In addition, new fertilizer materials (polymer-coated, slow-release, biofertilizers) and amendments are becoming available to farmers with unverified claims of high productivity gains.

Objective: Address the above issues (except parts, services, and maintenance) by focusing on capacity building, developing training materials, and providing standardized soil and plant samples for QA/QC. Develop standardized procedures for the evaluation of "new" fertilizers, biofertilizers, and biostimulants.

Activity: Currently, the laboratory assessment is being conducted under the Feed the Future Enhancing Growth through Regional Agricultural Input Systems Project (EnGRAIS) for West Africa; strengthening of the regional capabilities will be conducted under the Dundël Suuf project in Senegal.

Partnership: International Organization for Standardization (ISO), International Fertilizer Association (IFA), Association of American Plant Food Control Officials (AAPFCO), EnGRAIS (cost-share), Dundël Suuf project (cost-share)

Progress:

IFDC, in partnership with IFA, ISO, and AAPFCO, is working toward improving analytical methodologies for the quantification of fertilizer materials. Several virtual meetings took place during this period, and a few meetings were canceled due to the COVID-19 pandemic. IFDC is now actively involved in a "International Network on Fertilizer Analysis (INFA)" project developed by Food and Agriculture Organization of the United Nations (FAO). The main mission of INFA will be to improve the quality of fertilizer laboratory data to support decision making at field and policy levels, in support of the overarching goals of eradicating hunger by achieving food security, improving nutrition, and ensuring environmental quality.

The main objectives of INFA are to:

1. Standardize methods and protocols for the analysis of fertilizers. This links to the harmonization of fertilizer quality data.
2. Strengthen the performance of fertilizer laboratories using standardized methods and protocols.
3. Harmonize fertilizer quality standards (classification and definitions) so that fertilizer information would be comparable and interpretable across laboratories, countries, and regions.

The work on improving local capacity building and the laboratory assessment under EnGRAIS was, unfortunately, put in hold at the start of the COVID-19 pandemic. Nigeria and Ghana are the last two countries to complete this work and will start implementing the action plan in the regions. Opportunities for soil laboratory assessment in Niger and Ethiopia will be followed under the SOILS Consortium.

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

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

1.4.1 Evaluation of the Synergistic Effect of CA Practices in Combination with ISFM and Activated PR Amendment in Ghana (Completed)

The synergistic effects of CA practices and ISFM along with activated PR as a P fertilizer source is being evaluated for maize in northern Ghana were evaluated and results are presented below.

Locations/Timeline: *Ghana (Completed)*

Partnership: Africa Research in Sustainable Intensification for Next Generation (Africa RISING) project (Ghana)

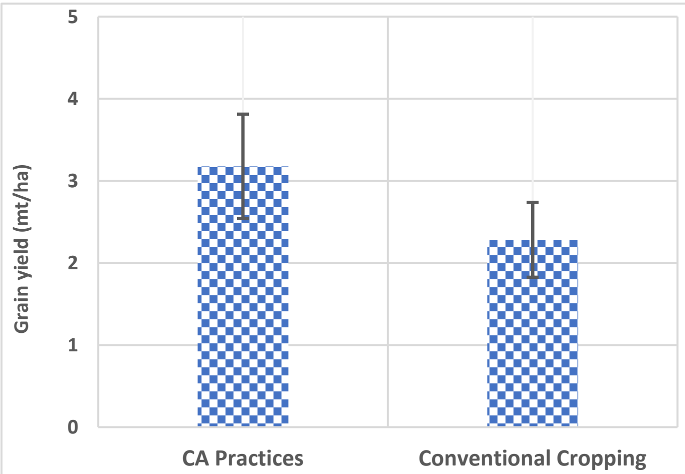
Progress:

Maize seedlings in a CA plot with soil surface cover of crop residue from previous cropping.

During FY20, in partnership with the Africa RISING Project, we established eight trials in northern Ghana to evaluate the synergistic effects of CA practices and ISFM along with activated PR as a P nutrient source. The trials were laid out in a split-plot design with CA practices (CA vs. non-CA farming systems) randomized on the main plots and the rates of P fertilizer sources randomized on the subplots. The P source by rate treatments were (i) activated PR applied at the locally recommended P rate (100% APR); (ii) activated PR applied at 75% of the locally recommended P rate (75% APR); (iii) DAP applied at the locally recommended P rate (100% DAP); (iv) DAP applied at 75% of the locally recommended P rate (75% DAP); (v) Togo PR applied at the locally recommended P rate (100% TPR); and (vi) control (0 P). For all treatments, macronutrients N and K were applied at enough such that P and micronutrients were the only limiting nutrients. P was supplied at predetermined levels based on the application rates specified for each treatment. To evaluate the efficacy of the CA practices, secondary and micronutrients were intentionally omitted with the assumption that decomposition of the organic materials in the CA treatment would release enough micronutrients for the crops. At each location, a climate-resilient, drought-tolerant maize hybrid was used as the test crop. Year 1 results showed synergistic benefits of CA and ISFM practices on maize grain yield. Grain yields from the treatments with CA practices were 30-45% greater than grain yields from the treatments without CA practices. Superimposing various ISFM practices on the treatments with and without CA practices further widened the yield gap between the CA and non-CA treatments for the respective treatments.

During the second quarter of FY20, we repeated trials to validate the results obtained from the Year 1 trials. The trials were harvested in September 2020 and the results were collated and analyzed during the first quarter of FY21.

Results:



Each bar represents average of 192 replicates (8 sites x 6 treatments x 4 reps) and error bars represent standard error of the mean.

Figure 23. Effects of conservation agriculture on maize grain yield.

CA practices had a significant effect on maize yield. Yields using conventional farming practices were significantly lower than the CA treatments. Averaged across the eight sites, the CA treatment produced an average 39.2% yield increase relative to the local farmer practice of conventional farming (Figure 23).

One of the key drivers of the improvements observed under CA and ISFM is the greater soil organic matter content, particularly at the surface of the profile, and the associated improvements in soil structural stability, fertility, and biological diversity relative to conventional agricultural systems. These benefits have led to the identification of CA as an important tool to help ensure future food production and help buffer agricultural productivity against extreme climate events (drought and heat waves), which are likely to increase in frequency under climate change.

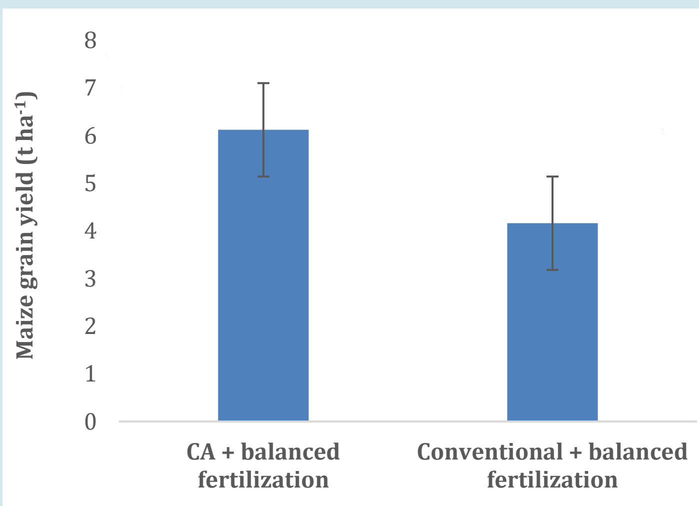
Effects of P Sources and Application Rates on Maize Yield: There were highly significant P source and application rate effects. Across the CA and the conventional farming practices and at all the study sites, based on an equal amount of P applied, DAP produced the greatest yield, followed by activated PR (APR), with the least effective P source being the Togo PR (TPR). Within the CA practices, yield averaged across the eight sites increased by 4 times with APR application compared to TPR application at the same P rate. At equal P rate, yields from DAP, relative to APR, were 30% and 45% higher for 100% and 75%, respectively, of the recommended P application rate. However, for the conventional practices, yields with the APR treatments were 40% and 35% lower than those with DAP for the 100% and 75% P application rates, respectively.

Balanced Fertilization in the Context of Conservation Agriculture for Resilient and Sustainable Intensification of Maize Production in Northern Ghana

Mohammed Muntala Abdulai, a farmer in Savelugu in the Northern Region of Ghana, said about the practice: *"Bushfires have completely destroyed our soil, so even if I apply fertilizers, I don't get the desired yield. With this approach, at least I can ensure a good harvest and still preserve my soil."*

A proud farmer admiring maize development in CA+ISFM field (right) and comparing it with conventional farming plus balanced fertilization (left).

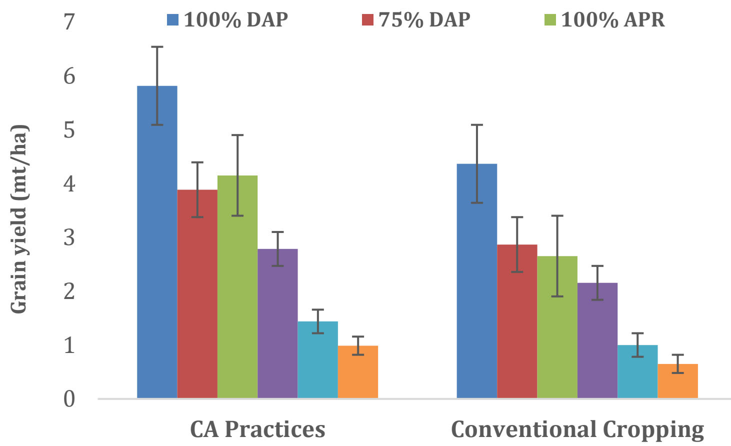
The savanna agroecological zones of northern Ghana experience annual bushfires in the dry season, which have contributed to land degradation in this area of grass-dominated vegetation. Conservation agriculture (CA), commonly defined around the principles of minimum tillage, soil surface cover, and diversified crop rotations, could be implemented to address the menace of land degradation, but it must include the use of balanced fertilization to achieve optimal benefits of improving the organic matter and microbial biomass and the health of soil, thereby making cropping more resilient to ensure food security. Thus, CA will be more effective when practices are carried out in the context of integrated soil fertility management (ISFM), which aims to assimilate best practices to maximize the use efficiency of fertilizers.



Effects of conservation agriculture on maize grain yield. Each bar represents average of 64 replicates (8 sites x 2 treatments x 4 reps) and error bars represent standard error of the mean.

Our field trial results (see Section 1.4.1 [B]) clearly show that CA and ISFM practices that are well-designed and adapted to local conditions can improve crop yield compared to conventional agricultural systems. There are also potential added benefits of improving the soil organic matter content, which can lead to significant improvements in soil physical, chemical, and biological properties and productive capacity. Given the need to reverse the trend of agriculturally induced soil degradation to ensure the long-term sustainability of agroecosystems, farmers in northern Ghana and in SSA, must be encouraged to adopt the CA+ISFM practices for the long-term benefit of both individual farmers and society at large.

Synergistic Effects of CA and ISFM: Application of fertilizers with the CA treatment increased maize yields significantly. Averaged across the eight sites, application of fertilizers within the CA treatment resulted in yield increases ranging between 0.3 and 6 times over the control (depending on the fertilizer treatment). Whereas for the conventional farming practices, yield increase over the control due to fertilizer application ranged between 0.25 and 4.6 times. Without applying any fertilizers (control), CA practices alone resulted in an average 30% increase in yield. The TPR treatments became more effective within the CA practice than in the conventional practice, with an average yield difference of >40%. Similarly, APR and DAP became more effective in increasing maize yields in the CA production system than the conventional farming practice, irrespective of P application rate (Figure 24).



Each bar represents average of 32 replicates (8 sites x 4 reps).

Figure 24. Effects of conservation agriculture and ISFM on maize grain yield.

In summary, the combined results clearly show that CA and ISFM practices that are well-designed and adapted to local conditions can improve crop yield compared to conventional agricultural systems. There are also the added benefits of improving the soil organic matter content, which can lead to significant improvements in soil physical, chemical, and biological properties and productive capacity. However, to increase the adoption of CA and ISFM in SSA, it is critical that the system be adapted to specific climates, soil types, and communities, particularly considering the farmers' investment capacity and the availability of resources. This may require some flexibility in approach to adapt agronomic management practices to local circumstances. The most effective systems are likely to be those that consider the production objectives and constraints of farmers in each region. Not only should the technical aspects of CA+ISFM be considered, but also the socioeconomic factors that make CA+ISFM cost-effective and attractive for farmers. However, given the need to reverse the trend of agriculturally induced soil degradation to ensure the long-term sustainability of agroecosystems, it is imperative to encourage farmers in northern Ghana and in SSA to adopt the CA+ISFM practices for long-term benefits for both individual farmers and the society at large.

Next Steps: Nutrient uptake data are being collated for statistical analyses and reporting.

1.4.2. Increasing System Productivity through Agronomic Biofortification with Crop Diversification and Intensification (Completed)

Crop diversification with balanced fertilization restores soil fertility and increases system productivity. The latter leads to (a) more profitable, sustainable, and environmentally friendly agriculture, (b) reduced yield risk due to climatic variability, (c) reduced price volatility of agricultural produce, and (d) food and nutrition security assurance. Diversified cropping can utilize short duration crops as a catch crop for better utilization of residual nutrients. Improved nutrient use efficiency is achieved through balanced crop nutrition with incorporation of secondary and micronutrients (including nanofertilizer) and sustainable soil intensification cropping patterns (T. Aman-mustard-maize [red amaranth or pulses as intercrop]).

Activity: Two field experiments with first crop of the pattern (T. Aman rice) were established in acid-prone, S-deficient, and monocropping areas of northern Bangladesh. The four crops in the pattern are T. Aman-mustard-maize with an intercrop (mung bean or red amaranth).

Partnership: Bangladesh Institute of Nuclear Agriculture (BINA)

Location/Timeline: Bangladesh, July 2020-September 2021

Progress:

The field experiment were conducted at Saidpur, Nilphamari and Sadar, Dinajpur from T. Aman 2020 to fit third crops in the fallow period and to introduce fourth crops in the pattern as intercrops and study the comparative performance of enhanced efficiency fertilizers, improving nitrogen use efficiency, and balanced crop nutrition through biofortification secondary and micronutrients of crop sequences (T. Aman-mustard-maize) for increasing cropping intensity, productivity, and land use efficiency (Figure 25).

The experiment was laid out in randomized complete block design with three replications. There were 12 treatments consisting of four sulfur sources (Thiogro ES 13%, Thiogro ESS 13%, Thiogro ES 75%, and locally available sulfur sources), three nitrogen fertilizer sources (prilled urea, urea briquette, and compound fertilizer), and five nutrient omission plots (-N, -S, -Zn, -B, and -ZnB) and farmers fertilizer practices. N, P, K, and S (plus B for mustard and maize) were used at a recommended rate on all plots (FRG, 2018). Binadhan-17 for T. Aman, Binasarisha-9 for Rabi, and hybrid maize (Pioneer) were tested in a T. Aman-mustard-maize pattern, respectively. Binamug-8 were sown as an intercrop with maize. Fertilizers were applied to each plot as per treatment and design.

In all three crops, the full dose of all fertilizers except nitrogen was applied as basal to the individual plots of the layout. On T. Aman rice, three equal doses of nitrogen were given, whereas in mustard, nitrogen fertilizer was applied in two equal splits. Intercultural operations, including weeding and pesticide spraying (insecticide and fungicide), were done as required. Crops (rice and mustard) were harvested when they attained maturity. Data were recorded on yield and yield-contributing characteristics. The grain yield was recorded on a 14% moisture basis. In this report, only the grain yield of T. Aman and mustard is reported. In both locations, maize crops currently are in the field at V-6 to V-7 leaf stage. Harvest and analysis data will be given in the next report (by September 2021).

Figure 25 ***Mustard field (left) and sowing of maize with mungbean (right) in crop diversification and intensification trials across two locations in Northern Bangladesh.***

Rice grain yields reflected the treatments applied, where N, S and to a minimal extent Zn were limiting rice production in the two locations. N, S, and Zn fertilization had a positive effect on grain yield (mt/ha) of rice, although the magnitude varied by source and location. The plots in which urea briquettes were applied gave the highest yield over the other N sources (prilled urea and compound fertilizer [NPSZn]), which was statistically significant (Figure 26A). The control treatment gave the lowest yield (3.81 mt/ha). Among the different sulfur sources, ESS 13% produced the highest yields compared to other sources, i.e., gypsum, ES 13%, ES 75%, and compound fertilizer, however, results varied between locations (Figure 26B). Results shows that Zn fertilizers had an additive effect on the grain yield, showing an increase of up to 7.3% over the zinc control plots (Figure 26C). Grain yield of Binadhan-17 was significantly influenced by balanced fertilization and different fertilizer sources (Figure 26D), and the grain yield with farmer practice was also found to be significantly different than the balanced fertilizer treatments.

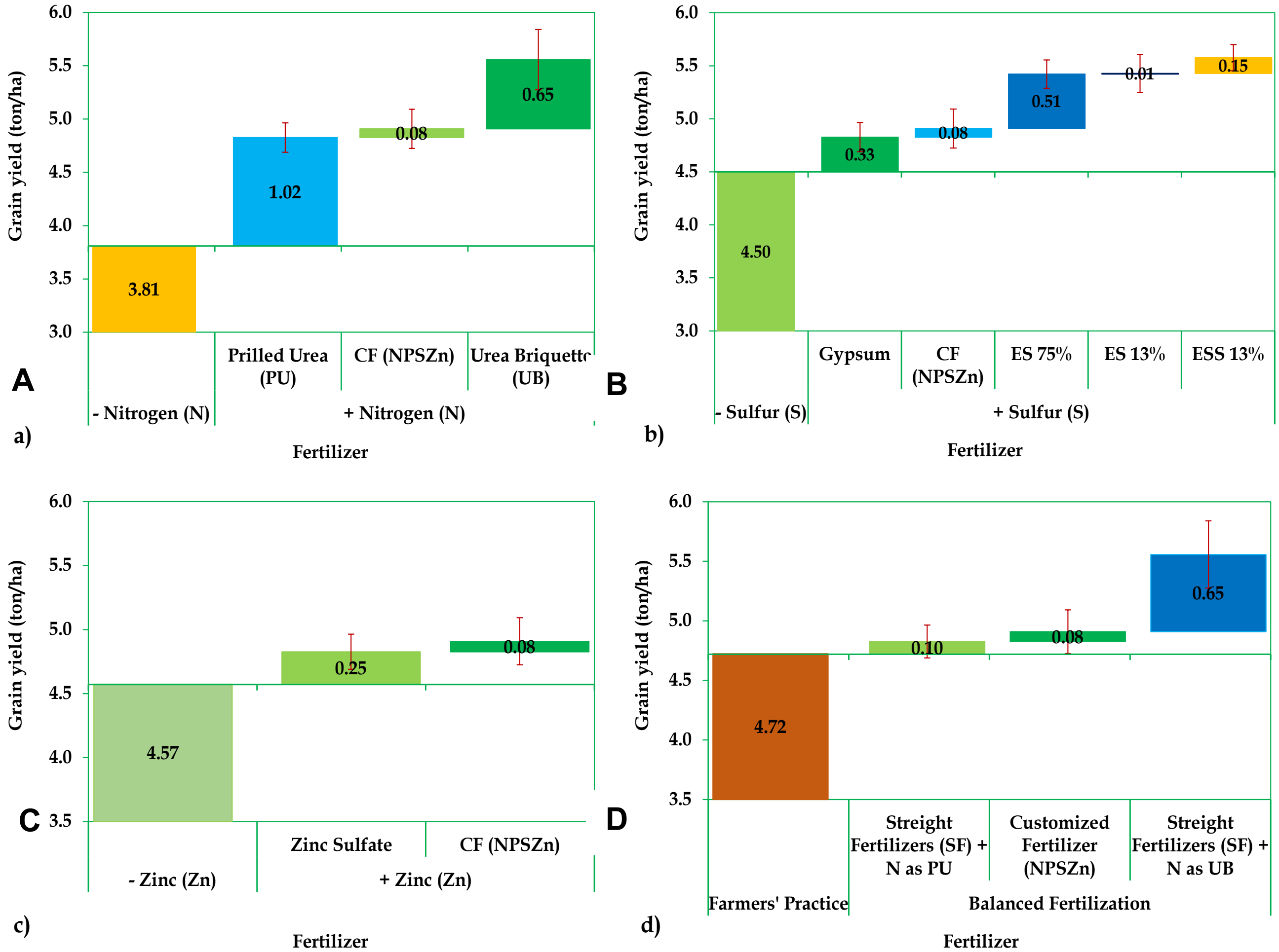


Figure 26. ***Effects of nitrogen, sulfur-enriched urea fertilizers, micronutrient (zinc) fertilizer, and balanced fertilizer practices on T. Aman rice grain yields in northern Bangladesh.***

The Way to Financial Independence – Farm Labor to Farm Owner

Surendra Nath Ray, a small farmer, lives in Sundarban village, Dinajpur division, in northern Bangladesh, which is characterized by poor soil fertility conditions. Ray worked as a farm laborer for more than 30 years before he engaged in crop cultivation in 2018 by leasing a small plot of land in his village. He usually grows rice or wheat and jute in his leased in plots. Yet, he realized that his plots remained fallow for two months or more. Ray decided to put the knowledge gained through his association as a farm laborer to work on the RFS-SFT project's trial research plots on maize in 2018.

