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

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Top: Salma Begum, briquetting machine owner, Bangladesh; self-healing polymer coating schema; high-capacity briquetting machine, Uganda. ***Bottom***: COVID-19 Fertilizer Watch weekly bulletin; Nepal rice trials on N-use efficiency.

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List of Acronyms

AAPFCO	Association of American Plant Food Control Officials
AAPI	Accelerating Agriculture Productivity Improvement
AEZ	agroecological zone
AFAP	African Fertilizer and Agribusiness Partnership
AFO	AfricaFertilizer.org
AFRAD	Supported Crop Fertilization for Sustainable Agriculture in Niger
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
AGRIFOP	Agribusiness-Focused Partnership Organization
APEX	Agricultural Policy/Environmental eXtender
ARS	Agricultural Research Service
AS	ammonium sulfate
ASABE	American Society of Agricultural and Biological Engineers
ASAL	arid and semi-arid
B	boron
BAME	Bureau d'Analyses Macro-Économiques
BARI	Bangladesh Agricultural Research Institute
BAU	Bangladesh Agricultural University
BCIC	Bangladesh Chemical Industries Corporation
BDT	Bangladeshi Taka
BINA	Bangladesh Institute of Nuclear Agriculture
BPCU	bio-based polyurethane-coated urea
BRRI	Bangladesh Rice Research Institute
C	carbon
Ca	calcium
CA	conservation agriculture
CASC	Conservation Agriculture Service Center
CASCAPE	Capacity Building for Scaling up of Evidence-based Best Practices in Agricultural Production of Ethiopia
CEC	cation exchange capacity
CE SAIN	Center of Excellence on Sustainable Agriculture Intensification and Nutrition
CIMMYT	International Maize and Wheat Improvement Center
CIRAD	Centre de Coopération Internationale en Recherche Agronomique pour le Développement
CNLS	Crop Nutrition Laboratory Services
CO_2	carbon dioxide
CoE	Center of Excellence
COMRAP	COMESA Regional Agricultural Inputs Programme
CORAF/WECARD	West and Central African Council for Agricultural Research and Development
CRH	critical relative humidity
CT	conventional tillage

Cu	copper
DAE	Department of Agricultural Extension
DALRM	Department of Agricultural Land Resources Management
DAP	diammonium phosphate
DAT	days after transplanting
DDGS	dried distillers' grains plus solubles
DLEC	Feed the Future Developing Local Extension Capacity Project
DSSAT	Decision Support System for Agrotechnology Transfer
DST	Decision Support Tool
EiA	Excellence in Agronomy
EIAR	Ethiopian Institute of Agricultural Research
EnGRAIS	Enhancing Growth through Regional Agricultural Input Systems (project)
ES	elemental sulfur
EthioSIS	Ethiopian Soil Information System
FAIR	findable, accessible, interoperable, and reusable
FAK	Fertilizer Association of Kenya
FAO	Food and Agriculture Organization of the United Nations
FAR	Food security through climate Adaptation and Resilience in Mozambique
FDP	fertilizer deep placement
Fe	iron
FTF	Feed the Future
FY	fiscal year
GDA	General Directorate of Agriculture
GHG	greenhouse gas
GSSAT	Geospatial Decision Support System for Agrotechnology Transfer
HNS	hollow nano-silica
HQ	Headquarters
HWSD	Harmonized World Soil Database
HYV	high-yielding variety
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
INRAN	Institut National de la Recherche Agronomique du Niger
IRRI	International Rice Research Institute
ISA	Integrated Surveys on Agriculture
ISFM	integrated soil fertility management
ISO	International Organization for Standardization
IZA	International Zinc Association
K	potassium
KALRO	Kenya Agricultural and Livestock Research Organization
KeFERT	Kenya Fertilizer Platform
KGF	Krishi Gobeshona Foundation
KMT	Kenya Markets Trust
KSU	Kansas State University
LandPKS	Land-Potential Knowledge System
LCC	Land Capability Classification

LSMS	Living Standards Measurement Study
LTAR	Long-Term Agroecosystem Research
MAP	Monoammonium Phosphate
MCA	Millennium Challenge Account
MCC	Millennium Challenge Corporation
Mg	magnesium
MoA	Ministry of Agriculture
MoALD	Ministry of Agriculture and Livestock Development
MOFA	Ministry of Food and Agriculture
MSU	Michigan State University
N	nitrogen
NARC	Nepal Agricultural Research Council
NARCS	National Agricultural Research Council Secretariat
NARES	National Agricultural Research and Extension System
NARS	National Agricultural Research Systems
NAS	National Academy of Sciences
NDVI	Normalized Difference Vegetation Index
NP	nanoparticle
NSAF	Nepal Seed and Fertilizer
NV	native vegetation
OSAM	open systems agricultural machines
P	phosphorus
PARSEN	Fertilizer Sector Reform Support Project in Niger
PB	Peanut Basin
PCU	polymer-coated urea
PEER	Partnerships for Enhanced Engagement in Research
POXC	potassium permanganate oxidizable C
PR	phosphate rock
PRDSS	Phosphate Rock Decision Support System
PTWG	Policy Technical Working Group
QA	quality assurance
QC	quality control
QUEFTS	Quantitative Evaluation of the Fertility of Tropical Soils
RAPID	Resilient Arid Lands Partnership for Integrated Development
RARI	regional agricultural research institute
RF	recommended fertilizer rate
RFS	Bureau for Resilience and Food Security
RP	recommended practice
RUA	Royal University of Agriculture
S	sulfur
SA	sodium alginate
SARI	Savanna Agricultural Research Institute
SBPCU	self-assembling modified bio-based polyurethane-coated urea
SEMEAR	Feed the Future Improved Seeds for Better Agriculture (project)
SFT	Soil Fertility Technology
SIL	Soybean Innovation Lab
SIIL	Innovation Lab for Collaborative Research on Sustainable Intensification

SMaRT	Soil testing, Mapping, Recommendations development, and Technology transfer
SOC	soil organic carbon
SOILS	Sustainable Opportunities for Improving Livelihoods with Soils
SRI	intensive rice cropping system
SRD	Senegal River Delta
SRDI	Soil Resources Development Institute
SSA	Sub-Saharan Africa
SSBPCU	self-assembling and self-healing bio-based polyurethane-coated urea
SWAT	Soil and Water Assessment Tool
TAFAI	The African Fertilizer Access Index
TSP	triple superphosphate
UCF	University of Central Florida
UDP	urea deep placement
UDS	University for Development Studies
UF	University of Florida
UNADA	Uganda National Agro-Input Dealer Association
USAID	U.S. Agency for International Development
USDA	U.S. Department of Agriculture
WAAPP	West Africa Agricultural Productivity Program
WRB	World Reference Base
WSP	water-soluble phosphate
WUR	Wageningen University and Research
XRF	X-ray fluorescence
Zn	zinc
ZnO	zinc oxide
ZnO-NP	zinc oxide nanoparticle
ZOI	zone of influence

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

Semi-Annual Report FY2020
April 2020 – September 2020

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. In March 2015, USAID and IFDC entered into a new 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 Feed the Future countries by developing more nutrient-efficient, profitable technologies, supporting related markets and policies, and strengthening country partner 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. The activities under the RFS-SFT project focus on the key result areas described below and continue to contribute to major intermediate outcomes – phases of research and peer-reviewed publications.

Basic principles of engagement under RFS-SFT: All the research activities under SFT engage women and youth farmers and entrepreneurs in all phases of research, deployment, and capacity building. Most of the technologies developed and disseminated through the SFT project are inclusive and effectively engage women, youth, and other minority people. Soil fertility technologies and practices are carefully developed from the research to uptake stages to be gender neutral to gender friendly and transformative. Other key features of all the SFT activities 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 ready 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 FY2020: Activities are implemented in the following countries to generate technologies, practices, and policies with broader geographic coverage, suitability, and scalability.

Asia: Bangladesh, Nepal, Myanmar (using FY2017 funds)

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

West Africa: Senegal, Burkina Faso, Ghana, Niger, Nigeria

As part of the work planning process under the RFS-SFT project since FY2019, IFDC has initiated engagement with country-level missions to obtain concurrence for research activity implementation, funded by the RFS central mechanism. So far, RFS-SFT has received concurrence from four missions in East and Southern Africa, Kenya, Uganda, Rwanda, Mozambique; two in South Asia, Bangladesh and Nepal; and two in West Africa, Niger and Nigeria. IFDC has regularly reported the progress of RFS-SFT activities to these missions since early 2019. We further plan to expand this to other countries where we are engaged through RFS-SFT project activities. The activities under the current work plan (FY2020) reflect three workstreams (**Error! Reference source not found.**), including SOILS Consortium-related r esearch as Workstream 3, contributing to the FTF Soil Fertility Technology Adoption, Policy Reform, and Knowledge Management (RFS-SFT) project.