Seeing the benefits of using GAPs, especially from maize that was introduced as a part of sustainable intensification farming practices, during the fallow period, he became motivated to include maize in his cropping systems also. In 2020, Ray increased his leased farming area to 4 bighas, and with advice and informal training from the RFS-SFT project, he introduced short-duration crops with ISFM practices incorporated as a part of GAPs. He began to follow a diversified cropping pattern (T. Aman-mustard-Boro/jute/maize), which allowed him to include an additional crop. Diversified cropping systems further allowed him to earn Tk 12,600.00 in additional income. Ray said, "My income has increased, and I'm able to save money by following GAPs."

Ray sowing maize; sharing knowledge with his neighbors; harvesting rice from his plot

Ray further diversified his cropping choices and introduced short-duration mustard along with rice and was able to share mustard seeds with his neighbors. He explains, "Now that I have experience with crop diversification practices, I have my own financial resources, allowing me to save Tk 50,000 by year-end; I am independent now and rely on my own resources to take care of my family and needs."

As with T. Aman rice, the highest mustard grain yield was obtained from fully fertilized plots (2.03 mt/ha) and the lowest grain yield was produced by plots without nitrogen fertilization (0.83 mt/ha). The lowest yield in 0 N plots indicates there is no substitution for N application, which has highest contribution to seed yield (Figure 27A). The seed yield of mustard was significantly affected by the application of S from both sources. The application of S in different doses increased the seed yield of the crop over the control plot. Seed yield increased by 18.3%, 19.3%, 22.1%, 25.1%, and 25.9% with the application of gypsum, compound fertilizer (NPKSB), ES 75%, ESS 13%, ES 13%, respectively (Figure 27B). Results suggest that the interaction effect between Zn and B significantly and synergistically influenced seed yields of mustard, which were observed to be highest (2.01 mt/ha) with ZnB fertilized plots. The percentage increase in seed yield of mustard in plots that had zinc and boron application were 1.8% and 10.9%, respectively (Figure 27C).

Results also indicate that the response to B supply increased with Zn supply and vice versa. The yield increased progressively and significantly with each successive balanced fertilizer management. The balanced fertilization practices had an additive effect on grain yields, showing an increase of up to 9.3% yields over farmer practice (Figure 27D).

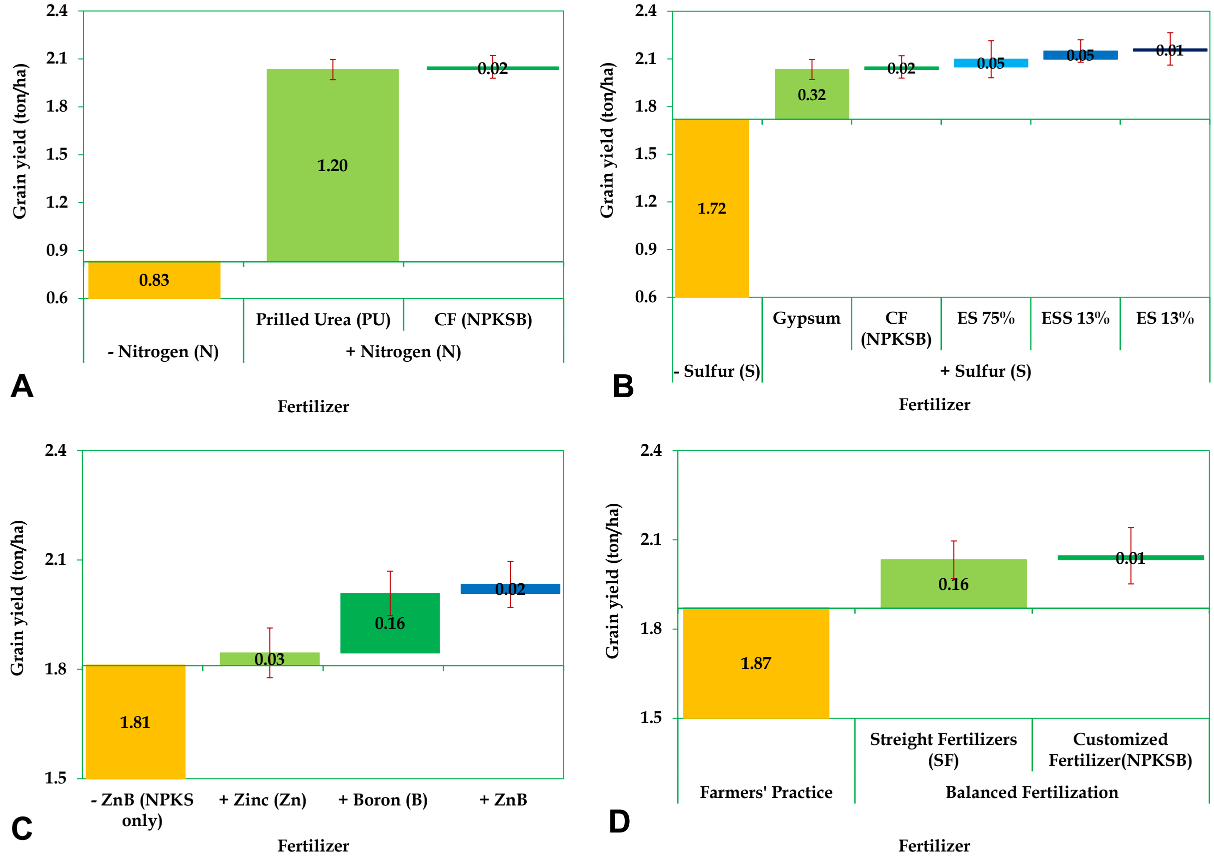


Figure 27. ***Effects of nitrogen, sulfur-enriched urea fertilizers, micronutrient (zinc) fertilizer, and balanced fertilizer practices on mustard seed yields in northern Bangladesh.***

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

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

Partnership(s): Feed the Future Innovation Lab for Collaborative Research on Sustainable Innovation (SIIL), Kansas State University, USA; Royal University of Agriculture (RUA): Center of Excellence on Sustainable Agricultural Intensification and Nutrition (CE SAIN), Faculty of Agronomy, Faculty of Agricultural Engineering and Faculty of Land Management and Land Administration, Cambodia; Conservation Agriculture Service Center (CASC), General Directorate of Agriculture (GDA), Department of Agricultural Land Resources Management (DALRM), Cambodia; Partnerships for Enhanced Engagement in Research (PEER), funded by the United States Agency for International Development (USAID) and implemented by the National Academy of Sciences (NAS); Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD), France; United States Department of Agriculture (USDA), Agricultural Research Service (ARS), National Soil Dynamics Research Laboratory, Auburn, Alabama

Location/Timeline: Cambodia, Ongoing-September 2021 (no-cost extension)

Progress:

The objectives of the ongoing study are to: (i) quantify soil organic C and N storage using a diachronic approach based on a paired-plot comparison of paddy fields under conventional tillage (CT) and conservation agriculture (CA) for different years (2014 and 2018); (ii) assess the changes of three main soil functions (Biofunctool® approach: C transformation, soil structure, and nutrient cycling) between CT and CA; and (iii) simulate soil organic C and N storage under CT and CA production systems. The experimental design discussing cropping patterns, treatments, and soil and plant sampling were reported previously.

Rice Production and Soil Health

Rice Yield – Cropping Season 2019 and 2020: The study was continued for the 2020 growing season, and rice was harvested in November. Rice yields are still being processed and analyzed and will be integrated with the previous results and reported in the final report of this project.

Soil Organic Carbon Buildup and Available Nitrogen: The results were reported in the previous annual report. Some new samples were received in this reporting period. The samples are currently being analyzed and results will be processed by the team and integrated with the results from the other parts of this experiment. This will be fully reported in the annual report.

Trend of C-Stabilization and C-Mineralization: The results were reported in last year's annual report. The data from the KSU samples currently being analyzed will be processed, interpreted by the team, and integrated with the results from the other parts of this experiment.

Crop Simulation Modeling

Summarizing Data for Long-Term Predictions of Soil Health: The team has been continuing to parameterize the cropping systems, soils, topography, and weather data and collecting the corresponding yield and soil health data from the plots for long-term modeling using the Soil and Water Assessment Tool (SWAT), Agricultural Policy/Environmental eXtender (APEX), and Decision Support System for Agrotechnology Transfer (DSSAT) models.

Two papers were presented virtually at the 2020 Annual International Meeting of the American Society of Agricultural and Biological Engineers (ASABE). The papers were on "Modelling Soil Carbon Sequestration under Conservation Agriculture and Conventional Farming Practices in Stung Chinit Catchment, Cambodia, using the APEX Model" and "Assessment of Impacts of Land Use and Climate Change on Streamflow and Soil Erosion in the Stung Chinit Catchment, Cambodia, using the APEX Model."

Link with Cambodia RHEAS: Recurring droughts in the Lower Mekong have inflicted enormous pressure on the natural resources, agricultural productivity, and water resources, resulting in the need for an advanced integrated modeling system to assess the subtle, intrinsic nature of drought and its impact on rice yield. A group from Michigan State University has carried out a regional-scale assessment of Cambodia to examine the linkages between rice productivity and meteorological/hydrologic drought variability from 2000 to 2016. A comprehensive drought and crop yield information system (Regional Hydrologic Extremes Assessment System [RHEAS] framework) was implemented; it couples a hydrologic model with a crop growth model to capture the subtle, intrinsic nature of drought and assess the impact on interseasonal and intra-annual rice yields. This work has been conducted for the entire Lower Mekong Basin, and provincial-level studies for Cambodia are ongoing. We are currently working with the team to evaluate the intra-annual rice yield comparison of different rice cultivars. We will also evaluate different management practices at provincial scale to assess cultivar response to dry periods and develop strategic planning accordingly.

Figure 28. **USDA-ARS engineer, Dr. Kornecki, with conservation agriculture field technician, Vuthy Suos, in Stung Chinit field plots, Cambodia.**

Capacity Building on Watershed and Field-Scale Modeling Tools: Nut Nareth is continuing with his Ph.D. degree, with Dr. Jaehak Jeong, faculty with expertise in the SWAT, Department of Biological and Agricultural Engineering, Texas A&M University, as part of his committee. The training of a team of graduate students and undergraduates has been continuing, with modeling conducted in synergy with other projects. A master's-level student at the Institute of Technology Cambodia is modeling the Tonle Sap Basin in the SWAT and will complete his degree in August 2021. A Royal University of Agriculture agricultural engineering bachelor's-level student is modeling the CA and CT in Santuk District, Kampong Thom, using APEX. Due to limited data, she can only evaluate the yield of rice between different management practices. If she continues with her master's degree, she can use APEX to model the multiple projects (including those of IFDC) on experimental plots in Santuk.

Agricultural Machinery and Tools in Conservation Agriculture for Sustainable Intensification

Conservation Agriculture for Commercial Vegetable Home Garden Tools and No-Till Vegetable Transplanter: Two extension handbooks, one on CA for commercial vegetable home gardens and the other on CA for commercial vegetable home garden hand tools, were completed. This was reported in the previous annual report; however, they were revised. The first described steps for households to establish CA home gardens, and the second described and recommended hand tools on CA for commercial vegetable home garden production systems, such as digging tools for no-till transplanting (hoes, rakes and cultivators, forks, sickles and weeding knives, shears, and scissors). The links to download are available in the list of presentations and publications of this report.

Methods of Cover Crop Crimping, Rice Seed Drilling, and Rice Harvesting: Performance testing of the Kornecki no-till vegetable transplanter, donated by the National Soil Dynamics Lab (NSDL), USDA-ARS, together with the no-till Morrison seed drill, was the dissertation research of Lyhour Hin. He will defend his dissertation on April 28, 2021. A manuscript related to his dissertation, has been published (see Hin et al. [2020] at https://www.doi.org/10.17265/2162-5263/2020.06.002).

1.4.4 Agronomic Biofortification of Cereal Grains and Biomass with Zinc in a Dual-Purpose Cereal-Legume-Livestock Production System *(New FY21)*

New fertilizer products that utilize the seed core technology and controlled-release coatings for fertilizers that contain macronutrients and a micronutrient (i.e., Zn) for crop production is perceived to be a breakthrough for micronutrient biofortification. The Zn-enriched fertilizer product provides a cost-effective means to overcome deficiencies for Zn and is also expected to fortify the Zn content of staple food crops (particularly in cereal grains, which are inherently very low in Zn) to address Zn deficiency in humans, a priority nutritional issue in most parts of the developing world.

Activity: Conduct two trials per season in each of the six locations.

Partnership : Private sector, Harvest Plus, SIIL (KSU), Tennessee State University, Institut Senegalais de Recherches Agricoles (ISRA) – Centre National de Recherches Agronomiques de Bambey (CNRA/Bambey), University of Thies, Institut de Technologie Alimentaire (ITA), Agence Nationale de Conseil Agricole et Rural (ANCAR), Réseau des Organisations Paysannes et Pastorales du Sénégal (RESOPP)

Location/Timeline: Senegal (Louga, Diourbel, Kaffrine, Kedougou, Kolda and Sedhiou regions)

Progress: *The activity has yet to begin; this will be reported in September 2021.*

1.4.5 Impact of Nutrient Recycling, Biofertilizers, and Biostimulants on Yield and Soil Health *(New FY21)*

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

1.4.5 (A) Exploration of simple soil test system as soil fertility/soil health indicator (Ongoing)

Objective: Compare N mineralization using conventional soil incubation studies with a simple 24-hour field CO_2 test.

Activity: While the multiweek soil incubation technique quantifies potentially available soil N, a quicker test is needed for routine analysis. The Solvita Field CO_2 Test provides an alternative that only requires a 24-hour incubation period, with evolved CO_2 directly correlated to the quantity of N mineralized.

Location/Timeline: HQ, with global focus/October 2020-September 2021

Partnership: Auburn University, private sector, and farmers

Progress:

Long-Term Incubation vs. Solvita

Two long-term incubations were set up for comparison with Solvita probe data. The first experiment began on May 14, 2020 and involved soils from four different plots in the Cullars Rotation at Auburn University. The plots varied in crop rotation, cover crop, and fertilizer regimen. To accommodate for the long incubation period, 250 grams of each soil was measured into a quart-sized plastic container. This was done four times for each soil, for a total of 16 containers of soil. Each soil was wet to 80% of field capacity, according to measurements taken in the lab. Each soil was extracted with 1 M KCl and 0.1 M $CaCl_2$ to provide a baseline measurement for inorganic nitrogen in the soil. Each week for 20 weeks, the soils were extracted with both solutions and water content was evaluated. The second experiment began on July 21, 2020 and involved soils from all over the state of Alabama. Soils were cultivated under a variety of crops, cover crops, animal rotations, tillage programs, pest management programs, and fertilizer regimens. Soils also had a variety of soil organic matter contents and textures. A total of 13 soils were included in the experiment using an identical protocol. When the data between the two methods were compared, the greatest issue was the lack of a basis for comparison between the mineralization data and the CO_2 production data. In experiments in literature, mineralization data, Solvita data, and another method for directly measuring CO_2 were employed. Since there was a lack of foundation for the comparison between only nitrogen mineralization data and CO_2 production, this method was discontinued, and we moved to comparisons of CO_2 evolution by titration and the Solvita probe (described next).

Back-Titration vs. Solvita

To test the efficacy of the method, experiments were set up on December 20, 2020. The soils from the Cullars rotation were used in this trial. In this method, incubations of 40 grams of soil were measured into a beaker and rewetted to 80% of field capacity. The beakers were sealed inside airtight jars with base traps. The base traps were composed of 10 mL of 0.1 M KOH. These traps capture CO_2 produced by the soil. This was done four times for each of the four soils from the Cullars rotation. Four blanks were also set up. On day 7 after the start of the incubation, the base traps were backtitrated with 0.1 M HCl. The traps were replaced after titration. Incubations identical to the ones from the long-term incubation experiment were set up as well. On titration days, these incubations were extracted with 0.1 M KCl to determine inorganic nitrogen content. Solvita data from the original experiment were used for comparison. Carbon dioxide data are now well correlated with extraction and Solvita data.

IRGA Analysis vs. Solvita

Even though the issues with the titration method were fixed, infrared gas analysis was explored as a way of checking and reinforcing the accuracy of the method. The experiment was set up on April 5, 2021 and is ongoing. Four soils from the Alabama-wide samples were chosen for a trial. Beakers of soil were set up identically to those in the titration protocol. They were sealed in airtight jars with septa in the lid. After hours 1, 3, and 24 and days 7 and 28 from the start of the experiment, air samples were taken by injecting a needle into the septum of the jar, mixing the air, and pulling out a 10 mL sample. The samples were inserted into vacuumed 5 mL vials. We are in the process of analyzing these samples for comparison with the other methods. To date, this method is working very well. We will continue this process and will expand it to include all of our sampled soils (using this method). Full results will be presented in our next SAR.

With an additional $10,000 grant from the Water Resources Research Institute, the anticipated completion date for this project is January 2022.

1.4.5 (B) Effective recycling of nutrients, use of biofertilizers and biostimulants for improving soil fertility, soil health, and crop yield and improving nutrient use efficiency (Ongoing)

Objectives: Improve recycling, enhance shelf life, and increase use efficiency of nutrients from organic fertilizers and amendments using biological processes, such as fly larvae, and chemical or physical processes, such as vacuum pyrolysis, with private sector and university partners.

Quantify effect of biofertilizers and biostimulants on crop yield and soil health/microbial changes

Activity: Laboratory and greenhouse research will quantify characteristics of recycled organic wastes, biofertilizers, biostimulants, nutrient release, and synergistic relationships with mineral fertilizers (N, P, K, Zn, etc.) and the effect on crop performance and nutrient use efficiency. Target crops will be soybean, sorghum, and vegetables. In the following years, if successful, this activity will be carried out under field conditions in SSA and South Asia.