Table 1. FTF Soil Fertility Technologies (RFS-SFT) 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							
Improving the Decision-Making Tools for Cropping System Model for Soil Sustainability Processes							
University Partnerships, Capacity Building, Workshops							

**From March 2019 onward*

Under **Workstream 1**, IFDC continues “**Developing and Validating Sustainable Agricultural Intensification Technologies and Practices**,” addressing nutrient management issues and advancing sustainable agricultural intensification in FTF countries. Workstream 1 activities concluding in FY2019 and those beginning in FY2020 are summarized in Section 1 and Table 8.

Under **Workstream 2**, IFDC supports “**Policy Reform Processes, Advocacy, and Market Development**.” Relevant research will be conducted to support IFDC’s global activities related to agricultural policy reforms, advocacy for change, and related efforts to achieve impact in FTF countries’ agriculture. Workstream 2 activities are summarized in Section 2 and Table 9.

Under **Workstream 3**, IFDC supports activities under the **SOILS Consortium**, initiated by IFDC in collaboration with the Innovation Lab for Collaborative Research on Sustainable Intensification (SIIL) at Kansas State University (KSU), with support from USAID-RFS. The SOILS Consortium also partners with a host of U.S. academic research entities from Michigan State University (MSU), University of Colorado, Auburn University, and USDA-ARS. SOILS Consortium partners will further engage in identifying research activities that offer holistic solutions to developing a roadmap toward enhancing soil fertility in selected countries. The objectives and research activities to be carried out through Workstream 3 are presented in Section 3 and Table 10.

Cross-cutting activities that include activities associated across all three workstreams above, such as monitoring, evaluation, learning, and knowledge management and outreach-related activities, are described in Section 4 and Table 11. These include data management systems and tools, outreach activities with partner organizations, training, and capacity building initiatives.

Activity Highlights during the FY 2020

- N Use Efficiency: Urea coated with zinc oxide (ZnO) nanoparticles and dual-capped Zn-based nanoparticles were formulated and evaluated under greenhouse conditions. Enhanced crop productivity with lower nano-ZnO highlights a key benefit of nanofertilizers: reduction of nutrient inputs into agriculture without yield penalties. In addition to overcoming the potential for drift with application of nanofertilizers at field scale, coating of urea also improved N use efficiency through reduced N loss and improved plant N uptake.
    - Various improved N use efficiency products and technologies, including controlled-release urea, urea with elemental sulfur, and urea deep placement (UDP), were evaluated under field conditions in Bangladesh, Burkina Faso, Burma, Ghana, and Nepal, confirming greenhouse findings of improved yield and lower use of N fertilizers compared to conventional sources and practices. Field trials with UDP also showed improved crop resilience under drought, saline, and submergence conditions.
    - During the past 12 months, our research team had six journal articles published on improved nitrogen use efficiency and greenhouse gas (GHG) emissions.
- Activated PR: Under greenhouse and field conditions and through on-farm demonstrations, we showed that low reactivity phosphate rock (PR) in combination with only 20-25% water-soluble P, such as diammonium phosphate (DAP) or monoammonium phosphate (MAP), gave similar yields as the 100% water-soluble P. This intervention on activated PR allows the use of local PR deposits that are economically not viable for conventional P fertilizer production in many Feed the Future countries. Activated PR is effective on a wide range of soils (pH 5-8) and crops.
    - A private company is evaluating the production of activated PR in Angola and a potential public-private partnership for Tahoe phosphate rock in Niger.
- Balanced Crop Nutrition: Greenhouse evaluation of urea coated with ZnO and zinc sulfate ($ZnSO_4$) gave similar sorghum grain yield and Zn uptake as urea and blends of Zn uniformly applied. These results confirmed the results of soil incubation studies showing that urea-Zn interactions within the coated urea granule did not reduce bioavailability of Zn. However, $ZnSO_4$ granulated with MAP gave significantly lower yield and Zn uptake, indicating that bioavailability of Zn was compromised. In addition to improving N use efficiency (reduce ammonia loss), micronized elemental sulfur (ES) with urea across field trials in Bangladesh, Burma, Ghana, and Nepal gave significantly higher yields or similar yields and higher grain protein content than conventional sulfate fertilizers. For residual trials (with no new application of S fertilizers), ES gave a significantly higher yield, highlighting its greater efficiency (yield, S uptake, and reduced sulfate leaching) compared to ammonium sulfate. Nutrient omission and balanced fertilization trials in Bangladesh, Ghana, Kenya, and Nepal demonstrated the significant yield advantage of balanced fertilization, either as blends or

compounds, over NPK, with an average increases in yield of 11-36% compared to NPK or NPK + manure.
  - Updated fertilizer recommendations are being shared with stakeholders.
  - Fertilizer quality also plays a critical role in adoption and rate of fertilizer use. Unfortunately, a lack of quality labs for fertilizer analysis is a reality in many Feed the Future countries. Utilizing IFDC's large fertilizer collection, X-ray fluorescence (XRF) results when compared with wet-chemistry results gave R^2 values of 0.99 to 0.85 for P, K, Mg, S, Cl, Ca, Cr, Fe, Co, Cu, Zn, Mn, Ni, Mo, As, Se, and Pb.
- Soil Health and Sustainable Intensification Practices: Benefits of conservation agriculture (CA) practice were observed on maize grain yield. In general, grain yields from the treatments with CA practices were 30-45% greater than grain yields from the treatments without CA practices. Likewise, under CA, rice yield was 3,230 kg/ha on average compared with conventional tillage (CT) at 2,846 kg/ha, an increase of 380 kg/ha (monetary equivalent of $114/ha). Soil carbon buildup was higher under CA than CT as evident from higher values of potassium permanganate oxidizable C and soil respiration. Mineralization of soil organic carbon was the dominant process in CT. Available N and cation exchange capacity were higher under CA practice.
- Mapping of Land Capability Classification (LCC) for Dosso Region, Niger, has been completed and presented to stakeholders through a virtual meeting. Further validation and improvement of the Land Use Management Decision Support Tool is ongoing. Efforts are underway to establish research and technology parks to empower farmers and researchers and create a Center of Excellence (CoE) at local organizations to build institutional capacity, with the overall goal of improving capacity of farmers and research and extension actors as well as other organizations
- A unified fertilizer trial protocol has been developed for targeting fertilizer source and rate in Ethiopia, and more than 300 field trials are in progress. Combined with ongoing field results, historical fertilizer trial data has been compiled to help produce a model for prediction of responses to different nutrient combinations and rates. The teff model has been developed with the capability to simulate response to rainfall, temperature, and management (fertilizer, variety, plant population, transplanting, direct sowing).
- COVID-19 Fertilizer Watch Updates in SSA: RFS-SFT supported a collaborative initiative towards informing fertilizer value chain stakeholders through weekly fertilizer bulletin viz., COVID-19 Fertilizer Watch bulletin across SSA on the impact of COVID-19 on fertilizer markets and the agro-input supply chain aspects including movement/transportation of essential agri-inputs for cropping season. Weekly updates were initiated in April 2020 with the *Fertilizer Watch* in the East and Southern Africa region due to the COVID-19 shutdown through a collaboration between IFDC and AfricaFertilizer.org (AFO). https://ifdc.org/2020/08/06/measuring-covid-19s-impact-on-the-fertilizer-sector-in-sub-saharan-africa/
- Influencing Fertilizer Policy Reforms in Niger and Kenya: With RFS-SFT support, IFDC partnered with organizations and stakeholders at various levels in countries showing a high potential for policy change through various forums, consultations, and other advocacy modes in Kenya and Niger.
- Effectiveness of Agro-Dealer Efforts in Technology Transfers in Rwanda: The effectiveness of agro-dealer development programs on input supplier networks on access to and use of agro-inputs were assessed. This included a rapid assessment of the effects of the COVID-19

shutdown on input supply through the last mile in Rwanda, which was the first country in the region to impose restrictions.