Location/Timeline: HQ, with global focus/October 2020-September 2021

Partnership: Private sector and farmers

Progress:

The objective of this activity is to compare the performance of organic amendments and biostimulants recycled from wastes, such as pine sawdust, corn distillers dried grains with solubles (DDGS), and poultry manure. The vacuum pyrolysis process is used to convert sawdust into two products – biochar and fulvic and humic acid. DDGS biochar is also produced using the same process. Poultry manure is biologically processed using black soldier fly (*Hermetia illucens*) larvae to produce recycled fly larvae manure. The performance of these organic products was compared with conventional NPK fertilizers on soybean and sorghum grown in the greenhouse. The treatments comprised:

1. 100 mg P/kg soil and 150 mg K/kg soil plus micronutrients (minus N).
2. NPK at 200 mg N, P at 100 mg, and K at 150 mg per kilogram of soil plus micronutrients.
3. Humic-fulvic acid as recommended by the supplier at 1.8 mL diluted to 24 mL/pot.
4. Humic-fulvic acid as above + 3 grams of biochar as recommended by the supplier.
5. DDGS biochar at 30 g/pot, equivalent to 200 mg N/kg.
6. Humic-fulvic acid as Treatment 3 plus 50% NPK rate.
7. Humic-fulvic acid at 360 mL/pot plus 30 g/pot DDGS biochar.
8. Fly larvae manure at 30 g/pot, equivalent to 75 mg N/kg, 85 mg P/kg, and 150 mg K/kg.

The crops were grown in low fertility Lakeland sandy soil to maturity. Stover, grain, and total dry matter were determined. Nutrient content data will be presented in the next report.

As expected for the soybean crop, N fertilizer application did not affect grain yield or total dry matter production (no significant difference between Treatments 1 and 2). Humic-fulvic acid and humic-fulvic acid plus biochar were only 24-31% as effective as the conventional fertilizer treatment with respect to grain yield response (Figure 29). Their performance increased to 50% effectiveness when combined with NPK at 50% of the recommended rate. The DDGS biochar was more effective, achieving 73% of grain yield compared to conventional fertilizers. Fly larvae manure achieved up to 85% of target soybean yield.

Soybean and sorghum trials with organic amendments.

Unlike soybean, sorghum on Lakeland sandy soil was significantly affected when grown without N fertilization, achieving only 33% relative yield compared to the complete NPK plus micronutrients. As the sole source of nutrients, humic-fulvic acid with or without pine biochar, was ineffective, with almost no grain yield (Figure 30). However, when combined with NPK at 50% of the recommended rate, humic-fulvic acid application achieved relative yield of 52%. DDGS biochar, on its own and in combination of humic-fulvic acid, produced 48% and 53% of relative yield, respectively. Fly larvae manure was 61% as effective as conventional fertilization.

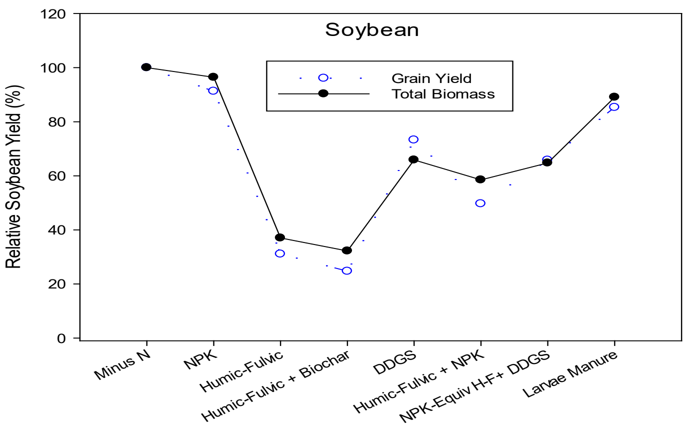


Figure 29. **Relative grain and total dry matter yield of soybean with 100% yield for recommended fertilization (PK+ micro).**

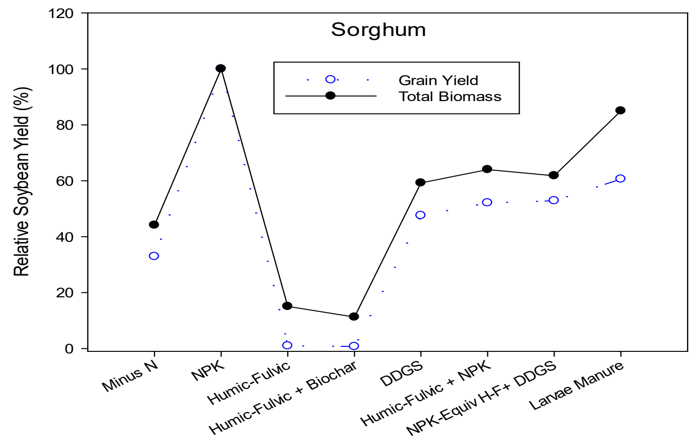


Figure 30. **Relative grain and total dry matter yield of sorghum with 100% relative yield set for recommended fertilization (with NPK+ micro).**

Overall, the performance of the recycled organic amendments DDGS biochar and fly larvae manure differed, achieving 73% and 80% relative yield of soybean and 50% and 61% relative yield of sorghum, respectively. Pine sawdust-derived humic-fulvic acid and biochar were the least effective at the supplier-recommended rates. Plant uptake data will provide greater insight into the nutrient supply capacity of these amendments.

Table 11. Workstream 1: Developing and Validating Technologies, Approaches, and Practices FY21

Workstream 1		Country	Activity	Output (Oct 2020-March 2021)	Partnership	Research Phase (1 -4)
1.1	**Technologies Developed, Refined, and Adapted for Improving Nitrogen Use Efficiency**					
1.1.1	Development of Enhanced Efficiency N Fertilizers	Global (Ongoing)	Developing smart N fertilizer products that are climate-resilient, require one-time application, have high N use efficiency, and reduce reactive N additions to the environment. Use agricultural wastes, plant biostimulants, alternative renewable and biodegradable resources, and alternative slower release fertilizers and amendments, such as PR, ES, Zn, B, polyhalites, and urea-polymers as coating material. Lab and greenhouse characterization.	New products for field evaluation, publications	University of Central Florida, TERI (cost shared)	I
1.1.2	Field Evaluation of Existing Enhanced Efficiency N Fertilizers and Technologies for Improved Yield and Reduced N Pollution	Nepal and Bangladesh (Ongoing)	Evaluate modified urea products, including urea-ammonium sulfate, urea-sulfur (S), urea-Zn, urea-B, various forms of inhibitor-coated urea (such as Agrotain, neem-coated), and controlled-release urea products (such as polymer-coated urea, S-coated urea) on wheat, maize, and vegetables.	Laboratory analysis of plant and sample of 2020 trials completed. Report, data documentation.	NSAF, Shell	II
1.1.3	Scaling Fertilizer Deep Placement (FDP) Technology for Granular and Briquette Fertilizers	Uganda (Ongoing)	1. Development of a high-capacity briquetting machine that can be placed with a fertilizer distributor.	Briquetting machine for key rice-growing areas, blueprints, reports	Private sector	II
		Global/HQ (Ongoing)	2. Transplanter/FDP applicator development under a university partnership grant.	Blueprints made available to potential partners	Mississippi State University	I-II

Workstream 1		Country	Activity	Output (Oct 2020-March 2021)	Partnership	Research Phase (1 -4)
1.1.4	Climate Resilience and Mitigating GHG Emissions	Bangladesh (Ongoing)	1. Increasing fertilizer use efficiency and resilience in saline soils	Two trials were stablished in saline affected areas. Crops are in the field and passing ripening stages. Reports.	BRRI Soil Science Division, Khulna Agricultural University	III
		Burkina Faso (Ongoing)	2. Adapting balanced subsurface fertilizer management (NP, NPK briquette) to intensive rice cropping systems (SRI)	Reports, data documentation	[INERA]) and farmer-based organizations	II
			1.2 Activated Phosphate Rock			
1.2.1	Activated Phosphate Rock Trials under Greenhouse Conditions	HQ (ongoing)	Greenhouse residual trials on the performance of activated Togo PR against DAP	Reports, scaling of activated PR, publication	Private sector	II
1.2.2	Alternative Activation Process for Enhanced Efficiency P Fertilizers	HQ (Ongoing/ to be reported in Sept'2021)	Alternative "activation" processes using bio-organic acids, biofertilizers, and bio-nanotechnology. Improve beneficiation process and provide opportunities to remediate heavy metals from phosphatic fertilizers.	New process/products for field evaluation, report	UCF, TERI, private sector	I
1.2.3	Quantifying P Use Efficiency of Liquid P Fertilizers	Mozambique (New)	Compare performance of liquid P fertilizer and activated PR with conventional fertilizers on soybean, rice, groundnut, and maize.	Reports and data documentation, publications	Private sector, FAR project	I
			1.3 Balanced Crop Nutrition for Site-Specific Fertilizer Recommendation			
1.3.1	Efficient Incorporation of Micronutrients into NPK Fertilizers and Evaluation of Multi-nutrient Fertilizers	HQ/Ghana (Ongoing)	1. Micronutrient rates, sources (S, Zn, B, Cu), and nutrient omission trials in cereals. Grain samples from selected trials (Ghana) analyzed for methionine and cysteine, Zn, Cu, P, and phytate content.	Improved recommendations and products, reports, publications	UCF, Tennessee State University, Harvest Plus, Soybean Innovation Lab (SIL)	III
		Nepal (Ongoing)	2. Improving crop performance through balanced fertilization using customized compound fertilizers in rice-wheat-legume system (one trial each for maize, legume, and rice)	Improved recommendations and products, Technical reports and publications	FTF-NSAF, Tribhuvan University, Agriculture and Forestry University, (NARC) (in-kind)	III
		Rwanda (New)	3. Evaluation of zinc sources for coated fertilizer blends. Determine the most	Improved recommendations and	Rwanda Agriculture and Animal Resources	I

Workstream 1		Country	Activity	Output (Oct 2020-March 2021)	Partnership	Research Phase (1 -4)
			economical source of Zn to apply to coated blends.	products; reports; data documentation	Development Board (RAB)	
1.3.2	Facilitate Site- and Crop-Specific Fertilizer Recommendations for Increased Economic and Environmental Benefits from Fertilizer Use	Ghana (Completed)	Stakeholder workshop on site- and crop-specific balanced fertilizer recommendations and nutrient omission trials in Ghana	Improved fertilizer recommendations, capacity building, publication, report	MoFA, PFAG, UDS, Soil Research Institute, SARI, AFAP, CABI, RELC, PPRSD	III
1.3.3	Wet Chemistry-Spectral Analysis Relationship for Rapid and Reliable Fertilizer, Soil, and Plant Analyses	Global (Ongoing)	1. Wet chemistry-spectral analysis relationship to crop yield and nutrient response. Provide options to partners and development agencies for rapid and reliable techniques for fertilizer, soil, and plant analyses. Create database and use statistical correlation and calibration.	Reports, recommendations	Bruker (equipment), Optionline (equipment and data), NARES	I
		Kenya (Ongoing)	2. Evaluation of spectral and wet chemistry methods for detecting changes in soil nutrient status	Reports	Local labs	II
		HQ/Global (Ongoing)	3. Working with partner organizations to improve fertilizer methodologies and lab standards	Methodologies for fertilizer analysis and lab standards, lab guide, and capacity building	ISO, IFA, AAPFCO, EnGRAIS (cost-share), Dundël Suuf project	II
1.4	**Soil Health and Sustainable Intensification Practices: Integrated Soil Fertility Management, Conservation Agriculture, Nutrient Recycling**					
1.4.1	Evaluation of the Synergistic Effect of CA Practices in Combination with ISFM and Activated PR Amendment in Ghana and Niger (crosscutting with Workstream 3)	Ghana (completed)	Performance of maize under CA versus non-CA and amendments – activated PR	Improved CA practices and nutrient recommendations, data documentation, reports, publications	Africa RISING, private sector	II
		Niger (Ongoing) – delayed due to COVID-19	Performance of millet under CA versus non-CA and amendments – activated PR	Reports, data documentation, field days	Private sector, Institut National de la Recherche Agronomique (INRAN)	II
1.4.2	Increasing System Productivity Through Agronomic Biofortification with Crop Diversification and Intensification	Bangladesh (Ongoing)	Improved nutrient use through balanced crop nutrition with incorporation of secondary and micronutrients (including nanofertilizer) and	Cropping systems and fertilizer recommendations, field	BINA	II

Workstream 1	Country	Activity	Output (Oct 2020-March 2021)	Partnership	Research Phase (1 -4)
		sustainable soil intensification cropping patterns	days, reports, publications		
1.4.3 Developing a Highly Productive and Sustainable Conservation Agriculture Production System for Cambodia	Cambodia (Ongoing)	Assessing and modeling changes in soil organic C and N stocks and soil functions of sandy paddy fields under conventional tillage and conservation agriculture production systems	Improved CA practices, reports, publications	RUA-CE SAIN, GDA, DALRM, CASC, CIRAD, SIIL-KSU (university partnership)	II
1.4.4 Agronomic Biofortification of Cereal Grains and Biomass with Zinc in a Dual-Purpose Cereal-Legume-Livestock Production System	Senegal (New/in progress - reporting in Sept. 2021)	Increase Zn content in grain crops, while simultaneously increasing agricultural productivity and economic returns for smallholder farmers.	Improved crop and fertilizer recommendations and products, technical reports, publications	Private sector, Harvest Plus, SIIL (KSU), Tennessee State University, ISRA-CNRA/Bambey, ITA, ANCAR, RESOPP	II
1.4.5 Impact of Nutrient Recycling, Biofertilizers, and Bio-stimulants on Yield and Soil Health	Global, HQ (Ongoing)	1. Exploration of simple soil test system as soil fertility/soil health indicator.	New and simpler methodologies, reports, publications, organic recycling technologies for scaling	Private sector, Auburn University, farmers	I
	Global, HQ (New)	2. Effective recycling of nutrients, use of biofertilizers and biostimulants for improving soil fertility, soil health, and crop yield and improving nutrient use efficiency	Organic products and recycling technologies for scaling, reports, publications	Private sector	II

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

Under Workstream 2, IFDC conducts evidence-based research to support polices and market development focusing on fertilizers and soil fertility management practices and to complement other improved agricultural technologies. The associated activities primarily focus on FTF countries, although an exception can be made for a non-FTF country if there are useful replicable lessons to be learned. There are three broad focus areas of research under workstream 2.

2.1 Soil fertility-related policy reform processes and market development.

2.2 Impact assessment studies.

2.3 Economic and market research studies.

A summary of FY21 activities under Workstream 2 and deliverables associated with each activity are described below and summarized in Table 12.

2.1 Document and Advocate Fertilizer Policy Reform and Market Development

With RFS support, during FY21 IFDC will continue to partner with organizations and stakeholders at various levels in countries that show a high potential for policy change through:

2.1.1 Support with stakeholder meetings, consultations, and advocacy in Kenya via the Kenya Fertilizer Platform (KeFERT).

2.1.2 Support the Fertilizer Watch to provide fertilizer market updates during the COVID-19 pandemic across SSA countries.

2.1.3 Produce policy briefs based on rapid assessment to build the capacity of stakeholders on soil fertility-related issues for wider dissemination in Niger and Nigeria.

2.1.1 Support Fertilizer Platform and Policy Reform Processes in Kenya ***(Ongoing)***

During October 2018, at the request of the Kenyan Ministry of Agriculture, Livestock and Fisheries (MoALF), a fertilizer roundtable was initiated in Kenya to initiate discussions among stakeholders on issues constraining the use of fertilizers, specifically balanced soil nutrition and use of lime. The stakeholder dialogue further led to the formation of KeFERT in June 2019. KeFERT is a public-private initiative to serve the interests of the stakeholders toward an effective roadmap on fertilizer policy reforms and markets in Kenya. IFDC serves as the advisor and coordinator for KeFERT in providing technical advice on soil heath- and fertilizer market-related issues (https://ifdc.org/kefert/).

Activity: *Organize consultations, meetings, and workshops between KeFERT stakeholders and MoALF, as necessary.* Disseminate key soil fertility-related messages and topics of interest to the stakeholders through expert forums (webinars, in-person workshops).

Partnership: Activities are conducted in collaboration with partners on a cost-share basis. Partners include members of the Fertilizer Association of Kenya (FAK), county-level representatives, Alliance for a Green Revolution in Africa (AGRA), Tegemeo Institute, African Fertilizer and Agribusiness Partnership (AFAP), Kenya Markets Trust (KMT), and other development partners in Kenya.

Progress:

Following the success of the webinar conducted in August 2020 on soil mapping among stakeholders in Kenya (attended by more than 110 participants), a second webinar in the series on Kenya's soil fertility status was also hosted. On November 10, 2020, KeFERT hosted an online webinar to raise awareness of the mapping portal for use in research and learning in Kenya and globally (https://www.youtube.com/watch?v=l5-IAshEeBs).

The webinar was organized to present the Kenya soil map platform and portal and showcase its utility to various stakeholders. The event demonstrated potential applications for policy and decision making for the lime and fertilizer industries in Kenya, gathered feedback from the audience on the mapping portal, and spurred investments in soil mapping.

The mapping portal can be accessed at https://mapping.cropnuts.com/projects/ifdc/kenya. The portal was dedicated to stakeholders by the Principal Secretary, State Department for Crop Development and Agricultural Research, MoALF.

Next Steps:

During FY21, RFS-SFT will further continue to collaborate with KeFERT and MoALF to facilitate partnerships and build consensus to formulate an agenda that supports necessary actions on factors affecting fertilizer/soil health issues and bring about the desired policy outcomes in Kenya.

1. Under a potential partnership between the Kenya Agriculture and Livestock Research Organization (KALRO)/KeFERT and the Guiding Acid Soil Management Investments in Africa (GAIA) project, coordinated by CIMMYT, KeFERT will support the dissemination of the project results through two planned workshops in Q2 and Q3 of 2021.
2. Under the IFDC and KMT collaboration, a webinar is planned for Q2, 2021 on Kenya's Agricultural Lime Market: Options, Opportunities and Economic Potential for Granulated Lime.

Participation in the USAID/Kenya Mission-initiated Policy Technical Working Group (PTWG) Meetings

USAID/Kenya formed the Policy Technical Working Group (PTWG) in 2019 to coordinate the policy-related activities of USAID implementing partners. The PTWG is coordinated by USAID/Kenya's Africa Lead program and USAID Senior Program Management Specialist – Policy and Research, Samson Okumu.

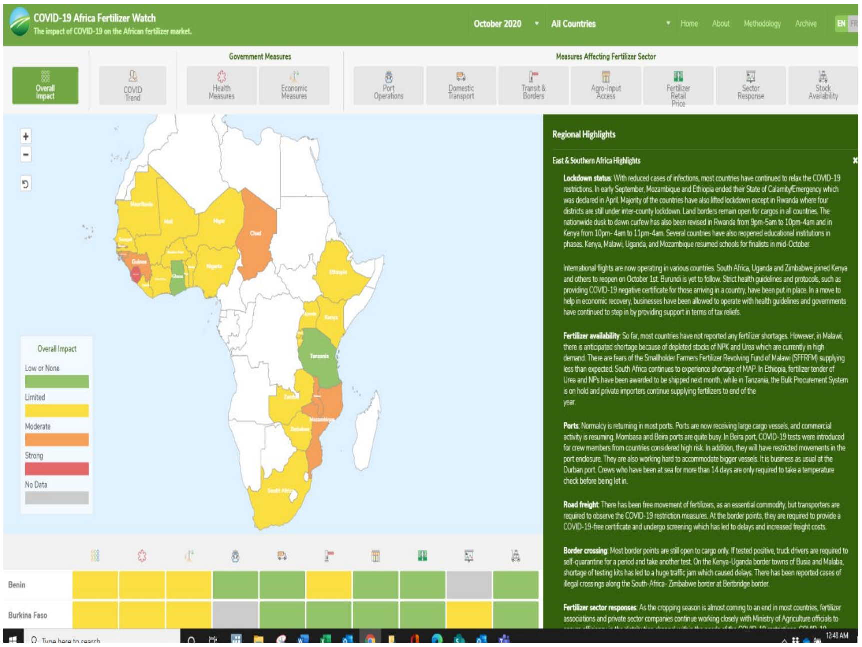
Progress:

During this reporting period, USAID/Kenya PTWG meetings suffered from lack of in-person field activities due to COVID-19 restrictions. The PTWG conducted a virtual meeting for implementing partners in March 2021 and conducted a "policy pause and reflection exercise" among the partners. The exercise reflected what worked and what policies did not work and how the implementers visualize the continuity in policy processes. The next step is for the team members from PTWG to present reflections from the exercise to USAID mission staff in Kenya. There are two more meetings scheduled in Q2 of FY21 to discuss policy thematic areas and emerging priorities for food systems in Kenya.

2.1.2 Fertilizer Watch Updates in Sub-Saharan Africa (FY20 and Completed)

Partnership: AfricaFertilizer.org (AFO), USAID-supported Feed the Future EnGRAIS project, Development Gateway's Visualizing Insights on Fertilizer for African Agriculture [VIFAA] program

As an immediate response to the COVID-19 pandemic, IFDC and our ongoing fertilizer marketing initiative, https://africafertilizer.org/ (AFO), launched a weekly Africa-wide Fertilizer Watch in April 2020. The weekly Fertilizer Watch (https://ifdc.org/tag/fertilizer-watch/) has continued to provided updates, with a mix of quantitative and qualitative data on nine indicators in 28 countries in Africa. The RFS-SFT grant has been supporting this collaborative initiative since April 2020 and continued until December 2020.



In July 2020, the Fertilizer Watch was integrated into AFO (https://africafertilizerwatch.org/#/en/). It is currently published quarterly in a dashboard format. The goal of this dashboard is to support development partners and the private sector to respond efficiently and effectively as the global health emergency evolves, ensuring that enough appropriate fertilizers reach farmers in time for planting.

The Fertilizer Watch has attracted a lot of interest from various stakeholders (nearly 2000 users per week), including the African Union (AU) and other regional economic communities (RECs), including the Economic Community of West African States (ECOWAS) and the East African Community (EAC). The web analytics and feedback from stakeholders are being collected to understand demand and use by the covid watch. The detailed analytics from user groups will be submitted in the next reporting period.

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

This activity involves generating country-level policy brief(s) among selected FTF countries where significant changes have occurred due to key policy changes or regulatory approvals that have improved competition and resulted in a conducive market environment. Progress has been made in Niger and Nigeria on documenting key issues related to fertilizer (or inputs in general) and technology access and availability.[1] The data from rapid surveys are being analyzed, and preliminary results have been presented here. The delays are due to the COVID-19 shutdown, during which time surveys could not be implemented among stakeholders as planned.

Niger (FY20; Completed) "*Dissemination of New Fertilizer Regulations in Niger*" (Link for Draft summary of results: **Draft Summary)**

In 2019, the Government of Niger, with the financial assistance from MCC/MCA-Niger and the technical support of IFDC through the Fertilizer Sector Reform Support Project in Niger (PARSEN) project, started implementing the plan, which was adopted in January 2018, for reforming the domestic fertilizer sector. One important component of this plan is the creation of an enabling regulatory and policy framework. Under this component, fertilizer regulations pertaining to the import, distribution, and control of fertilizers have been signed by the Ministry of Agriculture (October 29, 2019). To complement this effort, IFDC, with funding from the USAID Bureau for Resilience and Food Security (RFS), has initiated an activity to support the large-scale dissemination of these new fertilizer regulations across the country to the primary stakeholders (fertilizer suppliers, crop producers, and agricultural technicians) in the domestic fertilizer value chain.

The dissemination activity sought to raise awareness among key stakeholders on the new legal framework for fertilizer and has involved the distribution of outreach materials (hard copies of the regulations in

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

French, Zarma, and Hausa) to stakeholders and messaging through mass media channels, specifically audio and video spots aired on nation television and local radio stations. Then, a stakeholder survey of 211 respondents across seven regions was conducted (October-December 2020) to determine whether the use of those specific outreach mechanisms proved helpful in spreading information and improving awareness of the fertilizer regulations among stakeholders.

Preliminary results from the surveys among users indicate that:

- Face-to-face meetings (37%) and person-to-person (33%) exchanges were the most common and effective ways to disseminate information on the regulations.
- 21% of the respondents indicated the requirement of a license for fertilizer trade was the most recognized regulation among five regulations passed.
- 35% of stakeholders opined that the licensing regulation for fertilizer trade is expected to formalize and strengthen the fertilizer supply sector, since only professionals will be able to enter the business.

The following policy options can be derived from the dissemination activity related follow-up surveys conducted:

- The IFDC RFS project-initiated efforts to widely disseminate the regulations across the country among stakeholders and similar such efforts should be intensified by other program-interventions in Niger. Interactive meetings and training sessions that allow person-to-person exchange can be supported to further create awareness among targeted people (fertilizer dealers, crop producers, agricultural technicians, etc.) on the five key new fertilizer regulations.
- The intensified effort can be phased, focusing on different segments of the policy and actors in the domestic fertilizer value chain over time. The most focus should be on the aspects of licensing, sale, and sanction regulations, which are of direct interest to the most critical actors (including private operators desiring to enter the fertilizer sales business), followed by production of manuals for inspecting and analyzing fertilizers, which are primarily meant for technicians in charge of quality control.

The detailed results from the dissemination activity analysis can be found in this link on : Draft Summary. The final policy note will be included in the next semiannual report.

Nigeria (FY20 Completed) *"How do the recent fertilizer bans (on urea and NPK) affect fertilizer uptake in value chains in north east Nigeria?"(* Link for draft summary: Nigeria Policy Note)

The Government of Nigeria recently (2018) set restrictions or banned urea and NPK distribution to the northeast and had previously banned sourcing of official foreign exchange, so importers can no longer bring any type of fertilizer or its raw materials into the country. The restriction of fertilizer to the northeast is a result of strong safety measures taken to prevent the use of fertilizer for improvised explosives devices in the region. With dwindling stocks of urea, the private sector has been halting all major investment activities in the country. With this ban in effect at the start of the cropping season, farmers are turning to the purchase of illegally traded fertilizer at higher prices.

Key stakeholders in the fertilizer sector (private sector traders, firms) in Nigeria approached the IFDC Nigeria office in late 2019 and requested the immediate formation of an advisory/advocacy group, led by IFDC, to sensitize and better inform the government on the impact of the ban on fertilizer access and availability to farmers. Hence, the RFS-SFT project worked with IFDC Nigeria office to conduct a rapid survey among the key stakeholders in the fertilizer value chain, including farmers in the northeastern Nigeria, to derive implications on crop production and any effects on food security in the region.

Since the concurrence from the mission was finalized during early 2020, this activity was initiated during the second half of FY20. However, due to the COVID-19 onset, followed by the shutdown through August 2020, survey activities only began in December 2020 and were completed during Q1 of the FY21 reporting period. Rapid key informant interviews with private suppliers/distributors and farmers in three states – Adamawa, Borno, and Yobe – in Northeastern Nigeria. One of the key impacts of the ban resulted in increased smuggling of banned products as supply shortfalls increased 25-30% and prices of urea and other fertilizers soared, coupled with the emergence of a black market, as products were no longer available from distributors (see Table 1 in the link on draft Nigeria Policy Note). The results from the discussions are summarized below. Detailed results are presented in the policy note at the link above.

The ban on fertilizer distribution in northern Nigeria was enacted against a backdrop of a non-performing fertilizer market in Nigeria. The reasoning behind the ban is that urea and NPK fertilizers can be used to produce improvised explosive devices (IEDs), otherwise known as bombs, thereby escalating human insecurity in northeast Nigeria. However, this reasoning is not only fallacious, according to scientists and other experts, but the policy is based on what is seen as a hoax. After five years (since 2017-18 cropping seasons) of implementation, the ban has completely failed to achieve the desired effects. The ban does not provide a solution to the current problem and contributes to agricultural production issues. Hence, the urgent call by stakeholders for change leaves two options for policy officials is either to abrogate the ban on fertilizer distribution in the northeast and or/restrict its implementation to specific areas where the threat to human lives and properties is real.

2.2 Assessment Studies

To support policy reforms for the development of input markets and value chains, this sub-activity will include research activities on the following issues related to fertilizer market development.

2.2.1 Determination of factors influencing fertilizer use among smallholder farmers in Senegal (initiated during FY20; completed in FY21)

2.2.2 Exploration of options for fertilizer certification to curb counterfeiting and improve the quality of fertilizer products in Kenya (in progress; delayed due to COVID-19)

2.2.3 Ex-ante evaluation of proposed policy change regarding the distribution of inputs through a centralized mechanism in Burkina Faso (no progress; postponed FY22)

2.2.1 Determinants of Small Farmer Demand for Fertilizers in Senegal ***(From FY20; Completed)*** ***Link on draft in progress :*** Draft Summary Report on Determining Factors of Senegal Fertilizer Use.

Despite massive public investments in the Senegal agriculture sector through input subsidies, fertilizer adoption is still low but highly variable across crops and production systems. To improve fertilizer, use for food security and agricultural sustainability, its consumption needs to be understood. This research aims to study determinants of fertilizer demand in two agroecological areas of Senegal. For this purpose, farm-level surveys were conducted through Senegalese Institute for Agricultural Research Bureau of Macroeconomic Analysis (ISRA/BAME) in the Groundnut Basin (GB) and the Senegal River Valley (SRV) zones to assess fertilizer consumption and factors that determine adoption and use of this critical input.

Progress:

Detailed household data were collected from 420 small farmers located in SRV, where a national-level rice and vegetable crop-based system for self-sufficiency program through irrigation is implemented, and in the GB, where other high fertilizer consumption crops (peanut, maize, cotton) are grown, mostly under rainfed systems. The farmers come from five departments (Dagana and Podor in the SRV and Kaolack, Nioro, Kaffrine, and Fatick in the GB) and 60 villages. The study was conducted by ISRA/BAME researchers and graduate students. Rural household sampling and field surveys have been completed.

A preliminary report based on an initial analysis can be found at this link: Draft Summary Report on Determining Factors of Senegal Fertilizer Use.

To summarize:

- The two zones, GB and SRV, exhibit quite different fertilizer use profiles: producers in the rainfed GB apply fertilizer on groundnut, maize, and millet in large proportion (62-78%); in contrast, all producers in the irrigated SRV use fertilizer on rice and vegetables (onion, tomato, okra).
- The main fertilizer types/formulas used in both zones are urea, NPK, and DAP: urea is used on tomato, okra, rice, onion, and peanut; DAP on rice, onion, and peanut; NPK 6-20-10 on peanut; and 10-10-20 on millet and vegetables.

Major factors that determine fertilizer use or not among smallholder farmers include.

- Age: More experienced (older) producers are less likely to adopt and use mineral fertilizer, tending to apply other practices (manure or other organic fertilizer) they are familiar with.
- Labor: Farmers with more available household labor are more likely to use fertilizer; this ensures enough labor is available for necessary labor-intensive tasks (weeding).
- Access: Most producers (92%) think access to fertilizers is difficult because of its high price and lack of availability when needed.
- Expected yield and cash availability just before the crop season were most cited reasons for buying fertilizer, followed by good rain prospects and type of crop, more access to credit and to land.

The results from our analysis demonstrates the need for focused interventions and policies to:

- Improve access to fertilizer: Current public subsidy programs should be reviewed and reformed to increase availability of fertilizer in the field when needed by potential users and at affordable prices.
- Devise public rural programs to promote the return of youth to agriculture, hence boosting youth employment in rural areas and halting or slowing rural-urban migration, while increasing labor availability at critical times of the crop calendar in rural areas. Small agriculture machinery that offers multiple uses, such as fertilizer cum seed drills and mini tractors for land preparation, can be explored and create business opportunities through leasing and other options.

Next Steps:

A detailed final report based on economic analysis of the data along with implications will be submitted during the next reporting period.

2.2.2 Analyze impact of counterfeit fertilizer products and options for fertilizer certification in Kenya ***(Ongoing, delayed due to COVID-19)***

Counterfeit fertilizers not only result in an inferior product for farmers and reduce the profitability of fertilizer use (which is already the most expensive input), but they also dilute the brand reputation of fertilizer companies, many of which are investing in balanced fertilizers (crop- and soil-specific blends) that significantly increase yields and profits for farmers. IFDC undertook a "Fertilizer Quality Analysis" activity in 2016-2017, which included an investigation and analysis of sealed fertilizer bags sold through the private sector in Kenya. A recent issue noted by fertilizer blenders, counterfeit fertilizers are fertilizers of unknown origin that are sold in bags branded as Kenya's leading fertilizer companies. This was highlighted as an issue during the Kenya Fertilizer Roundtable and in subsequent Fertilizer Association of Kenya (FAK) and KeFERT meetings. Certain fertilizer companies (e.g., Baraka Fertilizer Blends, sold through Toyota Tsusho) are already taking steps to protect their brands through SMS/scratch-off labels (e.g., mPedigree) like those used in the pharmaceutical and seed sectors.

Our objective is to document a detailed literature review on best practice and successful models along with policy options (e.g., fertilizer regulations/certification in Malawi and Ethiopia) implemented across countries for fertilizers and for other agro-inputs (seeds, pesticides), and other industries (pharmaceuticals, animal health related). This will allow us to determine suitable options for Kenya fertilizer certification to prevent or reduce adulteration at different levels of the chain and develop options for fertilizer certification in Kenya with public and private sector participation.

Next Steps:

Due to the COVID-19 shutdown in Kenya, the survey of the stakeholders could not begin until March 2021. Key informant interviews with fertilizer value chain actors in Kenya are planned, which includes representatives from industry, public sector regulators, FAK, Kenya Bureau of Standards, and the Ministry of Agriculture, to seek their input.

Deliverables:

- A policy brief outlining the options for Kenya fertilizer certification will be generated during the next reporting period.
- Dissemination through a webinar or presentation through KeFERT to obtain the necessary feedback from the Kenyan fertilizer sector stakeholders.

2.2.3 Ex-ante analysis of policy change in subsidized fertilizer distribution in Burkina Faso **(New FY21; To be postponed to FY22)**

The Burkina Faso government has recently set up a new entity called *Centrale d'Achat des Intrants Agricoles* (Central Purchasing of Inputs and Farm Implements) that will oversee procurement and distribution of agricultural inputs in the country through the public sector. This contrasts with the existing private sector-dominant fertilizer sector with private fertilizer importers, wholesalers, and distributors (namely AGRODIA) operating effectively across the country since 2004. Such a centralized, public-dominant system for distribution of inputs is expected to undermine the role of the private sector and further reduce competition. Further scrutiny is required to understand impacts on the access to and availability of fertilizer at competitive prices by farm households. The study will evaluate the anticipated effects of this important policy change on the existing and proposed system, its main actors (AGRODIA), and beneficiaries (crop producers and related producer organizations). The outcomes from this exercise will provide an understanding of the rationale behind such a policy measure and implications for suitable policy options for effective implementation.

Partnership: EnGRAIS and *Institut de l'Environnement et Recherches Agricoles* (INERA), the national research partner organization, and Association of Wholesalers and Retailers of Agricultural Inputs (AGRODIA).

Progress:

This activity could not be taken up due to COVID shutdown. Discussions with INERA suggest postponement of the activity until FY22.

2.3 Economic and Market Studies

IFDC's economic studies include evaluation of various soil fertility-enhancing technologies in terms of economic returns and efficiency for small farm adoption as well as financial returns to various actors in the value chain; stakeholder analyses and assessment of cost buildups and market margins to identify value chain constraints; and market analysis of the supply and demand of fertilizers.

Two activities have been initiated during FY21 and the progress is reported below.

2.3.1 Gender analysis on access to and use of fertilizers in Uganda (in progress) and Mozambique.

2.3.2 Analysis of the determinants and extent of adoption of micronutrient fertilization in rice farming in Bangladesh.

Two additional activities (below) approved in the workplan for the FY21 could not be initiated due to intermittent COVID shutdowns and we propose to initiate during the second half of the fiscal year (from April 2021 onward).

2.3.3 Minimizing Market Distortions (Subsidies, Taxation, Logistics/Cost Build-Up) Economic Analysis/Assessment – Kenya (In partnership with Tegemeo Institute, AfricaFertilizer.Org, KeFERT)

2.3.4 Tracking Niger Fertilizer Sector Reform Process Transition to Smart and Market-Oriented Input Subsidies – Niger (In partnership with PARSEN (MCA-IFDC)and SOILS Consortium

*2.3.1 Women's access to and use of fertilizers in field crops and vegetables – case studies in Uganda and Mozambique **(New FY21; in progress but delayed)***

Progress:

Activities undertaken during this reporting period include:

- Field locations, survey crops, and participants list (input dealers and farmers) finalized.
- Methodology and sample finalized.
- Survey tools produced and pre-tested by farmers and input dealers.
- Locations finalized for Mozambique (women rice growers in Buzi District, Beira Corridor; input retailers in Beira/Chimoio).

Uganda

Studies show that female farmers are as efficient as male farmers, but they produce less because they control less land, use fewer inputs (less fertilizer, seed, etc.), and have less access to important services, such as extension advice and input services. The objective of this research study is to document comprehensive case studies based on field survey research to understand: (i) the perceptions of women farmers toward fertilizer use and soil management practices; and (ii) factors that determine the access to soil fertility technologies including fertilizers in Uganda.

For this purpose, we selected two regions in Uganda, focusing on smallholders (men and women) who are engaged in growing potato, rice, and maize. Potato is a fast-growing, high-value cash crop and very nutritious and thus relevant for poverty reduction and food security in Uganda. Smallholders in eastern Uganda (Sebei Region) and southwestern Uganda (Kigezi Region) grow potatoes for commercial purposes as well as home consumption (35%).

Virtually all households in southwestern Uganda grow potatoes, harvesting over 60% of the national crop. Though women in general, as laborers, are engaged actively in all the crop production activities, in recent years women as farmers have become involved in crop value chain activities, especially in potato-growing regions in Uganda. In the eastern region, smallholders grow rice and maize in addition to potato. New seed varieties are extensively used by maize and potato growers recently. Considering the high costs of fertilizer technologies, smallholders use integrated soil fertility management practices – incorporating both organic and inorganic fertilizers – especially for commercial production.

During this reporting period, we finalized the survey methodologies and survey tools and piloted tools among the farmers/input dealers. The study will be conducted at the farmer and at the input retailer levels. The field locations for the survey of farmers and input retailers will include:

Eastern Uganda – Sebei region for rice and potato.
Southwestern Uganda – Kigezi region for maize and potato.
The methodologies for the study will include focus group discussions (FGDs) among women and men farmer groups separately for all three crops in the two regions and individual surveys among women- and men-owned input retailer shops in major towns around the crop production areas.