COVID Challenges and Responses

Challenges: The COVID-19 shutdown was universal from March through May in all Asian and African countries in which we operate. COVID-19 did affect the implementation of few key activities, especially during the second half of the reporting period. The effect was moderate on all the ongoing research activities, especially field related SFT operations. However, the impact was much higher on a few in-person social science-related research surveys that were to be conducted from March onward, as well as a few training and outreach dissemination activities, such as technology demonstrations and field days for farmers and stakeholders. However, as described above, we promptly made changes so that all activities (70%) were conducted during the reporting period. There were two key areas in which modifications could not be made:
(i) research trials that were about to start were delayed for a year due to the single cropping season in sub-Saharan African countries, including the trials in Niger to begin in May;
(ii) research activities on fertilizer policy reforms in Kenya and gender in Uganda could not take place because the partner organization could not travel to the field to conduct those studies.

Responses: Timely efforts were made to lessen the impact on ongoing field activities using remote work tools – mobile tools to engage with local partners on the ground. Further, we insisted upon strict hygienic practices for all the local partners who assisted us in their communities by providing us the necessary information regarding field trials and implementation of field research trials protocols without a compromise in quality. This was possible due to the involvement of local stakeholders in all our research activities with partnerships that have been built since the activity began. Dissemination meetings among stakeholders were held virtually through webinars (e.g., the Kenya Fertilizer Platform [KeFERT]), enabling greater access and wider participation.

We also utilized the opportunity to conduct some quick surveys remotely in Bangladesh and Rwanda to understand the effects of the shutdown on farmers and input suppliers. No additional changes were required for reprogramming from the existing activities. Specific scientific studies to capture the effects of COVID-19 on cropping systems through decision tools and data, e.g., a simulation study on how changes in planting date (delays) and fertilizer availability (N, for example) could affect maize production in Ethiopia were conducted. A short research piece comparing long-term trends in temperature and rainfall and their impact on wheat was also produced, including an evaluation of whether the COVID-19 lockdown had any short-term effect on weather (temperature and radiation).

Although all SFT research activities have been conducted in close partnership with national and local stakeholders, utilizing local partners capacities became integral part of our activities during the pandemic. The fertilizer policy advocacy forums in Kenya and Niger are good examples where dissemination efforts were taken up through local stakeholder platforms – electronically and closer to the farming communities. Since most of the field research trials are conducted in partnership with national research partners – BRRI and BINA in Bangladesh, Tribhuvan University in Nepal, INRAN in Nepal, and INERA in Burkina Faso, major disruptions towards monitoring the ongoing activities were averted.

Workstream 1 – Developing and Validating Sustainable Agricultural Intensification Technologies and Practices

With the primary emphasis on translational research, one of the main objectives of Workstream 1 is to bridge the gap between scientific research and effective technology dissemination to smallholder farmers in Feed the Future (FTF) countries. The technology dissemination process depends upon conducting research on well-characterized sites with a collection of site-specific data on soils, daily weather, socioeconomics, and management.

There are four focus areas of research under workstream 1, which includes.

(1.1) Improving nitrogen use efficiency.

(1.2) Activated Phosphate Rock

(1.3) Balanced crop nutrition; and

(1.4) Sustainable crop intensification practices.

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

1.1 Improving Nitrogen Use Efficiency

The major focus of this activity is improving nitrogen (N) use efficiency by minimizing N losses while increasing productivity. Improving nitrogen (N) use efficiency concentrates on minimizing N losses (accounting for more than 50% of applied N fertilizer) while increasing productivity. This is accomplished by developing and disseminating alternatives to urea, the world's primary N source, including modified and coated urea products, biofertilizers and biostimulants, and additives of organic materials and nutrients that improve N use efficiency. In general, increased efficiency can also be achieved by innovative N fertilizer application practices, improved cultural practices (split application, timing, etc.) and mechanized fertilizer deep placement (FDP) and application of fertilizer at the right time. Coatings and granulation of urea with sulfur (S), micronutrients, and organic additives also promote balanced fertilization. With N application in Africa already low, increased efficiency of applied N is key to achieving greater productivity and profitability while minimizing environmental impacts. Activities are conducted at laboratory, greenhouse, and field scales, targeting (i) development and evaluation of more efficient N fertilizers; (ii) resolving technology scaling constraints to FDP; and (iii) promoting climate resilience and mitigating greenhouse gas (GHG) emissions from N fertilizers.

1.1.1 Development and Evaluation of Enhanced Efficiency N Fertilizers

Development of smart fertilizers that are climate-responsive, enhance climate resilience, require one-time application, have high N use efficiency, and reduce reactive N and phosphorus (P) additions to the environment is one of the major focuses of the following sub-activities. Promising enhanced efficiency products already available or soon to be released in the market, including urea-ammonium sulfate, urea-S, urea-Zn, urea-B, Agrotain-coated urea, and controlled-release urea products, are being evaluated under field conditions in sub-Saharan Africa (SSA) and South 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.

A. Developing enhanced efficiency N fertilizers

The objective of this activity is to develop enhanced efficiency N fertilizers using agricultural wastes, alternative renewable and biodegradable materials, and alternative slower release fertilizers and amendments, such as PR, ES, Zn, B, polyhalites, biopolymers, and urea polymers as coating material. Some examples of these products are urea coated with capped ZnO nanoparticles and biopolymer coating.

Specific activities include product formulation, evaluating nutrient release in water and nutrient release during soil incubation, and quantifying volatilization and leaching losses.

Location: *IFDC HQ Labs*

Partners: University of Florida, University of Central Florida (UCF)

Outcome: Improved use efficiency of N fertilizers through development of a novel controlled-release fertilizer with biopolymer coating and using nano-zinc for improved N use efficiency and improved delivery of Zn.

Progress:

Self-Assembly of Hydrophobic and Self-Healing Bio-Nanocomposite-Coated Controlled-Release Fertilizers

To develop new enhanced efficient fertilizer, a novel self-assembly and self-healing bio-nanocomposite was developed as a coating material for controlled-release fertilizers in collaborative research between IFDC and University of Florida. In this research, bio-based polyurethane-coated urea (BPCU) was prepared by the reaction of bio-polyols with isocyanate. The BPCU was then modified via layer-by-layer technology to prepare self-assembling modified BPCU (SBPCU), focusing on fabricating novel bio-based, low-cost, and environmentally benign coating materials with a controllable and high-efficiency nutrient release rate.

Figure 1. Schematic of the self-healing polymer coating

The layer-by-layer self-assembly of hydrophobic, environmentally friendly, and self-healing bio-nanocomposites was successfully fabricated for development of a novel controlled-release fertilizer. The results demonstrate that self-assembling and self-healing BPCU (SSBPCU) had the slowest nutrient release rate. Both self-assembling of dopamine (DPM) and polyamine and the introduction of self-healing sodium alginate (SA)-modified hollow nano-silica (HNS) particles could increase hydrophobicity and surface roughness and reduce pore channels and cracks of biopolymer coating membranes. This study is published and can be accessed at https://pubs.acs.org/doi/10.1021/acsami.0c06530?fig=fig1&ref=pdf.

Nano-Zinc-Coated Urea Fertilizer for Efficient Delivery of Zn Micronutrient

IFDC and UCF have partnered to develop nano-zinc-coated urea fertilizer, both for the efficient delivery of Zn and for improving N use efficiency in crops. Using capped ZnO-nanoparticles (NPs) synthesized at UCF, capped ZnO-NP-coated urea at 1% and 3% Zn-to-urea ratios was produced. Greenhouse evaluation on sorghum, with the objective of quantifying the effect of the urea-zinc products, compared to conventional zinc sources (bulk zinc oxide and zinc sulfate) on biomass production, grain yield, and shoot and grain Zn, N, and P accumulation, has been conducted (Figure 2). Data are being reviewed and results will be presented in the next reporting.

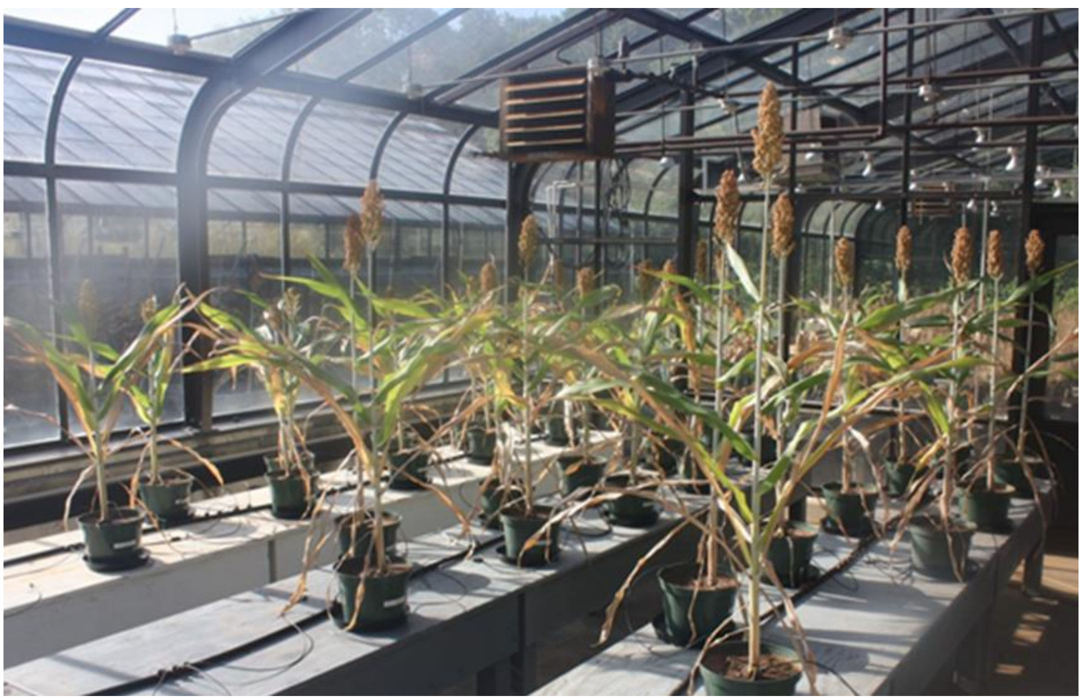


Figure 2. Evaluation of nano-Zn coated urea on sorghum

B. Field evaluation of existing enhanced efficiency N fertilizers and technologies for improved yield and reduced N pollution (Ongoing)

The objective of this activity is field evaluation of enhanced efficiency N fertilizers and deep placement compared to conventional urea in Bangladesh, Ghana, Nepal, and Myanmar (FY2017-18 funds). Except for Myanmar, officials of the Ministries of Agriculture in the other countries have been engaged in dissemination.

Locations: Bangladesh, Ghana, Nepal, and Myanmar

Partners: Africa Research In Sustainable Intensification for Next Generation (Africa RISING), Nepal Seed and Fertilizer (NSAF) project, and national agricultural research systems (NARS) except Burma, private sector

Outcome: Improved N use efficiency fertilizers (urea deep placement [UDP], polymer-coated urea [PCU], urea with ES) evaluated under field conditions with potential for scaling and adoption by farmers.

Progress:

Ghana: Field trials evaluating the agronomic effectiveness of UDP on upland maize production were initiated in FY2016. These results were validated in FY2017 and FY2018. A paper on the technology was submitted for publication in 2019, accepted in 2019, and published in 2020 (https://doi.org/10.1007/s10705-019-10039-8). Farmers are enthusiastic about the technology and began adopting the practice in 2019 and 2020.

UDP Technology for Upland Maize Production Catching Up to Smallholder Farmers in Upper East Region of Ghana

Maize is an important crop in Ghana, particularly in the Savanna agroecological zone. Most farmers in the region rely on mineral fertilizers to increase maize yields, and N fertilizers have become the single most important input that farmers provide to their crops. Our research has confirmed that fertilizer efficiency, and consequently, crop yields increased when fertilizers are applied by subsurface incorporation, rather than surface broadcast application. Unfortunately, most smallholder maize farmers have been reluctant to adopt this practice because they find it cumbersome and labor intensive, as it requires measuring the needed fertilizer for each plant, applying it to a hole dug near the plant, and then covering the hole. We have introduced an innovative approach to overcome this obstacle, which involves briquetting (physical compaction of commercially available granular fertilizer) the quantity of fertilizer required by the plant using a briquetting machine and then applying these briquettes to the plants. This technology eliminates the critical step of measuring the granular fertilizer before applying it to the plant. This is a well-known and widely accepted practice in many parts of sub-Saharan Africa, including Ghana, and Southeastern Asia, so most smallholder farmers are aware of its efficacy for irrigated and lowland rice production but not for upland maize.

Mumuni Idrissu Bamba, 47, a father of eight children in the Sarkote community of the Upper East Region said: “With this new technology, my yield from maize has increased by about 50%. What is more fascinating is that I now use less fertilizer and my labor cost for fertilizer application and weeding is also lower. This is a great saving for me, which has enabled me to expand my farm. Most of the farmers in this community are adopting this practice and we are all happy about it.”

This sentiment was echoed by Madam Elizabeth Tibil, 39, a single mother of four kids. Madam Tibil farms in Pusu Namong community. She was full of praise for the technology and said, “Apart from increasing my yields, I now save money to do other things, such as buying books and school uniforms for my kids. When I come to the farm and see my crops, I am just very happy. Just look at these plants. They look very healthy and I’m expecting a bumper harvest. Thank you, IFDC, for bringing this to us.”

Mumuni Idrissu Bamba inspects his maize plants

Madam Elizabeth Tibil showcasing her maize with deep placement

Bangladesh: As a follow up to last season's maize trial, two additional maize trials were established for rabi maize in December 2019 with sulfur-enriched urea fertilizers in sulfur-deficient areas of Bangladesh (Figure 3). The treatments include S omission, different S sources applied at 50 kg S ha^{-1} – Thiogro ES 13%, Thiogro ES 75%, gypsum, Thiogro ESS 13%, and ammonium sulfate (AS) – recommended practice with straight fertilizers and blended fertilizer (NPKSB), and farmers' practice. Two additional treatments – Thiogro ES13% at 25 and 75 kg S ha^{-1} – were also added to determine the optimal S rate for maize cultivation. Nitrogen fertilizers (both urea and urea-sulfur) were applied in three equal splits at final land preparation, 6-8 leaves, and tasseling stages, and farmer fertilization was followed in the farmers' practice treatment. At maturity, crop biomass yields (grain and straw) and yield attribute data were recorded from each plot. In addition, plant samples (grain and straw) were collected to determine N and S use efficiency, and soil samples were collected to determine the effects on soils. However, laboratory analysis of plant and soil samples has been delayed due to the COVID-19 pandemic. This will be reported in the next progress report.

Figure 3. Evaluation of urea-sulfur fertilizers in the North-West part of Bangladesh (sulfur-deficient site)

Maize yield and yield components were significantly influenced by addition of S fertilizer, irrespective of its source, compared with S omission (no sulfur) or farmers' fertilizer practice. Maize yields increased by 0.44-2.51 mt ha^{-1}. Among the different sulfur sources, ES 13% produced the highest yields compared to other sources, i.e., gypsum, ESS 13%, and ES 75% (Figure 4). Maize yield with elemental sulfur (ES) sources were significantly higher compared to gypsum.

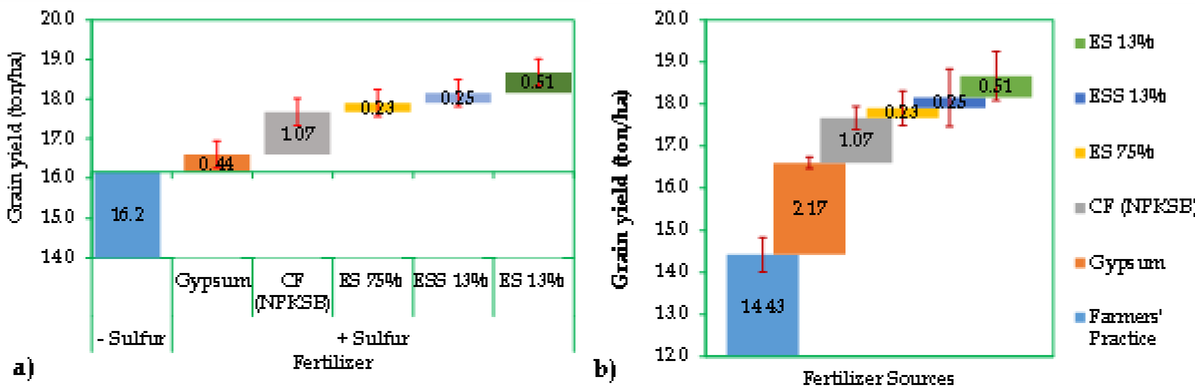


Figure 4. Effects of sulfur and sulfur-enriched urea fertilizers on maize grain yields in Northern Bangladesh (a) compared with sulfur omission treatment and (b) compared with farmers' practice

Crop Diversification Empowers Women for Successful Farming Ventures

Champa Rani Roy, from Palashbari Village of Nilphamari District, used to grow vegetables in her kitchen garden for family consumption but she wanted to farm in the field. She had observed the neighboring farmers growing tobacco for a long time. After discussion with IFDC's assistant soil scientists, she realized that production was being lost due to tobacco monoculture in the Rabi season since they must keep the land fallow. She contacted the Department of Agricultural Extension (DAE) field staff frequently and learned about IFDC's diversified farming system trial plots. She started farming on 0.3 acres of her land with a diversified cropping pattern: maize-T. Aman-mustard. She also practiced balanced fertilization and judicious use of irrigation. In 2020, she grew hybrid maize, which gave her a gross income of BDT 19,250 [BDT 17,850 from grain sales and BDT 1,400 from feed straw sales]. Crop diversification provided her a gross margin of BDT 10,550 and an additional BDT 3,700 compared to growing a single tobacco crop. The diversified cropping pattern also will allow her to grow early T. Aman and mustard crops before next Rabi season, which will also increase her farm income. Champa's successful maize production inspired all her family members and motivated neighboring farmers to follow IFDC-recommended diversification farming systems.