Participants	Goal/Survey Questions
Input dealers Individual surveys 30 agro-dealers (15 trained and 15 non-trained agro-dealers)	Understand the role of input suppliers in sharing soil fertility knowledge and providing access to fertilizers, especially for women, as well as the differences in transferring or sharing knowledge to women clientele by input retailers (men- and women-owned retailer shops). • What interventions/strategies have been used by agro-input dealers in facilitating access to and utilization of fertilizers for farmers, particularly women farmers? • Farmers' perceptions on accessing inputs and knowledge on soil fertility products through men-owned vs. women-owned input retailer shops. Note: *farmer-clients who visit the shops during the surveys and in separate discussion with dealers and farmers.*
Farmers – Focus Group Discussion (FGDs) 6 FGDs, with 10-12 farmers each 3-male farmer FGDs 3 female farmer FGDs	Understand farmer knowledge on fertilizers, perceptions of soil fertility products (fertilizers and organic), and soil management practices among women and men farmers, as well as utilization of existing soil fertility-enhancing products, benefits associated, and the constraints faced in access and adoption. Three different cropping systems – maize, rice, and potatoes – will be studied to draw contextual relevance. • What fertilizer types and soil management practices are being adopted and what knowledge has been gained by farmers in general, and women, who are engaged or managing farming activities for rice, maize, and potato in Uganda. • Are there any differences in terms of perceptions/decision making regarding allocation of resources and knowledge or information access and use among male and female farmers in accessing fertilizers or in the use of organic/inorganic soil fertility amendments for their crops?

Note: During piloting, mixed groups were used but this did not go well, as the responses were either biased or dominated by one gender.

Next Steps:

- Final surveys in Uganda; implementation beginning May 15, 2021.
- Final report with analysis for Uganda case (August 2021).
- Sampling framework and participants list for Mozambique (July 2021).
- Survey tools and implementation (August-September 2021).

2.3.2 Economic Analysis on the Adoption of Micronutrient Fertilizers in Rice Farming Systems in Bangladesh **(New FY21; Ongoing but delayed progress due to COVID)**

The introduction of fertilizer responsive HYV rice in the country in the mid-1960s, coupled with the favorable government policy for fertilizer distribution and price controls, resulted in a rise in fertilizer consumption in Bangladesh. Like other countries in the region or elsewhere in Asia, Bangladesh uses extensive quantities of nitrogenous fertilizers, followed by three to four different types of phosphatic fertilizers. Rice is the major food crop and consumes two-thirds of the total chemical fertilizers. The contribution of chemical fertilizer for rice yield is 26-50%. Besides N and P forms of fertilizers, secondary and micronutrients (SMNs) are also used extensively in rice farming in Bangladesh to enhance yields. Currently the SMN application is practiced by all rice growers in the country (especially Zn [7.5 to 10 kg/ha]) but practiced extensively by the farmers in northern provinces/districts of Bangladesh. Though no reliable data is available on the use of micronutrients fertilizers as government do not monitor except for macronutrients (N, P, K) besides S. The informal estimates of Ministry of Agriculture (2019) indicate that 96,399 metric tons (mt) of Zn (mono hydrate, hepta hydrate, and chelated) was used in 9.35 million ha of land (gross cropped area) for all crops, including cereals, vegetables, tubers, etc. Of this, 80% is being used in rice crops across all three seasons (Aus, Aman, and Boro). This is followed by Mg (82,765 mt), 81% of which was applied to rice, and 39,714 mt of B, 80% of which was applied to rice.

Unlike macronutrient fertilizers (N, P, K based), the sales of micronutrient-based fertilizers are primarily through importation by private sector firms and distributed through input retailers. This raises concerns about the quality of SMN-based products available in the market as well as the knowledge transfer, i.e., cultural practices associated with its application rate. It is not clear if the existing product formulations available in the market are based on soil deficiencies or based on soil mapping and requirements.[2]

Objectives: There is limited documented evidence in the literature regarding micronutrient fertilizers in Bangladesh. In this context, the current research has been undertaken, through detailed field surveys among farmers (users and non-users; input retailers, agri-extension officers) to understand:

1. Sources of micronutrient supply and products availability in the market (input retailer survey)
2. Use, impact, and perception of micronutrient fertilizers among farmers (farm-level survey)
3. Existing knowledge on micronutrient fertilizers among extension officers, input retailers, and farmers and how technology transfer or knowledge- sharing and dissemination of information on micronutrients occurs (extension officer-, retailer-, and farm-level surveys)

Activities undertaken during this period:

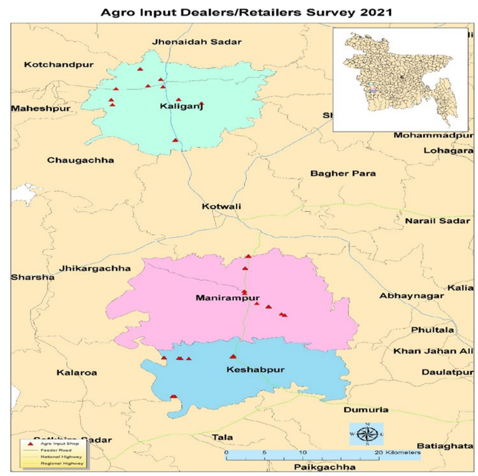
1. Finalized field locations for survey and participants (input retailers, extension agents, farmers).
2. Methodology and sample finalized for input retailers and extension agents.
3. Survey tools produced and pretested for both input retailers and extension agents.
4. **Final surveys implemented and completed among input retailers and extension agents**.

[2] The secondary and micronutrient fertilizer formulations are available separately for use and not through fertilizer blends based on major nutrients in Bangladesh market. Farmers apply SMNs formulations as a supplement to major nitrogenous and phosphatic forms of fertilizers.

Details of the survey among stakeholders:

Survey Locations and Number of Sample Dealers/Retailers Interviewed

District	Upazila	Village/Market	Dealers
Jashore	Keshabpur	Chingra Bazar	3
		Keshabpur Bazar	3
		Main Road	1
		Satbaria Bazar	4
		Trimohoni Bazar	4
	Manirampur	Baliadanga	1
		Begaritola	2
		Gopalpur	2
		Gorohata Road	1
		Kuada Bazar	3
		Main Road	1
		Manirampur Bazar	1
		Satnal Bazar	4
Jhenaidah	Kaliganj	Amtola Bazar	1
		Baliadanga	2
		Banoria Bazar	1
		Boro Bazar	3
		Chaprail Bazar	2
		Kaliganj Bazar	1
		Kashipur	1
		Lautola Bazar	1
		Nimtola	1
		Shingi Ghoshpara	1
		Singdoho Amtola	1
		Total:	**45**



a) Input retailer survey (45): To understand the supply aspects of micronutrients and available products in the markets; how the demand is assessed by the retailers for the micronutrient products; how different the promotion and dissemination of technologies associated with micronutrients vs. other fertilizer products; and constraints faced and suggestions for any policy changes expected from the government. For this purpose, we conducted surveys among 45 input retailers from two major rice-growing districts: Keshabpur and Manirampur Upazilas of Jashore District and Kaliganj Upazila in Jhenaidah District in southwestern Bangladesh.

b) Agricultural extension officer survey (15): To understand the knowledge transmission or technology transfer involved in these specialty products, we held key informant discussions among district-level assistant field extension officers at the selected upazilas, where we conducted the retailer surveys. This was done to ascertain the current knowledge level among the extension agents on micronutrient fertilization aspects and their expectations from the public research organizations and the private sector to promote adoption, e.g., need for more training and support from the government in terms of product quality monitoring and soil mapping. Results from the data are being analyzed and will be included in the next reporting period.

Macro Income through Micro Nutrition Sales

Md Towhidur Rahman, owner of M/s Towhid Enterprise from Keshabpur upazila in Jashore District, is an agro-input dealer who started his business about 22 years ago. He sells seeds, chemical fertilizers, micronutrients (zinc, boron, magnesium), pesticides, herbicides, and weedicides in his shop. He says, "*Sales of micronutrients was an additional boost to my business. It was really very challenging because the prices of some micronutrients, especially zinc and boron, are very high compared to other chemical fertilizers and some farmers cannot afford to buy it.*" But after observing the performance of some micronutrients in demonstration plots established by private companies and gaining knowledge from his interactions with private firms, he was encouraged to add micronutrient products to his portfolio. In 1999, during the initial stage of his business, only a few local farmers were using micronutrients for limited crops, especially vegetables. Some farmers were buying low-cost products with a very low nutrient content. The products were sold in small, unattractive packets as well as in bags. To motivate the farmers to use good quality products in crop production and to expand his business, Rahman took the following steps:

- Offered credit to farmer to buy inputs.
- Organized group meetings with neighboring farmers.
- Prepared leaflets and banners.
- Established demonstration plots using micronutrients as well as other inputs with assistance from private companies.
- Shared results of micronutrients with farmers.
- Provided inputs, including micronutrients, to some contract growers on 100% credit.
- Attended farmer training programs organized by different agencies.
- Shared information via attractive posters from private firms on symptoms of micronutrient deficiencies and benefits of using quality micronutrients to overcome the deficiencies.

All these approaches paid off well for Rahman, and his shop is well known for quality products with genuine good-quality brands of micronutrient fertilizers. Every month more than 800 farmers purchase micronutrients from his shop for paddy rice, vegetables, and aquaculture ponds. Rahman sold about 51 mt of micronutrients (magnesium, zinc, and boron products) during Boro season 2020, compared to 40 mt in 2019 and about 30 mt in 2017. He notes, "*It is really amazing that the farmers are now more aware of the benefits of micronutrients and are applying them in crop production.*"

Initial analysis indicates the following key findings:

- Most of the products are sourced from private firms who import the products from China. The source of origin for all the products are from China, except one from Bangladesh.

- In the sampled retailer shops, we found more than 70 different brands of products (zinc-, boron-, and magnesium-based) being sold. For example, 25 different brands of zinc products were recorded from 45 dealers surveyed. Of those, 22 were zinc sulfate (monohydrate forms), one was zinc sulfate (heptahydrate form), and two were chelated zinc products.
- All dealers in our sample sold micronutrients in their shops, and the demand is mostly from rice and vegetable growers.
- An average of 6,448 kg of micronutrient fertilizers (zinc and magnesium) was sold in 2020 by the dealers through their shops.

Various available brands of micronutrient products in the market

- On average, retailers have sold micronutrient fertilizers in their shops for more than 15 years. Most of the knowledge is gained from a few private firms who supply the products along with promotional materials, and few retailers also have received specialized training through the private sector.
- Most of the training received on micronutrients is on application rate/dosage and marketing aspects, followed by identification of deficiencies and storage and handling aspects.

Detailed data from the final retailer surveys are being analyzed, and a detailed report along with key results will be provided during the next reporting period.

Next Steps:

- Finalize farm-level survey instrument and sampling of farmers and pretest farm-level surveys.
- Administer farm-level surveys among 120 farmers in Jashore and Juneida districts (adopters vs non-adopters).
- Complete the analysis of the input retailers survey and agri-extension survey for detailed reporting.
- Produce a combined draft report of retailer, extension agent, and farm-level surveys.

Table 12. Workstream 2: Supporting Policy Reform Processes, Advocacy, and Market Development (FY21)

Title/Activities	Country	Deliverables	Partnership
2.1 Influencing policy reform processes (advocacy)			
2.1.1 Kenya Fertilizer Platform (KeFERT) Public-Private Dialogue and Coordination for policy advocacy	Kenya (Ongoing)	Stakeholder consultations, meetings, webinars	MoA, FAK, AGRA, private firms, KMT, One Acre Fund, Tegemeo, AFAP, AFO-
2.1.2 Supporting Fertilizer Watch	SSA (Completed 12/20)	Biweekly fertilizer market bulletins	AFO, EnGRAIS, WAFA, VIFAA
2.1.3 Policy Briefs on Fertilizer Policies, Reforms, and Market Development	Niger, Nigeria (Completed – draft)	Policy brief/Policy Note	PARSEN, MCA-Niger, EnGRAIS
2.2 Assessment studies			
2.2.1 Determination of factors influencing fertilizer use among smallholder farmers in Senegal	Senegal (initiated during FY20; completed in FY21) – drafts in progress	Research report / Policy Note	ISRA/BAME – graduate student
2.2.2 Exploration of options for fertilizer certification to curb counterfeiting and improve the quality of fertilizer products in Kenya	Kenya (New) In progress -delayed due to COVID	Analytical report/Policy Note	KeFERT platform members, MOALF
2.2.3 Ex-Ante Analysis of Policy Change in Subsidized Fertilizer Distribution	Burkina Faso (New, To be postponed FY22)	Interviews, consultations with stakeholders, analytical report	INERA, EnGRAIS, AGRODIA,
2.3 Economic studies			
2.3.1 Gender Series on Women's Access and Use of Fertilizers: Women's Access to and Use of Fertilizers	Uganda Mozambique (New, in progress)	Country-specific case study in SSA and research paper	DGIS-REACH Uganda
2.3.2 Economic Analysis on the Adoption of Micronutrient Fertilizers in Rice Farming Systems	Bangladesh (New, in progress)	Policy brief and research report on adoption determinants	
2.3.3 Minimizing Market Distortions (Subsidies, Taxation, Logistics/Cost Build-Up) Economic Analysis/Assessment	Kenya (New) To be initiated in August	Survey, analytical reporting, research paper	Tegemeo, IFDC-AFO, AGRA, KeFERT
2.3.4 Tracking Niger Fertilizer Sector Reform Process Transition to Smart and Market-Oriented Input Subsidies	Niger (New) To be initiated in July-Aug	Analytical report and research paper	AFO, PARSEN, MCA-Niger, Fert. Assoc.

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

In March 2019, the SOILS Consortium was launched to focus on conducting research on sustainable opportunities for improving livelihoods with soil fertility-related solutions in partnership with a range of likeminded academic and research partners globally. This workstream will support activities initiated by IFDC in collaboration with SIIL. SOILS Consortium university partners include Michigan State University, University of Colorado, and Auburn University. The major focus of the SOILS Consortium is to identify research activities that offer holistic solutions toward developing a roadmap for enhancing soil fertility and soil health in selected countries in sub-Saharan Africa. This work will improve productivity of crop and livestock systems, improve resilience of farming systems to cope with environmental stresses, and guide nutrition-specific innovations.

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

The Nigerien President has been a champion for improving soil fertility as the key to improving the livelihoods of all Nigeriens. As a first step toward this goal, the SOILS Consortium organized the "Joint Summit on Soil Fertility" in Niamey, Niger, on May 2 and 3, 2019, which brought together leading national and international soil scientists to develop a unified national strategy to improve Niger's soils. The activities included will improve productivity of crop and livestock systems, improve resilience of farming systems to cope with environmental stresses, and guide nutrition-specific innovations (Nutrition-Smart Agriculture).

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

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

Partnership: Colorado University, INRAN, SOILS Consortium, IFDC-Niger,

Progress:

University of Colorado Boulder has focused on the development of a Land Capability Classification (LCC) map in Niger and training support for the use of LandPKS for field use in the region. The LCC is a land potential evaluation system that classifies land based on its limitations for agriculture, including factors affecting both potential productivity and degradation risk. It has been used to identify and implement management interventions to improve agricultural productivity and sustainability. The LCC system is oriented to the assessment of soils and physical land properties, such as slope and texture. The LCC framework is a useful initial analysis of land use potential and is especially well suited to regions with limited prior land planning activity and/or limited site-level data. It also provides a biophysical basis for subsequent planning work that incorporates economic and social factors. LCC calculations can be modified to fit the landscape, management approach or crop in question.

LandPKS work on mapping LCC in Niger was targeted for the Dosso Region after consultation with various stakeholders in Niamey (fall 2019). The Dosso Region is important for regional food security and is a target area for multinational investments in improved agricultural output. It is also representative of many areas in Africa where both traditional and digital soil map products have been limited by a low density of soil profile descriptions and measurements. In fall 2019, we created an initial map product for the region, and in 2020, we carried out a series of additional steps to refine the map, add an assessment of soil nutrient status, and test whether remote sensing data could add additional value to the map products. The results of this analysis have been submitted for publication to the journal, *Land* and the map products have been shared with stakeholders, including the Millennium Challenge Corporation, for feedback or potential use. The University of Colorado Boulder team also worked closely with Michigan State University on training and outreach (see Activity 3.1.2). In response to feedback from the Niger WhatsApp group, we have incorporated changes into the LandPKS app, and particularly the new Soil Health module, to make it easier to describe hardened soils in Niger.

Land Capability Classification Mapping

Our approach to LCC mapping included the use of map products and field data collected by the IFDC. We built an LCC assessment using soil data from analyses of 0-20 cm deep soil samples collected at 1,305 sites throughout the region. We then compared this field data-based assessment to LCC assessments built using two popular, publicly available global soil maps (SoilGrids and HWSD) to demonstrate the opportunities and limitations of using different types of soil data for land planning. A comparison of the outputs from these three approaches and a regional spatial evaluation of land capability for use in future land planning activities has been published in the journal *Land* (Ippolito et al. [2021] https://doi.org/10.3390/land10050458).

Figure 31 illustrates a broad regional map of LCCs based off the IFDC field sampling in the region. As the left panel shows, much of the Dosso Region is classified as LCC Category 4, a category rating that indicates very severe limitations to agriculture with limited cropping options and/or more required conservation options. One of the useful features of the LCC framework is the identification of physical limitations and resulting changes in capability rating if that limitation is removed through management. In Dosso Region, there is widespread limitation of agricultural due to the available water capacity (AWC) of soils. This is a measure of the capacity of the soil to hold and release water in support of crop growth. It is notable to see the large shift in LCC when the AWC limitation is removed (right panel, Figure 31) to an LCC Category 3. This class represents an improved potential for agriculture (albeit a still severely limited category for agriculture). The removal of AWC functionally represents actions such as the introduction of irrigation technology and/or the use of irrigation to support plant growth toward the end of a growing season, when soil moisture would be otherwise depleted.

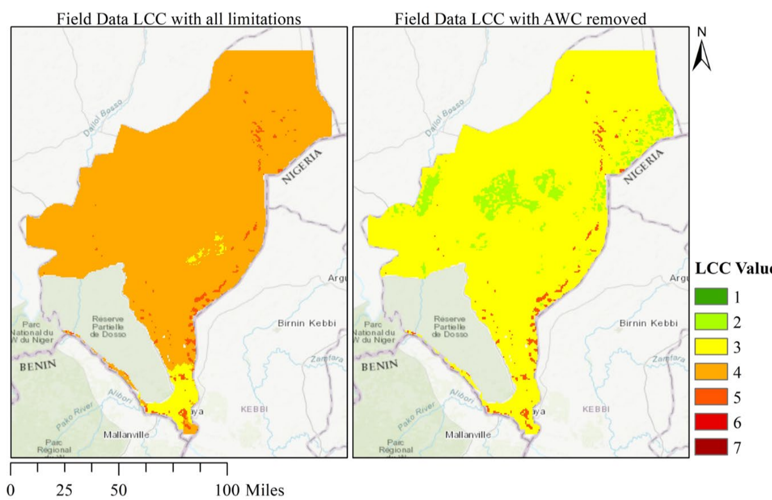


Figure 31. LCC mapping of field data with and without AWC as a limitation.

The analysis submitted to *Land* also explores the use of soil map products as an additional option for the development of LCC analyses when field data are lacking. Figure 32 illustrates a comparison of the spatial details of LCC using the field data from this study in comparison to the SoilGrids digital soil product and the Harmonized World Soil Database (HWSD) map from FAO. This comparison is a key step toward a more nuanced understanding of how best to scale the activities in Dosso to a broader regional level using a mix of field data and global soil data products.

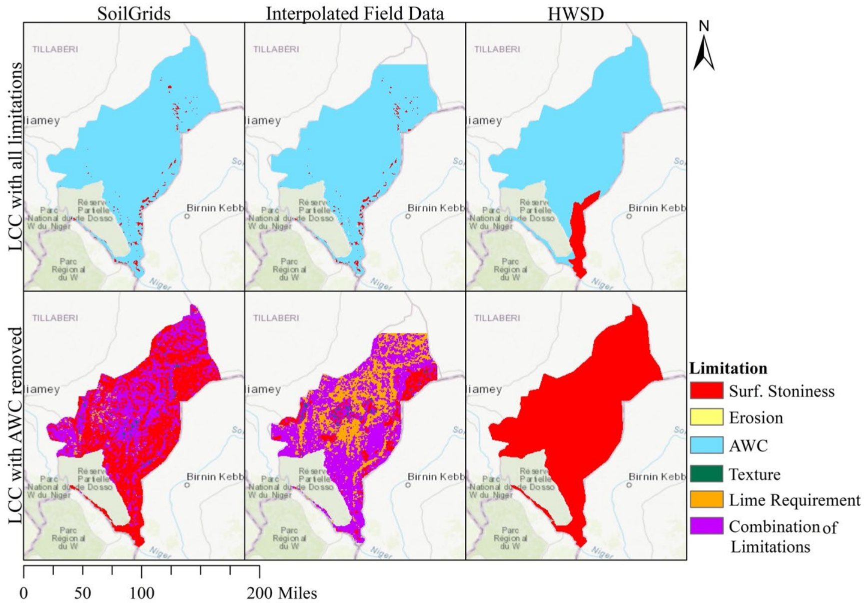


Figure 32. Comparison of LCC products from the SoilGrids digital soil product, the field data from this study, and the FAO HWSD soil map.

In addition to the LCC products here, we have completed spatial analysis of soil nutrient data from the Dosso Region and have done an initial study on the use of remote sensing greenness timeseries data as an additional potential data source for the analysis of agricultural potential and drought vulnerability. The remote sensing analysis shows a potential correlation between field nutrient status and indictors of vegetation greenness, but additional work would be required to fully evaluate the potential use of greenness trends as an indicator of spatial drought vulnerability.

3.1.2 Remote Sensing and Use of Soil Data

The objective of this activity is the use of Land PKS and remote sensing as tools of decision making and to aid in the identification of at-risk soils areas and selection of agronomic methods best suited for the soils.

Specific activities will include:

- Ground-truthing to calibrate LandPKS.
- Socioeconomic analysis using Niger Living Standards Measurement Study – Integrated Surveys on Agriculture (LSMS-ISA) data (available from World Bank).
- Household survey preparation and data collection; household survey analysis.
- Microdosing, FDP, and activated PR studies.
- Final workshops and training with LandPKS.

Partnership: Michigan State University, Colorado University, Auburn University, ICRISAT-Niger, INRAN, SOILS Consortium, IFDC-Niger

Progress:

Michigan State University

After major delays due to COVID-19, progress to date is presented here, and the anticipated completion date for this activity is December 2021. To overcome COVID-19 limitations for in-person training, training sessions for national partners were conducted via WhatsApp messenger service during January-March 2021. There are 27 members connected to the WhatsApp group, and 16 Nigerians have interacted with the group via the chat feature. We shared five videos (plus one translated into French) with the group and used this as the basis to train, ask questions, and discuss. Two Zoom discussions, one on the tools used by Nigerien farmers and the other on the use of the LandPKS, were held. Each Zoom conference was two hours and engaged several (7-12) of the Nigerien researchers and our team. These exchanges enhanced the team's understanding of what is promoted by Niger's Ministry of Agriculture to remediate soils and how to improve on training and promoting the LandPKS. The videos were created by each team member on their respective topic and can be found at the following links:

- Introduction, An Overview of Project. Vicki Morrone. (https://mediaspace.msu.edu/media/Overview+of+the+Niger+Soil+Video+Series/1_uw2mnye5)
- Insights of Farmer Practices in Niger. Nicole Mason-Wardell and Christina Biedny. https://mediaspace.msu.edu/media/Insights+on+Farmer+Practices+Niger+%28Presentation+is+in+English%29/1_kg1ar9cw (English) https://mediaspace.msu.edu/media/Insights+on+Farmer+Practices+Niger+%28en+fran%C3%A7ais%29/1_nqakccfd (French)
- Managing the Challenges of Niger Soils. Vincent Bado, ICRISAT-Niger. (https://mediaspace.msu.edu/media/Niger+soil+challenges+/1_4ylqkffs)
- Soil Mapping of Dosso Soils. Irashad Mohammed, ICRISAT-Niger. (https://mediaspace.msu.edu/media/Soil+mapping+of+Dosso+region/1_4gxkgaiw)
- LandPKS for In-Field Soil Assessment. Jeff Herrick USDA-ARS in Las Cruces, New Mexico. (https://mediaspace.msu.edu/media/Using+the++LandPKS+in+the+field.mp4/1_gc484q4d)

A policy brief on farmer practices in Niger related to erosion control and soil fertility management, based on the Niger LSMS-ISA data, was completed in August 2020. A socioeconomic analysis of the correlates of using these practices was completed in late 2020; the associated working paper is being finalized. The choice experiment that will be used to assess farmer willingness to adopt management practices to combat hardened soils was designed in fall 2020; the associated master's thesis (Plan B paper) was successfully defended by Biedny in January 2021. The thesis revisions and LSMS-ISA-based working paper are being finalized and should be completed by the end of May 2021. *See policy brief by Biedny and Mason-Wardell on "Insights on Farmer Practices in Niger: Preliminary Findings on Erosion and Soil Fertility Management from LSMS-ISA Data*" under the Publications and Presentation section. The household survey with LandPKS data collection activities has been postponed due to COVID-19, as no in-person surveys are allowed in Niger. Our plan is to conduct the survey fall 2021, with a report to be finalized by November 2021.

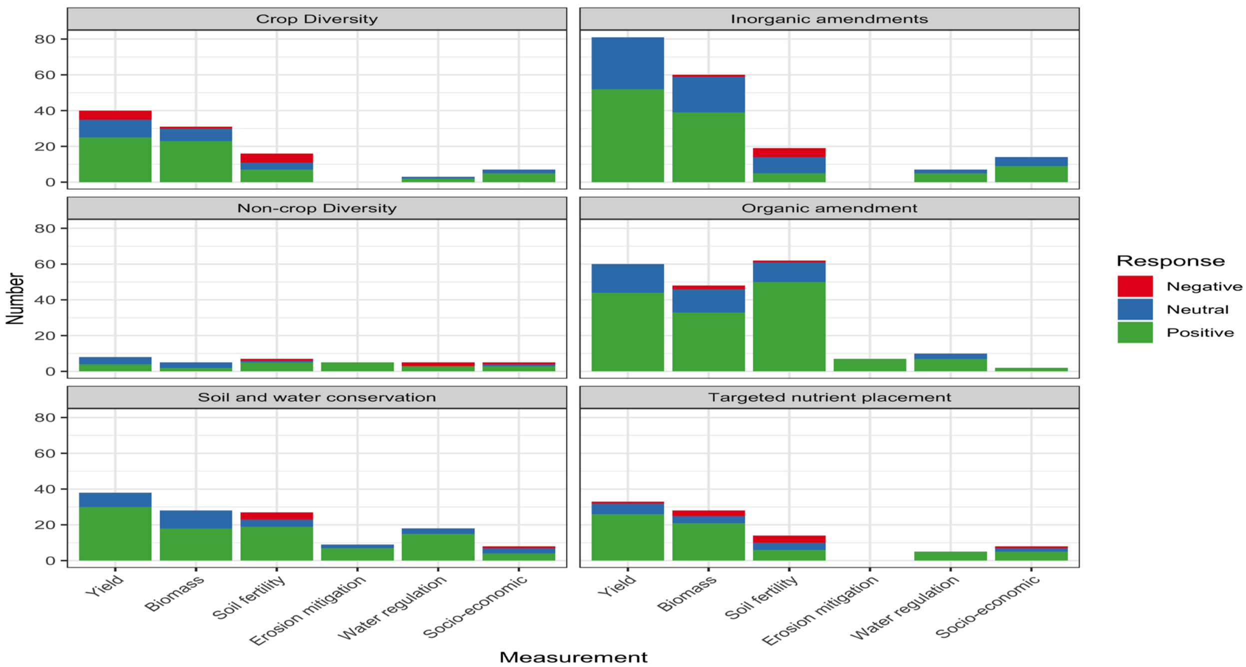


Figure 33. Findings of literature review to support soil management decision guides.

A systematic literature review has been conducted to support soil management decision guides in collaboration with Niger and ICRISAT partners (Figure 33 and Table 13). Manuscript on literature review "Sustainable Soil Management for the Sahel: A Systematic Review" is under preparation. The guide, currently under review by the national partners, will support recommendation options to be included with the LandPKS application when it becomes possible to do the survey. The final workshop cannot be planned now due to COVID-19. However, it is tentatively planned for December 2021.

Table 13. Site-specific findings noted in studies by practice groups.

Groups	Site-Specific Findings	References
Crop diversity (CD)	*Order of crops in rotation.	Falconnier et al. (2017)
	*Crop rotations performed differently in different soil types – best in "black soils" compared to "gravelly soil" or "sandy soil."	Falconnier et al. (2017)
	*Rotations performed best in years with >500 mm rainfall.	Subbarao et al. (2000); Abdou et al. (2012)
	*Relay cropping systems performed best in seasons with early onset of rains.	Sivakumar (1993)
Non-crop diversity (NCD)	None	
Inorganic amendments (IA)	*Soil acidity affected effectiveness of P fertilizer in particular – most effective in alkaline soils.	Van Asten et al. (2005)
	*Fertilizer least effective in low (600 mm) sites.	Bationo et al. (1997)
	*Fertilizer only found to be effective in years with sufficient rainfall (>600 mm).	Abdou et al. (2016)
Organic amendments (OA)	*Organic amendments able to effectively raise yields and improve soil quality in acidic soils.	Van Asten et al. (2005); Rebafka et al. (1993)

Groups	Site-Specific Findings	References
	*Topography/microtopography affected how much manure was needed to be applied to be effective.	Brouwer & Powell (1998)
	*Organic amendment application most convenient for fields closer to homestead.	Prudencio (1993)
	*Presence of mesofauna (termites) increased decomposition rates of organic amendments.	Esse et al. (2001)
	*Luvisols more responsive than Lixisols to compost application.	Ouattara et al. (2007)
	*Response to compost only seen in higher rainfall year (>600 mm).	Abdou et al. (2016)
Soil and water conservation (SWC)	*Ridging most beneficial in years with rainfall <500 mm.	Subbarao et al. (2000)
	*Zai not suitable on sandy or clay soils, best in areas with 300-800 mm rainfall and on flat, barren, hardened soils.	Barry et al. (2009)
	*Lixisols (higher sand content) more responsive to tillage than Luvisols.	Ouattara et al. (2007)
	*Stone lines and grass bunds only effective in increasing yields in low rainfall years.	Traore et al. (2020)
Targeted nutrient placement (TNP)	*Targeted application of nutrients may be more appropriate in areas with land scarcity vs labor scarcity.	Lamers et al. (2015)

Auburn University

This component of the activity is led by Elizabeth Guertal and Joey Shaw (Auburn University), in collaboration with Jonathan Maynard (University of Colorado at Boulder) and Jeffrey E. Herrick (USDA-ARS). FAO and World Reference Base (WRB) databases were used to improve soil taxonomic unit descriptions of the soil. In all, 24 group soil descriptions were used, with an average of four modifiers per soil. Descriptions have been developed for 14 soils, for a total of 72 modifiers. The specific soil characteristics and properties were described to improve the inventory and interpretive value of the taxonomic descriptions. Management information for each soil was developed. General management tools that fit every soil modifier were placed in a "general management" box, while specific management tools that only fit a modifier description were placed in that specific box. If there was no additional detail needed (for example, "Haplic"), the box was left empty. This information was then linked the LandPKS program. Two examples are shown in the following boxes. The remaining 10 soils will be completed by the next reporting cycle (see Linking Soil Descriptions and Management Information to LandPKS).

3.1.3 Analysis of Digital Extension Platforms, Tools, Approaches, and Services in Niger

The Sustainable Opportunities for Improving Livelihoods with Soils (SOILS) Consortium intends to establish a technology park in Niger. The Technology Park will function as an information and training service center and project agricultural information and innovations to accelerate dissemination and scaling efforts, as well as provide training to farmers and other agricultural value chain actors. The SOILS Consortium, in collaboration with the Feed the Future Developing Local Extension Capacity (DLEC) project, conducted this study to analyze the digital agricultural extension and advisory services in Niger to support creation of the technology park and to provide insights and recommendations on how the SOILS Consortium can better use digital extension platforms and services to increase the reach of their activities. The research study upon assessment concludes that:

- The low coverage of farmers by extension agents compounded by the restrictions on mass gatherings due to the COVID-19 pandemic and the limited coordination and collaboration among extension and advisory service (EAS) providers have reduced the potential benefits of traditional EAS in Niger.
- Digital EAS could be a game changer for smallholder farmers and other actors to access or render quality EAS from the comfort of their homes or workplaces.
- Niger has a limited but gradually advancing enabling environment and agricultural data infrastructure that support digital agriculture. Thus, there is a reasonable number of quality digital platforms that are accessible and effective in providing or supporting quality EAS that meets the needs of farmers and other actors across the country.
- Digital agricultural extension activities appear to be driven by donors and international development partners, which do not guarantee the sustainability of the digital EAS platforms.

Final Report on "*Analysis of Digital Agriculture Extension and Advisory Services in Niger,*" submitted to the Feed the Future Developing Local Extension Capacity (DLEC) Project and the IFDC-led Feed the Future Soil Fertility Technology Adoption, Policy Reform, and Knowledge Management (RFS-SFT) – SOILS Consortium Project, USAID, Washington D.C. The final version of the report is available in this link: Analysis of Digital Agriculture Extension and Advisory Services in Niger.

3.1.4 Validating and Promoting Activated PR using Local PR Sources and Producers

PR and activated PR demonstrations will be conducted on soils of varying pH with local PR producers to further validate the role of activated PR as an alternative to water-soluble P fertilizer. The crop trials also would include evaluating the synergistic effect of CA practices in combination with ISFM and activated PR amends for Millet in Niger. The trials in Niger will be initiated in June 2021 (delayed due to the COVID-19 pandemic) in partnership with local PR producers/mining firm (SOFFIA), INRAN and the SOILS Consortium, with help from IFDC's Pilot Plant. The soil amendment with activated PR as a nutrient source, combined with CA and ISFM, are expected to improve rooting and drought tolerance while reducing further soil acidification.

Locations/Timeline: Niger/June-December 2021

Progress:

Tahoua natural phosphate rock (PNT) from Niger with a relative agronomic efficiency (RAE) of <30%, is not suitable for direct application on most soils and crops. However, activation of PNT with MAP will make it as effective as commercial P fertilizers. The objective of proposed work is to: (1) produce activated PNT for greenhouse and field evaluation; (2) provide technical support to SOFFIA, a Nigerien company to produce the activated PNT locally; (3) evaluate effectiveness of activated PNT under controlled greenhouse conditions; (4) conduct field evaluation and on-farm demonstration of activated PNT in partnership with SOFFIA, INRAN, and University of Niamey. A Memorandum of Understanding has been signed between SOFFIA, a private phosphate rock mining company in Niger, and IFDC to evaluate and promote the use of activated PNT. A 50-kg sample of Tahoua PR was shipped from Niger, processed (series of grinding), and analyzed for total P content. The ground PNT was then mixed with ground MAP, with 75% of P derived from PR and 25% from MAP, and compacted. The compacted product was sieved to 2-5 mm size, analyzed for total P content, and shipped back to Niger for the planned field trials. Schematic representation of the process is shown in Figure 34.

Figure 34. Processing of as-received Tahoua natural phosphate rock (PNT) to compacted 75TNP:25MAP product for field trials.

Next Steps: The methodology for the preparation of compacted/activated PNT will be shared with SOFFIA.Activated PNT field research trials will be conducted on P-deficient acidic and neutral soils in partnership with INRAN in Dosso Region. For the 2021 season starting mid-June, the trials will be limited to sorghum. The treatments protocols are being finalized and planned for four replications in randomized complete block design framework. We will report the progress in September 2021.

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

Following the "Joint Summit on Soil Fertility to Scale" in Addis Ababa, Ethiopia, May 23-24, 2019, and work plan meetings, a proposal on "Targeting Fertilizer Source and Rate in Ethiopia" was developed by ICRISAT, IFDC, and the National Agricultural Research Council Secretariat (NARCS). This plan has been approved by the SOILS Consortium leadership team. Field and greenhouse experiments were conducted in Ethiopia and at IFDC HQ, respectively, as detailed below.

3.2.1 Decision Support Systems for Improved Access to Soil Fertility Information and Farming Practices

3.2.1 (A) Fertilizer Trials

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

Partnership: SOILS Consortium, ICRISAT, IFDC-East Africa, Excellency in Agronomy (EiA) of the CGIAR, Ministry of Agriculture-Soils Directorate*,* Ethiopian Agriculture Research Council Secretariat (EARCS), Ethiopian Institute of Agricultural Research (EIAR)*,* Regional Agricultural Research Institutes of Amhara, Tigrai, Oromia and Southern Regions, Capacity building for scaling up of evidence-based best practices in agricultural production in Ethiopia (CASCAPE) project, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ ISFM+) Ethiopia, and the International Center for Tropical Agriculture (CIAT).

Activities: Georeferenced nutrient response trials on teff, wheat, and sorghum conducted across target farming systems.
Partner meetings to develop a common protocol used across multiple institutions.
Compile data from past and present datasets for multivariate analysis.

Progress:

A. Trials Targeting Fertilizer Source and Rate in Ethiopia

Targeted and gap-filling field trials on teff (183 sites), wheat (119 sites), and sorghum (60 sites), for a total of 362, have been implemented in four regions (Amhara, Oromia, SNNPR, and Tigray) of Ethiopia, as shown in Table 14. Of these, 290 plots were harvested, and data collected. Field supervisions were conducted collaboratively by the ICRISAT and IFDC teams. Technical support was provided for focal persons and researchers at every project site, except Tigray regional state, due to travel restrictions. As a result, follow up and supervision was done virtually. Data on yield and yield components have been collected, and the preliminary results of the trials are summarized below.

Table 14. Number of trial sites per crop per region in Ethiopia.

Region	Crop	Number of Trial Sites		No. of Districts
		Implemented	Harvested	
Amhara	Wheat	38	37	6
	Teff	75	69	
	Sorghum	48	38	
Oromia	Wheat	9	9	5
	Teff	47	46	
SNNPR	Wheat	48	45	5
	Teff	49	49	
Tigray	Wheat	24	0	4
	Teff	12	0	
	Sorghum	12	0	
Total		**362**	**290**	**24**

Note: Some districts have more than one crop planted. Result data was not collected from Tigray region.

From the trial sites, 416 soil samples were collected at two depths (0-20 and 20-60/40 cm) and are being analyzed at IFDC HQ laboratory in Muscle Shoals, Alabama. It was not possible to ship samples from the Tigray region, first due to the COVID-19 travel ban and then the ongoing Law Enforcement Operation of the Government of Ethiopia. Spectral determination of the soil samples has been completed in Ethiopia at the Southern Agricultural Research Institute laboratory. The same determination will also be performed at the IFDC HQ laboratory after the wet chemistry analysis has been completed. The results of both the spectral and wet chemistry data will be used to determine their relationship with each other and with crop response data.

Sorghum in Belesa Woreda, Central Gondar Zone, Amhara Region. ***Wheat in Gozamen Woreda, East Gojjam Zone, Amhara Region.*** ***Teff in Sekota Woreda, Waghemra Zone, Amhara Region.***

Figure 35. Performance of some of the field trials on teff, wheat, and sorghum in Ethiopia.