Champa Rani Roy with her team during harvesting of trial plots, Palashbari, Nilphamari, Bangladesh

Myanmar: Sulfur trials evaluating effect of S sources on maize were conducted at four locations – Aungban, Inn Pet Let, Htat, and Taung Pul Win in Shan State. The following four treatments were evaluated under randomized complete block design with four replications:

1. 0 S: All limiting nutrients at recommended rates minus S (200:110:120 kg N, P_2O_5, and K_2O ha^{-1} plus 20 kg Mg, 25 kg Ca, 3 kg Zn, and 4 kg B ha^{-1})
2. FP: farmers' practice (75:19:19 kg N, P_2O_5 and K_2O ha^{-1})
3. GY50: Gypsum 50 kg S ha^{-1} with all other nutrients as (1)
4. TH50: Thiogro ES 13% 50 kg S ha^{-1} with all other nutrients as (1)

Only at Aungban, S application resulted in a significant increase in maize grain yield compared to farmers' practice and S check (Figure 5). At all other locations, S was not limiting; however, a significant increase in yield over farmer practice was observed either due to higher NPK rates and/or due to balanced fertilization (Ca, Mg, Zn, and B).

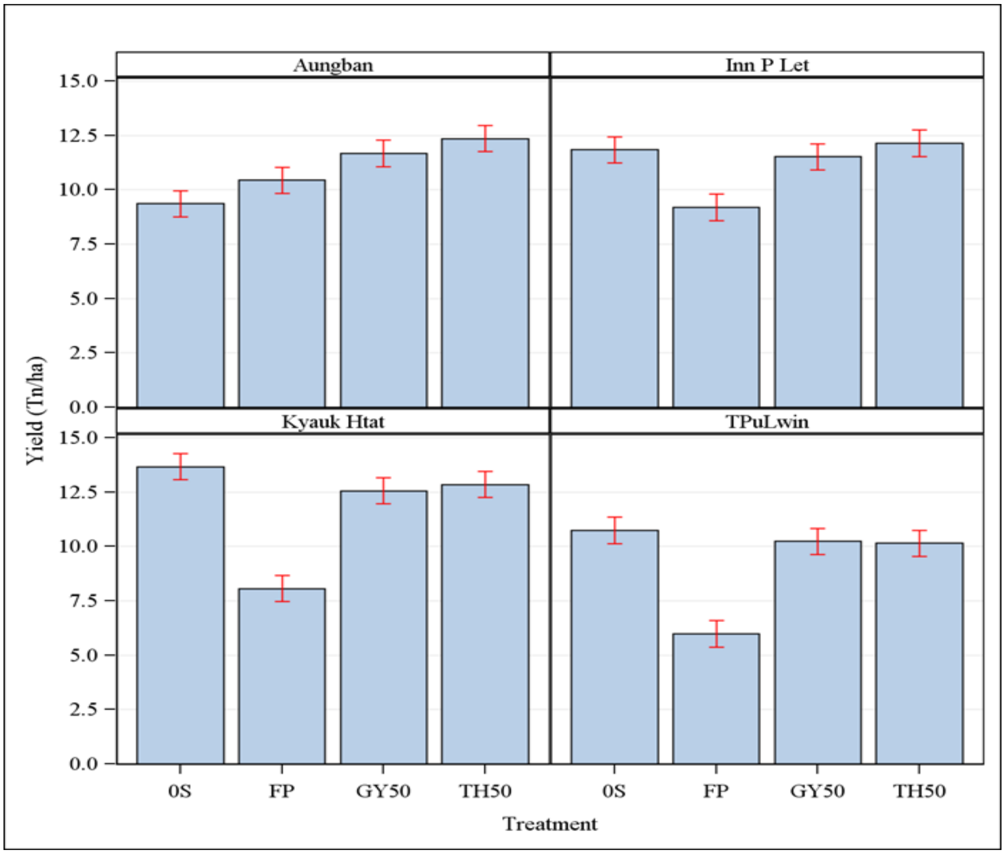


Figure 5. Effect of two S sources and farmers' practice on maize yield at four locations in Shan State

Nepal: Field trials on cauliflower were conducted across five districts (Banke, Bardiya, Kailali, Kanchanpur, and Dang), in partnership with the NSAF project, to evaluate the effects of different enhanced efficiency N fertilizers on cauliflower head (curd) yield. Curd yield increased by 84%, 105%, 108%, and 117% with the use of recommended practice (RP), Thiogro ES 13% (urea-ES), polymer-coated urea (PCU), and urea deep placement (UDP), respectively, compared with the current farmers' fertilizer management practice, FP (23.6 mt ha^{-1}) (Figure 6).

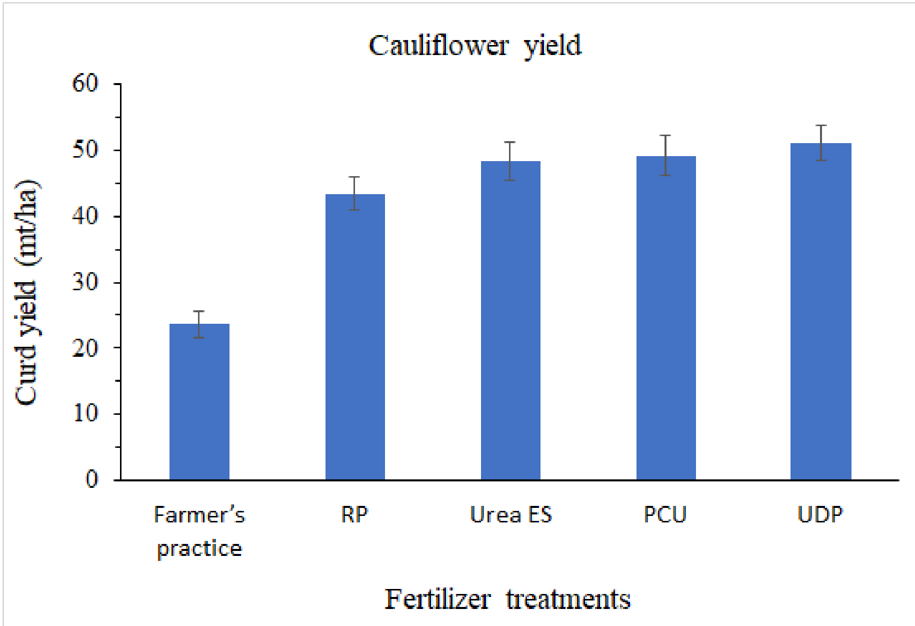


Figure 6. Effect of different N fertilizers on curd yields of cauliflower compared to farmers' practice in Nepal

UDP technology has only been recently introduced in Nepal. Its performance was found superior for rainfed rice (https://link.springer.com/article/10.1007/s10705-020-10086-6), maize, and cauliflower (this report). However, farmers' economic benefits have not yet been determined for these crops. Therefore, in addition to recording yields, a cost-benefit analysis was performed for each treatment and compared with farmers' practice (Table 2). Cost-benefit analysis was conducted for rice and maize based on the results of the trials conducted in past seasons.

In cauliflower, net profit could rise by 87% if farmers adopt recommend fertilizer as compared with farmers' practice. Nitrogen managed by PCU and UDP increase the net profit by 105% and 132%, respectively, over farmers' practice.

In rice, the analysis showed that farmers who adopted the recommended fertilizer rate could increase their net profit by 16% over farmers' practice. The application of PCU increased net profit by 44% over farmers' practice. Farmers can obtain the highest profit by applying briquetted urea – 65% more profit than with farmers' standard practice.

In maize, by adopting the recommended fertilizer rate, farmers could increase their net profit by 20% over farmers' practice. Nitrogen managed with PCU and UDP increased net profit by 19%, and 25%, respectively.

Table 2. Cost-benefit analysis of enhanced efficiency N fertilizers in cauliflower, rice, and maize compared to farmers' practice in Nepal

Treatment	Yield (mt ha^{-1})	Gross Benefit (U.S. $/ha)	Fertilizer-Related Cost (U.S. $/ha)	Net Benefit (U.S. $/ha)	Increment in Net Benefit over Farmers' Practice (%)
Cauliflower					
Farmers' practice	23.60	5,035	125	4,118	-
Recommended rate	41.92	8,755	281	7,682	87
N managed with PCU	47.59	9,824	587	8,445	105
N managed with UDP	53.56	10,890	551	9,546	132
Rice					
Farmers' practice	4.10	728	57	298	-
Recommended rate	4.60	837	118	347	16
N managed with PCU	5.50	1,001	199	430	44
N managed with UDP	5.70	1,050	187	491	65
Maize					
Farmers' practice	5.80	1,421	31	1,016	-
Recommended rate	7.40	1,790	200	1,215	20
N managed with PCU	7.30	1,765	180	1,210	19
N managed with UDP	7.60	1,838	193	1,270	25

1.1.2 Scaling Fertilizer Deep Placement (FDP) Technology for Granular and Briquette Fertilizers

While the benefits of FDP are well-documented, scaling has been slow. The most limiting factor for scaling of FDP is the availability of mechanized applicator. Briquette deep placement is a slow, tedious process, which limits its adoption by large-scale farms or where labor availability is low, or labor costs are high. To tackle the issues associated with FDP, with the support of RFS-SFT, currently two types of applicators and one mechanized briquetting machine are being built to suit cropping environments in Asia and Africa.

The equipment includes: (i) a manual injector-type applicator for African environments; and (ii) a sub-surface seed and fertilizer applicator for Asian environments. In addition to these prototypes, a high-capacity briquetting machine is being built in Uganda to produce briquettes.

Locations: *US, Kenya, Uganda, Myanmar*

Partners: Mississippi State University, private sector partners in Myanmar, India, and Uganda

Outcome: Constraints associated with scaling of FDP resolved with mechanized applicators and high-capacity briquetting machine.

Progress:

1. A *manual injector-type applicator* with adjustable volume has been developed. However, due to COVID-19 restrictions, testing has been delayed and will be completed during the first half of FY 2021 reporting period.
2. Development of a *high-capacity briquetting machine for Africa* (see Box below).

Development of a High-Capacity Briquetting Machine for Africa

Production of a high-capacity briquetting machine is near completion. This machine is anticipated to have a production rate of 5 mt per hour or more. It will be an important component of a briquette production and distribution model better suited to Africa. Unlike Bangladesh, rice is grown in dispersed locations, so it logistically better to place a high-capacity briquetting machine at a urea distribution point, where briquettes can be distributed to diverse rice programs as well as cooperatives. This differs from the Bangladeshi model in which briquettes are fabricated at the point of sale of urea using a small briquetting machine that can run intermittently at a capacity of less than 0.5 mt per hour. The high-capacity machine has an adjustable feed and speed control to suit various characteristics of urea (prilled or granular of varying moisture concentrations) and can be equipped with a cooled motor or a diesel-powered engine to permit continuous operation.

High powered briquetting machine under development in Ndeeba, Kampala, Uganda

3. Based on the field evaluation of *seed and subsurface fertilizer applicator* for dryland crops in Burma, changes are being made to the original applicator by the manufacturer in India.

   Following the initial tests, major changes were made to the rice transplanter/FDP applicator by Mississippi State University. New planter units with the needed components to meter, place, and cover the briquettes in a single self-contained unit were installed onto the transplanter. The team has designed and have 3D printed metering plates for each unit matching the desired pellet spacing in correlation with the transplanted rice. Field evaluation is needed to confirm that the units will place and cover the fertilizer pellets in a manner consistent with the intended design.

Figure 7. **Rice transplanter-deep placement applicator development at Mississippi State University**

1.1.3 Climate Resilience and Mitigating GHG Emissions

Fertilizers play a unique role in both emitting and sequestering greenhouse gases and improving crop resilience to abiotic and biotic stresses. The proposed activities will highlight the resilience and GHG mitigation features of deep placement technology in improving crop yields under adverse environments.

Locations: *Bangladesh, Burkina Faso*

Partners: Krishi Gobeshona Foundation (KGF), Bangladesh Agricultural University (BAU), Bangladesh Agricultural Research Institute (BARI), Bangladesh Rice Research Institute (BRRI), Institut de l'Environnement et de Recherches Agricoles (INERA) in Burkina Faso

Outcome: Improved fertilizer use efficiency to mitigate GHG emissions in rice-based cropping systems and to increase productivity crops under saline conditions. Adaptation of fertilizer deep placement to intensive rice cropping systems (SRI).

Progress:

A. Mitigating GHG emissions from rice-based cropping systems through efficient fertilizer and water management in Bangladesh

Results generated from 2013-2019 GHG trials in Bangladesh and IFDC HQ have being used to evaluate soil carbon (C), soil N, and GHG modules of the Decision Support System for Agrotechnology Transfer (DSSAT) model (see Section 4.1). In addition, through partnership with KGF, plans are in place to extend the GHG emission methodology to on-farm trials.

A research proposal has been submitted to KGF in partnership with BAU for extending the GHG mitigation research activities into different agroecological zones (AEZs) of Bangladesh. Approval of this proposal is pending. Recently, KGF has asked for a revision of the proposal and submission of a new proposal focusing on GHG emission under diversified cropping patterns adding BARI as a partner. A journal article has been published recently comparing GHG emissions of two irrigation regimes – alternate wetting and drying and farmers' practice of continuous flooding.

B. Increasing fertilizer use efficiency and resilience in saline soils in Bangladesh

About 1 million hectares (ha) of arable land in Bangladesh is affected by salinity (53% of the coastal zone) in different forms. Cropping intensity in the coastal zone is low at 133% compared to the national average of 192% (about two crops per season). Salinity causes unfavorable environmental and hydrological conditions that restrict normal crop production throughout the year. Fertilizer use efficiency must be improved in order to increase productivity of salt-tolerant crops.

Two field experiments were established in January 2020 on salinity-affected areas of Bangladesh in partnership with BRRI to evaluates different customized compound fertilizers (including secondary and micronutrients) along with organic amendments and deep placement for enhancing soil fertility, crop productivity, and farm profitability (Figure 8). In these field experiments, two varieties of *Boro* rice (BRRI dhan67 [salinity resistant] and BRRI dhan88 [farmers' choice]) were tested with six treatment combinations: 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. Soil amendments (cow dung and ash) were applied three days prior to transplanting. Urea briquettes were placed at a depth of 10 cm at the center of four rice hills 10 days after transplanting (DAT). Prilled urea was applied in three equal splits at 7, 35, and 55 DAT, respectively. The crop was harvested at full maturity in April 2020 with grain and straw yield and yield attributes recorded from each plot. Lab analysis of harvested plant and soil samples was delayed due to COVID-19 but is currently in progress.

Figure 8. Harvesting saline soil management trials in the South-West part of Bangladesh (saline soil areas)

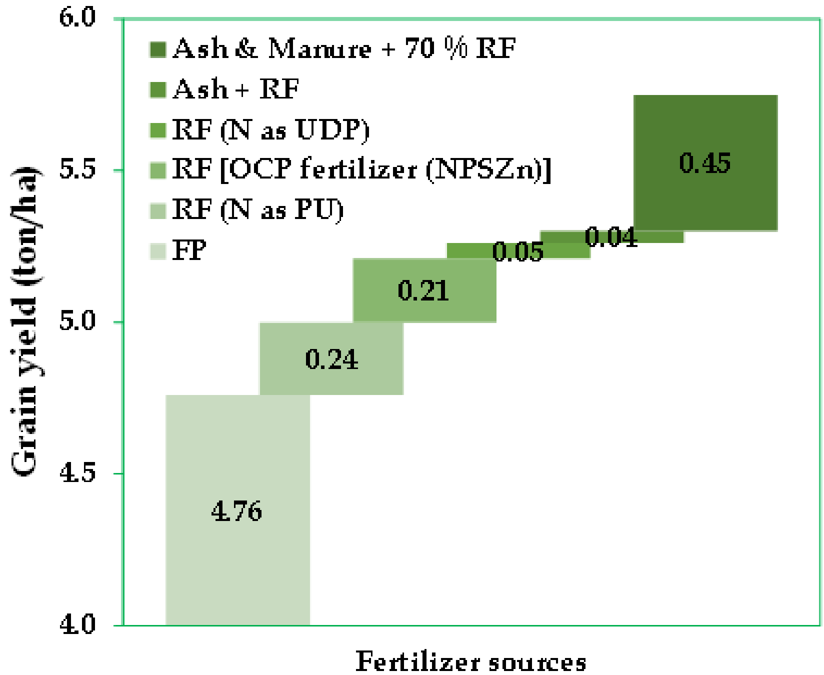


Figure 9. Effects of fertilizer source on grain yields (mt ha^{-1}) of Boro rice 2020 in the South-West part of Bangladesh (saline soil areas)