The summary of the **yield response of teff, wheat, and sorghum** to application of different nutrients and rates is summarized below.

- Yields of wheat and teff were significantly increased over 300% relative to the control, up to 8% relative to the NP treatment only, and over 25% compared to treatment with half of all the nutrients (50% of all nutrients + K) due to application of 150% all K treatment. Consistent differences were not observed among the fertilizer treatments containing K and micronutrients in mean crop yields.

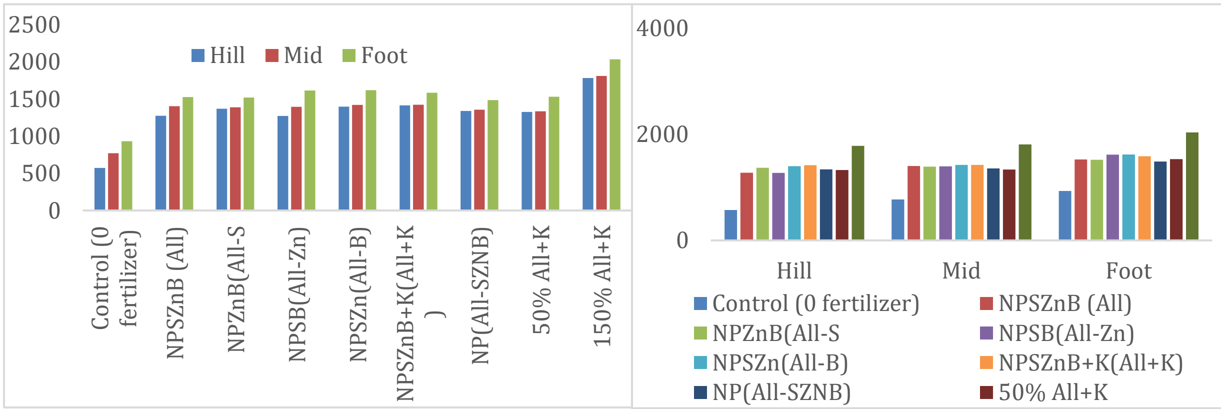
- All the fertilizer treatments gave significantly higher sorghum grain yields than the control treatment without fertilizers for the early-maturing sorghum varieties evaluated in the trials. On the other hand, late-maturing, local cultivars grown by farmers are less responsive to fertilizer application.
- Sorghum yield increments of about 37% and 21% were achieved at foot slope position compared to hill and mid-slope positions, respectively.
- There was a clear trend along landscape positions: higher yield response on lower slope positions and lower yield on hill slope positions. This is due to variations in soil depth, nutrients, and moisture retention characteristics of the soils. This will require determination of appropriate type and optimal fertilizer rates based on soil fertility status, rainfall condition, landscape position, and cultivars.
- In some areas, teff and wheat yields (even with the optimal nutrient levels) were very low. These areas are assumed to be acidic, and their response to fertilizers will not be economical unless reclamation measures are taken prior to planting and fertilizer application. These results indicate that fertilizer packages should be integrated with other soil health management practices, such as liming, for better yield of crops.
- This study provides general information on the response of crops to different fertilizer formulations. Further field research is needed to develop a comprehensive protocol on fertilizer response based on spatial variability of soil and topographic features and crop yield along the landscape.

Farmer-Led Demonstration of New Farm Technologies: What Next ?

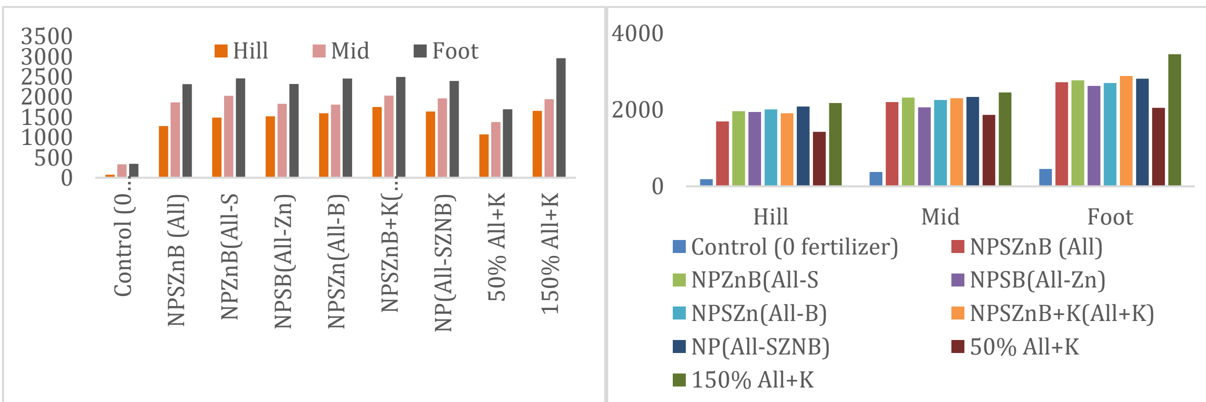
Girmay Fikadu observes the results of the teff trials.

A fundamental question in developing new agricultural technologies is how we ensure the new technologies reach farmers to realize the intended welfare gains. The same question was also on the mind of Mr. Girmay Fikadu, a smallholder farmer who participated in conducting balanced fertilization trials for teff in his farm plots in Sekota District, Ethiopia. Mr. Fikadu was excited about participating in the trials and the results so far, as he could see the plant growth and vigor of his fertilized teff plots from his traditional farming plots. He said, "I visit my plot frequently to see how the different plots perform, and I am happy so far and will select the best plots of fertilizer combinations after looking at the grain yields." Now, Mr. Fikadu wants to know how quick he or his farming community can get their hands on the demonstrated technologies for scaling! He commented: "You researchers are good at bringing new technologies to test them in our fields and show us that they are promising, but we could not get that product in the market the following year. Will it be the same for this trial too?" Other farmers must have this same question. Hence, a critical requirement to achieving our goal of targeted recommendations is ensuring the availability and accessibility of the innovative products. The SOILS Consortium is making sure that work is being done alongside national partners – EIAR and Ministry of Agriculture and Extension – from the beginning to reduce this technology transfer gap to ensure ease of access to farming communities.

Teff



Wheat



Sorghum

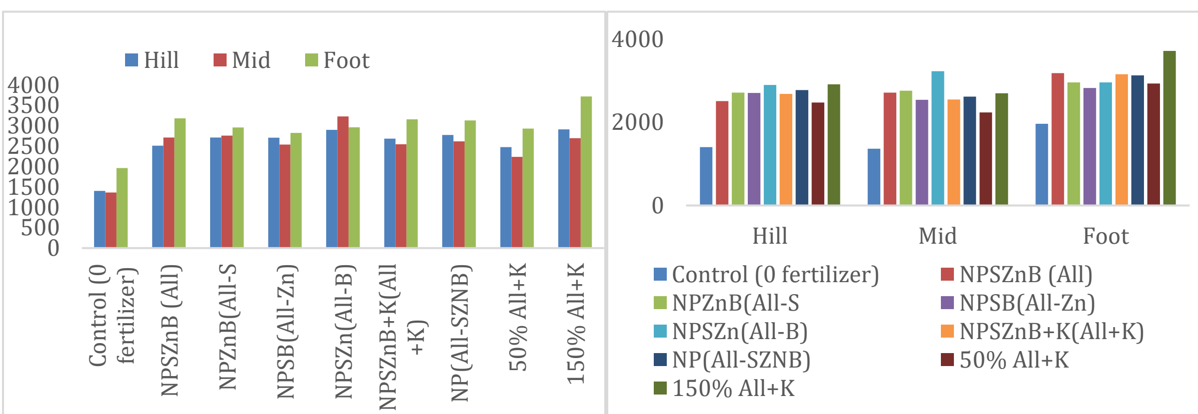


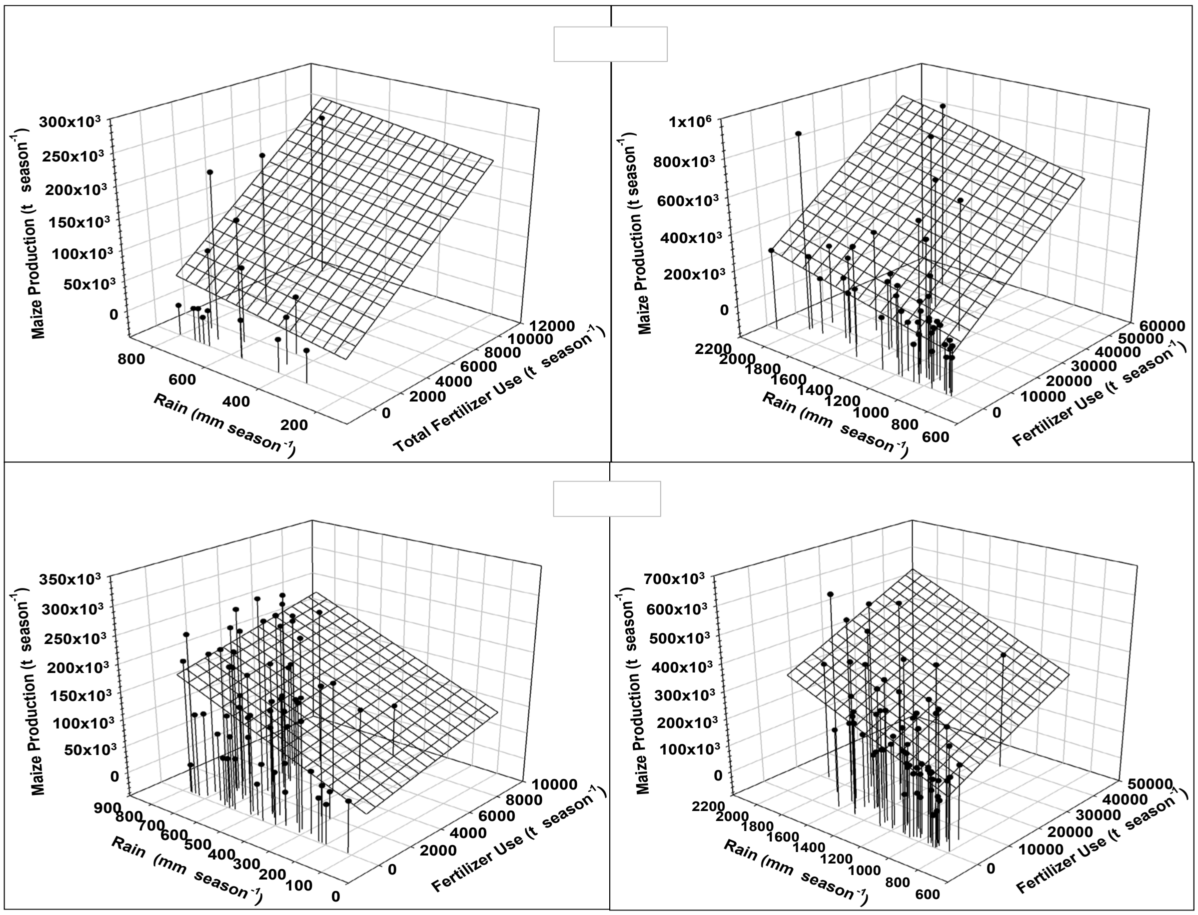
Figure 36. Response of teff, wheat, and sorghum to application of different nutrient combinations in three landscape positions in Ethiopia.

3.2.1 (B) Multivariate Analysis and Interpretation of *Past Data*

Previous data and reports on water and nutrients were also used as the most critical determinants of crop yields. The goal of this activity is to assess the yield trends of the three major crops (teff, maize, and wheat) across years and locations in the two major regions of the country (Amhara and Oromia) and identify the effect of different yield-limiting factors.

Progress:

Fifteen years of data on crop production and fertilizer use trend data from the Central Statistical Agency was compiled, analyzed, and interpreted. Results indicate that productivity of maize, teff, and wheat is affected by rainfall pattern and amount, amount of fertilizer used, and their interaction (Figure 37 and Annex Figure 2). Therefore, climatic variability must be considered in the targeted use of fertilizer and other improved technologies to improve productivity in decision-making at the farm level. A manuscript submitted to Sustainable Agriculture Research journal has been accepted for publication (https://doi.org/10.5539/sar.v10n3p1).



Significant coefficients are marked with an asterisk.

Figure 37. Maize production as affected by fertilizer use and rainfall under dry and wet climatic conditions in the Amhara and Oromia regions of Ethiopia during 2004-2019.

Historical data from fertilizer response trials relevant to the objectives of this research are being compiled and will also be reviewed with the intent of integrating such data into our model. Special attention was paid to collecting data from EthioSIS, EIAR, regional agricultural research institutes (RARIs), universities, and CGIAR centers that have a set of minimum characteristics that would allow integration. So far, 15,462 data points have been compiled from different sources (publications, IFDC, ICRISAT, CIAT, and CIMMYT databases) on crop response data conducted in different crops, locations, and years (Annex). Discussions are ongoing to get more data from national and regional research institutes through the Coalition of the Willing (CoW) initiative. This shared database of past datasets, plus this current year's datasets, will be the bases for our next steps of designing a unified research. The data may also be used to identify representative sites, monitor changes over time, and identify responsive and non-responsive spots within the landscape, thus augmenting the newly generated data for developing decision tools and fertilizer recommendation domains. The IFDC and ICRISAT teams have combined their datasets. Cleaning and organization of the combined data is in progress – details can be found in the link here: Annex.

3.2.2 Development, Refinement, and Evaluation of Teff Model under Ethiopian Conditions

Site- or farming system-specific management recommendations that build on existing data are critical to sustainably intensifying Ethiopian cropping systems as the foundation for food and nutrition security and economic growth. However, critical knowledge gaps exist for Ethiopia's most important crop: teff. The goal of this activity is to develop and evaluate the teff model for effects of N response, plant population, and flooding/waterlogging on growth, development, and nutrient status on teff.

Activities: Teff model development, refinement, and evaluation using data from ongoing (Activity 3.2.1) and past teff trials and collation, ground truthing, georeferencing and correlation of soils data from various sources for running the teff model.

Partnership: Ethiopian Institute of Agricultural Research (EIAR), Regional Agricultural Research Institutes of Amhara, Tigray, Oromia, and Southern Regions, CASCAPE project, ICRISAT, CIAT, EiA.

Progress:

Three different greenhouse experiments were conducted at IFDC HQ to quantify the effect of N rate, plant population, and waterlogging stress on yield and yield components of teff. Data on yield and yield components were collected at different stages. The trials were harvested, and the required data collected. Grain, straw, root, and soil samples are being analyzed in the IFDC HQ laboratory for their nutrient contents. The results on yield and yield components are presented below for each experiment.

a. Nitrogen Rate

Previous experiments in Ethiopia studying the effect of N rate were conducted only applying P and assuming other nutrients to be supplied from the soil. But the soil data show that other nutrients besides P could be limiting yield. To test the effect of five different levels of N under optimal application of other nutrients, a total of 48 pots were prepared and planted. The grain and straw yield are presented in Figure 38. The preliminary results indicate that both straw and grain yields of teff were significantly improved due to application of N. Grain yield continued to increase until reaching 150 mg/kg N and then decreased, while straw yield increased with an increasing N rate. Application of 150 mg/kg N increased grain yield by 110%. Straw yield was increased by 70% and 89% due to application of N at 150 mg/kg and 200 mg/kg, respectively.

Figure 38. Effect of N fertilizer rates on teff growth and yield

b. Plant Population

Teff is normally planted using broadcast seeded application. But recently, row planting and transplanting technologies were introduced, and farmers are adopting these technologies. Broadcasting results in high plant density, making plants susceptible to lodging with significant yield loss. To determine the optimal population of teff, we planted four different planting densities (80-1,000 plants/m^2 or 2-50 plants/pot) and two high-yielding teff varieties. A total of 32 pots were established. The preliminary results indicate that the two varieties respond differently to the effect of plant populations. The overall trend shows yield started to decline as the population goes beyond 25 plants/pot.

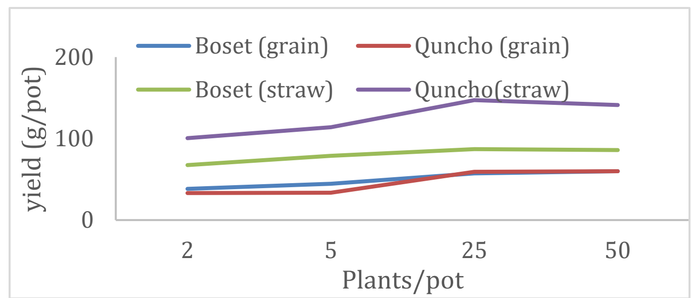


Figure 39. Effect of plant population on grain

c. Waterlogging

Previous reports indicate that teff is a crop that tolerates extreme weather conditions. However, there was no known research showing how long teff can tolerate the waterlogged conditions beyond the short duration seasonal waterlogging. To determine this, teff was tested under five different waterlogging durations, from upland to waterlogged during the entire growing season. An interesting result not previously reported was that teff, just like rice, can be grown from transplanting to maturity under flooded conditions with no significant reduction in yield.

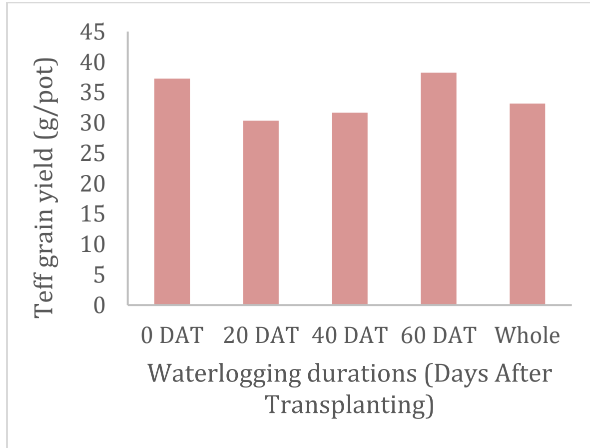


Figure 40. Teff grown under fully upland to fully flooded conditions.

Data from the “Targeting Fertilizer Source and Rate in Ethiopia” activity will be used for model validation and application.