Application of salinity amendments had additive effect on grain yields, showing an increase of up to 0.94 mt ha^{-1} over farmers' practice. Application of urea briquette and customized fertilizer (NPSZn) produced a significantly higher yield compared to farmers' fertilizer practice (Figure 9). In addition, sole application of ash along with the recommended fertilizer rate (RF) had a significant effect over only RF, while the combined application of ash and cow dung gave highest yield over location and variety. Increased yield with salinity amendments and UDP was associated with increased plant height, tillers per plant, spike length, grains per spike, and 1,000-grain weight. These results indicate that balanced fertilization and salinity amendment is required to support higher yield and to manage the paddy soils affected by salinity. However, validation trials must be conducted across other sites to confirm these findings.

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

The ongoing activity with INERA in Burkina Faso evaluated use of multi-nutrient FDP briquettes to rice production in lowland and irrigated systems, and adaptation of UDP to intensive rice cropping systems (SRI)

Use of Multi-Nutrients Briquettes in Rice Production in Burkina Faso

For this trial, two ecosystems were considered: lowland and irrigated cropping systems. The design is a randomized complete block with three replicates at Bama, Zorgho, and Bagré sites for the irrigated rice system and Sabou, Kombissiri, and Koumbia sites for the lowland rice system. The treatments being tested are T1= absolute control without fertilizer; T2= Recommended practice (basal NPK 14-23-14-5S 150 kg ha^{-1} plus topdressing with 100 kg ha^{-1} urea broadcast); T3= basal recommended NPK fertilizer plus UDP 113 kg ha^{-1}; T4= one-time deep placement of two briquettes of NPK 25-20-20 for every four rice plants 7-10 days after transplanting. In the irrigated rice systems, the recommended practice was 200 kg ha^{-1} NPK 14-23-14-5S plus topdressing with 150 kg ha^{-1} urea broadcast.

Adapting UDP to System of Rice Intensification

The design is a split plot with addition of compost as main plot factor with three levels (0, 5, and 10 mt ha^{-1}) and the following fertilizer treatments randomized on the subplots: T1= SRI without fertilizer; T2= SRI 200 kg ha^{-1} NPK and 72 kg ha^{-1} urea topdressing; T3= SRI 200 kg ha^{-1} NPK and urea briquettes 7-10 days after transplanting; T4= SRI 200 kg ha^{-1} NPK and 113 kg ha^{-1} urea broadcast in topdressing; and T5= conventional UDP (20 cm x 20 cm transplanting, basal 200 kg NPK ha^{-1} and one briquette of 1.8 g every four hills of rice 7-10 days after transplanting).

The trials were installed from August to September 2020 and were subject to routine agronomic maintenance including timely weeding. Data collection is underway.

Figure 10. Plot of UDP adaptation to SRI at the Zorgho irrigated site in Burkina Faso

1.2 Activated Phosphate Rock

All commercially available phosphatic (P) fertilizers contain 100% water-soluble P (WSP). However, 100% WSP achieves only 10-20% efficiency. WSP is rapidly converted to labile P, active P, or stable P pools in the soil. It can be rendered unavailable in acidic soils through fixation and in alkaline soils via calcium phosphate precipitation. In sandy soils and under high-intensity rainfall, WSP can be lost to leaching. By contrast, phosphate rock (PR) is less soluble, and its utility is limited to highly acidic soils.

Activated phosphate rock is produced by compressing or granulating phosphate rock with small amounts of WSP. In contrast to WSP and PR, activated phosphate rock is not constrained by soil conditions. The activation processes are inexpensive compared to WSP production, which requires investment of more than $1 billion, is limited to regions with very large deposits, and produces large amounts of phosphogypsum, a byproduct and disposal challenge. Activated phosphate rock can utilize smaller national deposits, reducing the need to import soluble P fertilizers and is equally effective in a wide range of soils.

Activated PR is produced by compressing or granulating phosphate rock with low amounts of water-soluble P sources, such as diammonium phosphate (DAP) or monoammonium phosphate

(MAP). Activated PR activities included: (i) greenhouse and field trials; (ii) validation and promotion of activated PR using local PR resources; and (iii) development of alternative PR activation processes.[1]

1.2.1 Activated Phosphate Rock Trials under Greenhouse and Field Conditions

Ongoing greenhouse and field trials are evaluating the performance of activated PRs from Togo and Angola against conventional P fertilizers, such as DAP, MAP, and triple superphosphate (TSP). To evaluate the long-term potential of activated PR, residual PR trials were conducted under both field and greenhouse conditions.

Location: *Ghana, IFDC HQ*

Partners: Private sector, University for Development Studies (UDS), Savanna Agricultural Research Institute (SARI), and local agricultural extension agents

Outcome: Activated phosphate rock as an effective P fertilizer for a wide range of soils and crops

Progress:

Greenhouse studies at IFDC HQ are being conducted to evaluate a wider range of MAP:PR blends, compare tableted (compacted) product versus granulated, and determine residual effect of PR on grain yield and P uptake with crops grown to maturity. The maize crop in the previous residual study was not grown to maturity. The main objectives of the new trials are to evaluate the agronomic effectiveness of PR as mined and various MAP:PR products for soybean-wheat-sorghum cropping with respect to: (i) four P sources at five rates (0, 25, 50, 100, and 200 mg kg^{-1}); (ii) the effect of product preparation (granular vs. tablet) at four P rates (25, 50, 100, and 200 mg kg^{-1}); (iii) the effect of seven MAP:PR ratios (PR only, 12.5:87.5, 25:75, 37.5:62.5, 50:50, 75:25, and MAP only) at a 50 mg P kg^{-1} rate; and (iv) the effect of fresh and residual MAP and PR application. The initial soybean crop was planted in April 2020 and the trial is in progress (Figure 11).

[1] Feed the Future #CultivatingHope through Phosphate Rock Research, https://ifdc.org/2020/09/17/feed-the-future-cultivatinghope-through-phosphate-rock-research/

Figure 11. Soybean crop testing WSP:PR blends

Field trials in Ghana were conducted with the engagement of UDS, SARI, private agro-input dealers, and local agricultural extension agents. During the last quarter of FY2019, we established follow-up activated PR trials across the entire savanna (Sudan and Guinea savanna) agroecological zones of Ghana to validate the results obtained during the Year 1 field study. As with the Year 1 study, we used maize and soybean as test crops. For maize, the trials were conducted in soils with strongly acidic, moderately acidic, and near-neutral pH levels, whereas the soybean trials were established in soils with near-neutral pH levels. The follow-up trials were harvested during the months of November and December 2019, and the yield results were presented in the previous report. Plant tissue and residual soil analyses for the activated PR trials have been completed.

Averaged across the sites with near-neutral soil pH, without P application (but with all other limiting nutrients applied), P uptake from maize was ~0.85 kg P ha^{-1}, whereas the average P uptake from soybean (averaged across all sites) was 0.46 kg P ha^{-1} (Figure 12). As expected, P application from the three P sources to both crops significantly increased P uptake, with the greatest P uptake consistently occurring with WSP treatment followed by activated PR > PR > P check, in that order. Differences between P uptake from the PR treatment and P uptake from the activated PR represented a quantitative estimation of the contribution of WSP compacted with the PR. Despite the small quantity of WSP compacted with the PR, the corresponding contribution to P availability from the PR was significant. For example, for the maize plants, an average P uptake from the PR treatments was 0.97 kg ha^{-1}, and the increase in P uptake from the PR due to activation was ~6.3 kg ha^{-1} (Figure 12). A similar pattern was observed for the soybean trials, although the extent of the increase was slightly lower (~6.5 kg ha^{-1}). This suggests that the WSP contained in the activated PR provided the initial P required by the plant for proper root development, which enabled the plants to subsequently utilize the PR efficiently for growth and development, as reported in the previous greenhouse studies.