Table 15. Workstream 3: Sustainable Opportunities for Improving Livelihoods with Soils (SOILS) Consortium

	Workstream 3	Activity	Deliverable	Partnership	Progress (October 2020-March 2021)	Research Phase (1-4)
3.1	**NIGER : Enhance Resilience to Food Insecurity and Conflict through Land-Use Planning, Soil Rehabilitation, and Capacity Building**					
3.1.1	Remote and On-the-Ground Land-Use Suitability Analysis to Guide Decision Making in Niger	Develop land-use planning maps in Niger that provide land capability classifications to guide commune-and/or individual-level decision making about appropriate land management.	Initial overlay for land capability classification, partial validation of LCC with remote sensing data, validated LCC map of the target Zones of Influence	SOILS Consortium, IFDC-Niger, Colorado University, INRAN	COMPLETED https://doi.org/10.3390/land10050458	II
3.1.2	Remote Sensing and Use of Soil Data	Ground truthing to calibrate LandPKS.; Socio-economic analysis using Niger LSMS-ISA data.; Household survey preparation and data collection; Household survey analysis. Microdosing, FDP, and activated PR studies.Final workshops and training with LandPKS.	Protocol development and implementation, list of soil categories in Niger, current farmer soil fertility management and soil water conservation practices documented and mapped, and soil key, demographic, and socio-economic determinants identified	Michigan State University, Colorado University, Auburn University, ICRISAT-Niger, INRAN, SOILS Consortium, IFDC-Niger	IN PROGRESS	II
3.1.3	Analysis of Digital Extension Platforms, Tools, Approaches and Services in Niger	1. digital extension landscape analysis in Niger; 2. Analyze effectiveness of the extension platforms, tools, approaches, and services in providing information to farmers 3. Recommendations to strengthen digital extension platforms in Niger.	Assessment report	DLEC, SOILS Consortium, INRAN, IFDC-Niger	COMPLETED https://www.digitalgreen.org/wp-content/uploads/2017/09/DLEC_Analysis-of-Digital-EAS-in-Niger-1.pdf	
3.1.4	Promoting Activated PR Using Local PR Sources and Producers	1. A three-cropping system greenhouse trial with fresh and residual P applications	Long-term evaluation report and publication	Private sector, IFDC's Pilot Plant	In Progress	I

Workstream 3		Activity	Deliverable	Partnership	Progress (October 2020-March 2021)	Research Phase (1-4)
		2. Validating and promoting activated PR using local sources	Field validation, reports; discussion paper on the future of activated PR use in SSA, in partnership with industry and government stakeholders	Private sector, NARES	Begin in July 2021	II
3.2	**ETHIOPIA: Enhancing Productivity and Food Security in Ethiopia through Improved Soil Fertility Management**					
3.2.1	Decision Support Systems for Improved Access to Soil Fertility Information and Farming Practices	1. Georeferenced nutrient response trials on teff, wheat, and sorghum conducted across target farming systems. 2. Partner meetings to develop a common protocol used across multiple institutions. 3. Compile data from past and present datasets for multivariate analysis.	1. A combined national fertilizer crop response dataset 2. A common protocol to be adopted by all stakeholders conducting fertilizer research in the country. 3. A smartphone- and paper-based nutrient management recommendations tool	SOILS Consortium, ICRISAT, IFDC-East Africa, Excellence in Agronomy (EiA) of the CGIAR, (EARCS), (EIAR), CASCAPE project, GIZ, (CIAT)	2020 field trials on wheat, teff and sorghum completed. Soil analyses in progress. 2021 maize trials to begin June.in progress. https://doi.org/10.5539/sar.v10n3p1	II
3.2.2	Development, Refinement and Evaluation of Teff Model under Ethiopian Condition	Teff model development, refinement, and evaluation using data from ongoing (Activity 3.2.1) and past teff trials and collation, ground truthing, georeferencing and correlation of soils data from various sources for running the teff model.	1. Teff model included within DSSAT suite of models. 2. Publications on development and applications of the teff model. 3. National soils and weather database.	(EIAR), Regional Agricultural Research Institutes of Amhara, Tigrai, Oromia and Southern Regions, CASCAPE ICRISAT, CIAT, EiA	Teff model to be released by Sep 2021. GH trial completed with data analyses in progress. Finding: ability of teff to thrive under fully submerged conditions for entire growing season.	I

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

4.1 Centralized Database and Improving the DSSAT Cropping System Model for Soil Sustainability Processes (Cross-Cutting)

Since March 2019, IFDC, in partnership with the University of Florida, has used and adapted the database platform developed for the global Agricultural Model Intercomparison and Improvement Project (AgMIP), which is being added to a new infrastructure of multiple databases developed internally. The partnership with the University of Florida will also improve the existing soil dynamics model in the Decision Support System for Agrotechnology Transfer (DSSAT) Cropping System Model (CSM) 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.

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

The IFDC data management and sharing services are organized based on FAIR principles, i.e., easily findable, accessible, interoperable (compatibility of systems), and reusable. The IFDC database is being developed to be compatible with CGIAR and USDA data platforms.

Activities: (a) Collect, prepare, and upload experimental data
(b) Execute improvement and maintenance on the database interface and search engine
(c) Conduct training activities to prepare IFDC personnel to interact with the system and upload and retrieve data. The training program will be conducted on all aspects of database management and use at HQ and at selected locations in Africa or Asia.

Location/Timeline: HQ and global field programs/March 2020-September 2021

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

Progress:

The IFDC database platform was redesigned and expanded, providing new features to import, export, search, visualize, and maintain different data types (raw data, papers, documents, manuals, photos, weather data, etc.). Based on the FAIR principles, the system is being developed and constantly updated to support data interchange between different and heterogeneous projects and institutions. Containers, Docker, and Kubernetes are being used to improve the system for automatic deployment, scaling, and management. The current platform runs as microservices and containers, making the platform expandable and replicable.

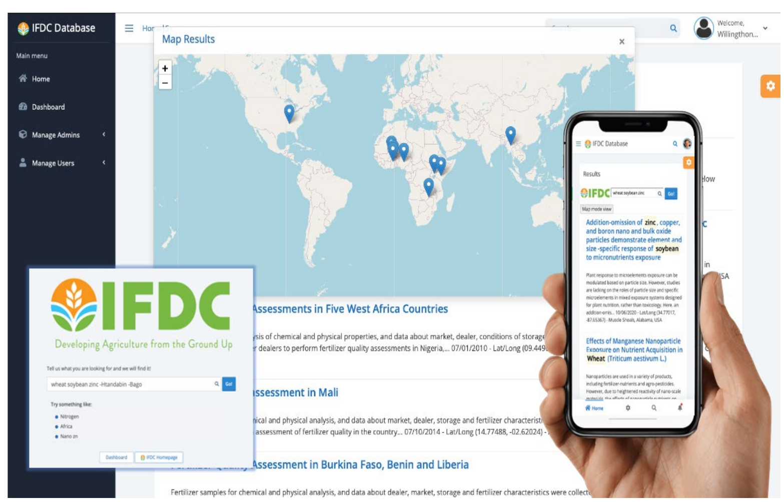


Figure 41. New user-friendly data discovery portal.

A new responsive and user-friendly interface was implemented to make data uploading far more agile, so the database is accessible for researchers to upload their data or consult data generated by other researchers. The search engine is being implemented, based on a standalone full-text search server, to provide an enterprise search and analytic solution.

The new interface (Figure 41) allows users to search text data uploaded to the database; shortly, users will also be able to search all stored PDFs, documents, pictures, and spreadsheet files. Public and global weather data acquisition will be facilitated for IFDC researchers, who will provide the location or areas of interest. Crop simulation runs are facilitated by the interface, using the data stored in the database or accessible through many organizations' platforms, where the results will be presented in user-friendly geographical interfaces.

A new feature was incorporated to the system: a worldwide monthly climate data Application Program Interface (API), with 2.5 minutes of resolution. The data provided by the API is a combination of the WorldClim 2.1 and the MarkSim database. Based on latitude and longitude, applications can grab the data needed and proceed with internal calculations, like the Phosphate Rock Decision Support System (PRDSS) software. The API is currently available through the following URL prototype: http://dev.ifdc.org:3000/{latitude}/{longitude}/{gddTBase}/{months}, where "latitude" and "longitude" are the decimal coordinates of a specific location, the base temperature is for Growing Degree Days calculation (default is 5), and "months" is an optional, dashed separated list with the desired months to include in the result (e.g. 01-07-12 for January, July, and December; or empty for all months). A functional URL would be http://dev.ifdc.org:3000/-28.26278/-52.40667/5/01-07-12, which results in a JSON object with totalized and monthly information.

The centralized platform allows the integration between IFDC and partners' different solutions, like PRDSS, GSSAT, Pythia (parallel crop simulation computing), Field Data Acquisition System, DSSAT, etc. Traditionally data acquisition procedures from experiments go through several steps that make them inefficient, expensive, and non-standardized. Usually, these procedures involve manual activities and several transcriptions of the data. Efforts are being made to collaborate and integrate different tools from CGIAR Big Data and IFDC Centralized platforms to make the data acquisition from experiments and labs standardized and more efficient in terms of significant reduction of the time, making the data accessible to researchers and reducing the probability of errors in the data.

4.1.2 DSSAT Cropping System Model Improvement and Application ***(Ongoing)***

Crop simulation models are widely used for fertilizer recommendations, yield gap analysis, climate change impact, adaptation, and mitigation. However, models' performance can be questionable in low fertility soils with low soil organic matter content and multiple nutrient deficiencies. The objective of this ongoing activity initiated under the university partnership program with the University of Florida is to refine and further develop the critical components of the DSSAT CSM.

Activities: (a) Refine and further develop the soil C dynamic and soil C balance in low soil organic matter soils.
(b) Develop nitrous oxide emission module using the improved soil C module and GHG emission data from IFDC's greenhouse and field research (completed).
(c) Simulate response of enhanced efficiency N products on yield, N losses, and crop N accumulation.
(d) Make improvements to the rice plant growth model to capture extreme temperature and drought stress (completed).
(e) Evaluate and disseminate improved tools through joint international training programs.

Location/Timeline: HQ; October 2019-September 2021

Partnership: University of Florida, University of Passo Fundo, Sustainable Opportunities for Improving Livelihoods with Soils (SOILS) Consortium partners in Ethiopia and Niger

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

Progress:

1. Parallel computing solution

A parallel computing solution was prepared to support studies for different scenarios. It was developed based on DSSAT requirements input data (weather, soil, harvesting area, management) and organized in a grid format. To run the models in parallel, the DSSAT-Pythia was used (a tool developed by DSSAT/UFL/IFDC to run spatial simulations based on present coordinates). To visualize and explore the results, a visual user-friendly GIS Web-based interface was developed in R Shiny (Figure 42). The data sources for this project are:

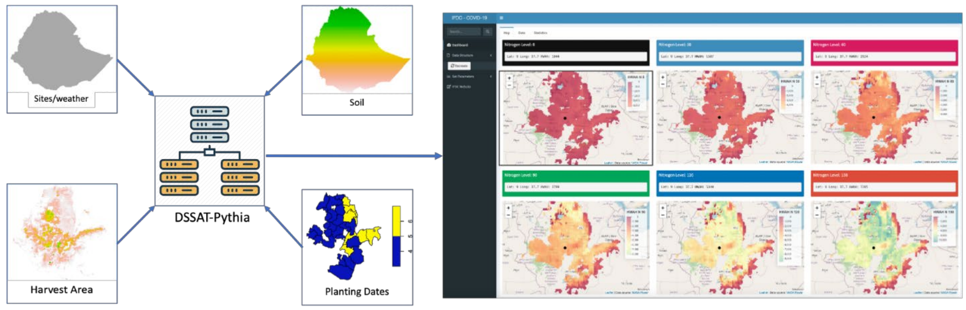


Figure 42. Parallel computing solution.

1. Weather from NASA Power and Climate Hazards Group InfraRed Precipitation with Station Data.
2. Soils from Global High-Resolution Soil Profile Database for Crop Modeling Applications.
3. Sowing areas from Global Spatially Disaggregated Crop Production Statistics Data for 2010 Version 2.0.

Strategies for treatments organization and run can be: (a) planting windows (in days); (b) irrigated or rainfed experiments; (c) different fertilizer levels of Nitrogen; (d) different Crops and cultivars; and (d) the number of simulation years (weather data available from 1984 to present).

2. Phosphate Rock Decision Support System – PRDSS

The Phosphate Rock Decision Support System (PRDSS) is a web-based tool used to predict the relative agronomic effectiveness (RAE) of phosphate rock (PR) compared to water-soluble P (WSP) fertilizers. Initially, developed jointly by FAO/IAEA and IFDC, the PRDSS offers the option to evaluate the agroeconomic feasibility for the use of PR under their farming conditions.

During the October 2020-March 2021 period, PRDSS was redesigned and re-implemented, providing a better user experience and new features. It was developed using new and modern technologies like Next.js, JavaScript, react, prime react, CSS, etc. The new PRDSS is currently available at https://prdss2.ifdc.org. It is a lightweight and progressive web application (PWA) intended to work on any platform that uses a standard-compliant browser, including both desktop and mobile devices (Figure 43).

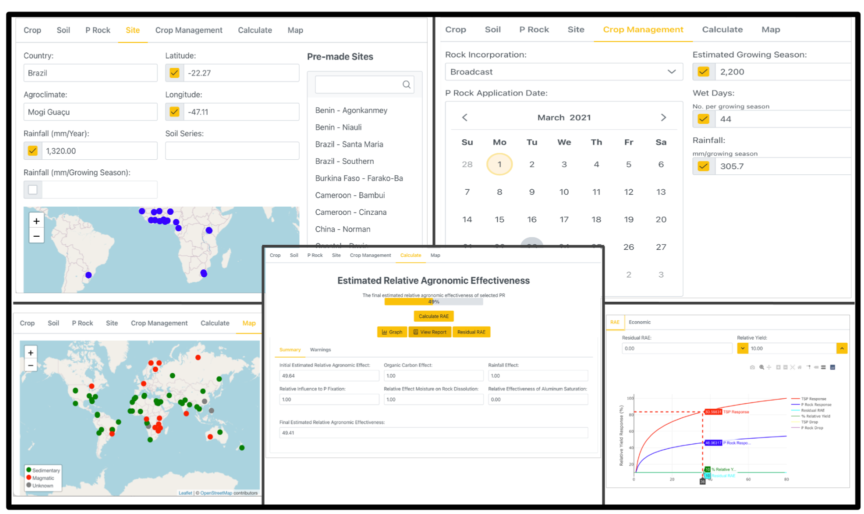


Figure 43. Phosphate Rock Decision Support System web interface.

One of the new features implemented allows users to select any site with just a click on a map, feeding the system automatically with historical weather data (like growing season rainfall and number of rainy days), allowing them to run and get outputs to help on decision-making. An agroeconomic feasibility indicator for substitution of PR for soluble P is given using a fertilizer price-ratio (price of WSP/price of PR) and RAE or substitution values (kg of WSP/kg of PR for a specific relative yield).

4.1.3 Refine and Evaluate the Interactive Geospatial Crop Modeling and Decision Support Tool (GSSAT) (Ongoing)

The interactive spatial crop modeling and decision support tool (GSSAT) is the Graphical User Interface to the DSSAT CSM with extended functionality.

Activity: (a) Improve the GSSAT (GIS-based DSSAT) spatial modeling platform. (b) Update GSSAT database using soil characterization data generated in northern Ghana and other IFDC projects in SSA (specifically, Burkina Faso and Benin and Ethiopia) through SOILS Consortium activities (see Workstream 3). (c) Evaluate the fertilizer recommendation capability of GSSAT in selected countries.

Partnership: University of Florida, University of Passo Fundo, SOILS Consortium partners in Ethiopia

Outcome: Decision support tools to help in making timely and reliable recommendations at spatial scale (farm, regional, national) on fertilizers, sowing dates, and other management inputs covering a wide range of biophysical and socioeconomic conditions.

Progress: Activities on GSSAT are scheduled from May-September 2021 and will be reported in the next reporting.

4.2 Workstream 3: Cross-Cutting Activities

Agriculture Technology Park (ATP) in Niger (in progress)

One of the key activities under SOILS Consortium is to improve in-country research capacities on soil fertility technologies and thus improving the accessibility of technologies by farmers, extension actors more effectively. In this context, agriculture technology parks play a key role, serving as local centers of excellence, allowing NARES to improve their research capabilities through effective regional collaborations, and also able to show-case technologies effectively. The setting up the Agriculture Technology Park (ATP) also helps to increase the adoption of agricultural Technologies & Innovations (T&I) available for the transformation of the agricultural sector. Specifically, enables (i) to showcase promising technologies ready to go for end-user's utilization and (ii) attract private firms for mass production of the technologies to avail them at affordable cost. The technology park, in the context of the iREACH initiative[3], is understood to be a space where cutting-edge technologies and innovations in the agricultural value chain are exhibited or full-scale demonstrations set up in the form of showcases where stakeholders can learn about them with the possibility of appropriating them to improve their own production systems. Similar models have been reported in Cambodia (http://www.cesain.org/en/where-we-are/technology-park) and in Laos (Hao and Ying, 2018).

iREACH envisages a future where CORAF is strengthened to meet the objectives of its strategic plan more widely with its broad range of partners throughout the region. The iREACH's three core objectives are to: (i) Improve coordination, alignment and integration of relevant activities; (ii) Create and strengthen technology parks and facilitate effective flow of information and innovations and (iii) Build human and

[3] The Innovation Research, Extension and Advisory Coordination Hub (iREACH) was co-created to respond to the need for better coordination, information sharing, collective engagement, and alignment of activities to increase the efficiency. The contributing partners for iREACH include CORAF, USAID-DC, USAID-West Africa Missions, Sustainable Intensification Innovation Lab, other FtF's innovation labs, IFDC, Africa-RISING and other interested partners

institutional capacity. iREACH will initially focus on regions within Ghana, Senegal, Mali, Burkina Faso, and Niger that USAID has prioritized in its Feed the Future and Resilience strategies.

The International Fertilizer Development Center (IFDC), currently implementing USAID-BRFS funded SOILS Consortium activities will be collaborating with iREACH initiative to set up an Agricultural Technology Park (ATP) in Niger.

Outcome: Technology platform collaboration through iREACH to Promote nutrition-smart agriculture through crop-livestock diversification and agronomic and genetic biofortification.

Partnership: INRAN, 3N Initiative, local universities, West and Central African Council for Agricultural Research and Development (CORAF/WECARD), IFDC, SIIL, development partners, private industry, local or regional universities, U.S. land-grant universities, USAID, MCC, World Bank

Progress: IFDC and KSU-SIIL have begun discussions with a CORAF representative and invited them to initiate the technology park initiative in Niger through INRAN.

Table 16. Cross-Cutting Activities: Data systems, Workshops, and Trainings in FY21 (October 2020-March 2021)

Activity	Location	Deliverable	Partnership	Progress (October 2020-March 2021)
Develop IFDC Centralized Database Using AgMIP Database Template	Global, HQ (Ongoing)	(a) Collect, prepare, and upload experimental data; (b) execute improvement and maintenance on the database interface and search engine; and (c) conduct training activities to prepare IFDC personnel to interact with the system, upload, and retrieve data.	Reports, centralized functional database, responsive web application for database interface.	IFDC projects (cost shared), university partnership (University of Florida), AgMIP
DSSAT Cropping System Model Improvement and Application	Global, HQ (Ongoing)	Refine and further develop the soil-water-nutrient dynamics component of the DSSAT Cropping System Model and conduct international training programs	Reports, publications, software, and training programs	University of Florida, University of Passo Fundo, SOILS Consortium partners in Ethiopia and Niger
Refine and Evaluate the Interactive Geospatial Crop Modeling and Decision Support Tool (GSSAT)	HQ, Ethiopia (Ongoing)	Improve the GSSAT spatial modeling platform; update GSSAT database using soil characterization data generated in northern Ghana and Ethiopia	Reports; publications; an improved version of GSSAT; training programs	University of Florida, University of Passo Fundo, SOILS Consortium partners in Ethiopia
Niger Technology Platform with CORAF and INRAN through iREACH	Niger (Soils Consortium) Partnership with iREACH-CORAF in progress.	1. Improve capacity of farmers, research, and extension actors as well as other organizations. 2. Enhance knowledge sharing and data management. 3. Monitoring, Evaluation, and Sharing plan and reporting - common to all three workstreams	Data documentation, field days, reports, technical guide	INRAN, 3N Initiative, local universities, (CORAF/WECARD), IFDC, SIIL, U.S. land-grant universities, USAID, MCC, World Bank

Appendix

Publications

Agyin-Birikorang, S., R. Adu-Gyamfi, I. Tindjina, J. Fugice, Jr., H.W. Dauda, and J. Sanabria. 2021. “Synergistic Effects of Liming and Balanced Fertilization on Maize Productivity in Acid Soils of the Guinea Savanna Agroecological Zone of Northern Ghana.” *Journal of Plant Nutrition*. **Manuscript under review**.

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