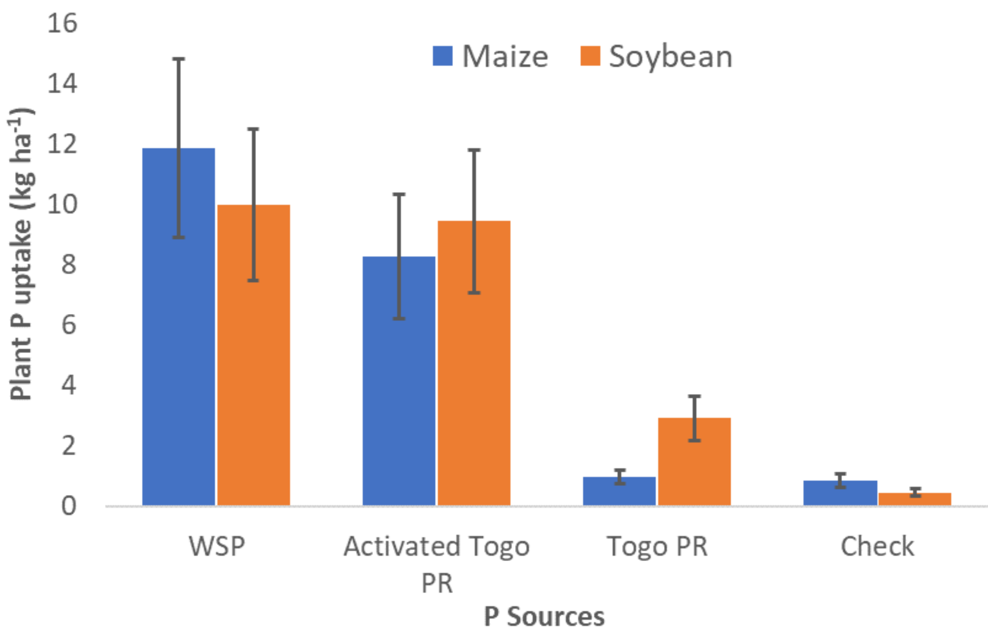


Figure 12. Average P uptake of maize and soybean in near-neutral soils in northern Ghana supplied with activated P, WSP, and raw untreated PR

Consistent with the P uptake data for both crops, post-harvest soil analysis showed minimal residual P accumulation in the soil (data not presented) with the WSP treatment, followed by the activated PR treatment, with the greatest P accumulation occurring in the untreated PR treatment. This confirms that a large portion of P from the untreated PR could not be utilized by the plants, while activation of the PR promoted P utilization from the rock.

1.2.2 Validating and Promoting Activated PR using Local PR Sources and Producers (Linked with Workstream 3)

PR and activated PR demonstrations will be conducted on soils of varying pH to further validate the role of activated PR as an alternative to WSP fertilizers. These trials will also serve to capture the interest of local PR producers and national governments.

Location: *IFDC HQ*

Partners: Local PR producers/miners, national agricultural research, and extension system (NARES), SOILS Consortium, and the IFDC Pilot Plant

Outcome: Local PR producers/private sector involved in production of activated phosphate rock as an effective P fertilizer for a wide range of soils and crops.

Progress:

Results from on-farm demonstrations using Togo PR for activated PR product within the savanna agroecological zones of northern Ghana was documented in the previous semi-annual report.

Field demonstration and promotion in Angola with Cabinda PR from Angola is conducted and supported by private sector.

Field trials in Niger have been postponed due to COVID-19 restrictions.

1.2.3 Alternative Activation Process for Enhanced Efficiency P Fertilizers

Current phosphatic fertilizers and fertilizer production processes are inefficient and result in poor use efficiency of PR, a finite essential resource. In addition to waste of P, large amounts of undesirable byproducts are generated during phosphatic fertilizer production, which poses a disposal problem. Expanding on our activated PR findings, laboratory and greenhouse research are being conducted to investigate alternative "activation" processes using bio-organic acids, biofertilizers, and bio-nanotechnology. This research will also provide opportunities to remediate heavy metals from phosphatic fertilizers.

Partnership: Private sector, TERI-Deakin Nanobiotechnology Center.

Outcome: Effective alternatives to current P fertilizers

Progress:

PR from Angola was calcined at 400-1000°C as an alternative activation process. Initial results from calcination showed increase in total P_2O_5 content of the PR. Further analyses conducted at IFDC lab on total P content and citrate soluble P did not show any significant improvement over the uncalcined PR.

1.3 Balanced Crop Nutrition for Site-Specific Fertilizer Recommendations

Balanced crop nutrition addresses most soil-deficient nutrients and soil problems, such as acidity, alkalinity, salinity, and moderate drought. Most sub-Saharan African farmers only have access to NP and NPK fertilizers, but landscape-level soil analyses by IFDC and others have indicated widespread deficiencies of other nutrients – S, zinc (Zn) and boron (B) – as well as acidity constraints and associated deficiencies of calcium (Ca) and magnesium (Mg). These nutrients are inexpensive in general to supply because they are required in smaller quantities relative to N, P, and K and can have major impacts on crop yields. Research to date indicates that multiple deficiencies of secondary and micronutrients are the norm rather than the exception and must be addressed simultaneously to optimize fertilizer response. Secondary and micronutrients may be added as granules in blends, incorporated as coatings on NPK granules, or incorporated into the NPK granules; however, the relative efficiencies of these different methods are not completely understood. In addition, the different characteristics of micronutrients (chemical composition, hardness, and fineness) affect their efficacy.

Activities focus on: (i) demonstrating improved returns to balanced crop nutrition; (ii) developing cost-effective ways of adding nutrients to NPK fertilizers; and (iii) evaluating and developing accurate and cost-effective soil testing methods to identify multiple soil nutrition constraints. The proposed activities highlight the importance of balanced-nutrient fertilizers and fertilization and the most cost-effective and efficient ways of delivering these nutrients to maximize nutrient use efficiency, productivity and, thus, profitability. All field trials included collection of soil, climatic, 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

The activities focus on the improved delivery, distribution, and efficiency of nutrients (N, P, K, S, Zn, B, Mg, Ca) supplied from multi-nutrient fertilizer granules. The effect of improved nutrient efficiency will be quantified with respect to increased yield, improved mineral nutrient and protein content of grains, and quality of protein. The studies are being conducted in the United States, Bangladesh (ongoing), Ghana (completed), Kenya (completed), Burma (completed), Mozambique (ongoing), and Nepal (ongoing).

Partners: Tennessee State University, Soybean Innovation Lab (SIL), Agriculture and Forestry University (AFU), Tribhuvan University, Bangladesh Agricultural Research Institute (BARI), Soil Resources Development Institute (SRDI), Kenya Agricultural and Livestock Research Organization (KALRO; in-kind), Nepal Agricultural Research Council (NARC; in-kind), Food security through climate Adaptation and Resilience (FAR) project, Mozambique Farmers Association, HarvestPlus, International Zinc Association (IZA), Shell-Canada (cost-share), US-Borax

Outcome: Improved delivery of secondary and micronutrients with N, NP and NPK fertilizers

Progress:

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

Zn, S, copper (Cu), and iron (Fe) deficiencies are widespread, affecting both crop yield and human nutrition. Grain samples from selected trials will be analyzed for methionine and cysteine, Zn, Cu, P, and phytate content.

Residual Sulfur Trials in Ghana: In partnership with a private client (Shell), we are evaluating the agronomic effectiveness of a new S fertilizer product (Thiogro ES) under field conditions in northern Ghana. The Year 1 results show that Thiogro ES was as effective in maize biomass yield, grain nutrient (N and S) concentration, and the total aboveground nutrient uptake as the locally available sulfate (ammonium sulfate) fertilizer in northern Ghana. Even at a lower application rate (25 kg S ha^{-1}), Thiogro ES produced yields that were not statistically different from those of ammonium sulfate fertilizer applied at 50 kg S ha^{-1}. However, despite the increase in S uptake with an S application rate from the Thiogro ES fertilizer product, the proportion of the applied S taken up by plants decreased with increasing S application rates. In general, across all treatments, the proportion of applied S taken up by the plants was <25%, suggesting that substantial quantities of the applied S were not taken up by the plants. Post-harvest soil analysis showed that large amounts of S remained in the soil after crop harvest in the plots receiving the Thiogro ES fertilizer product. The results of the soil analyses prompted a follow-up experiment during FY2019-20 to determine the residual effects of the Thiogro ES fertilizer in supplying S to subsequent crops. We established 12 trials to evaluate the effects of the residual S from the applied Thiogro ES fertilizer product.

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 (Figure 13). Plots that previously received the Thiogro ES product during the previous cropping, at an S rate of at least 50 kg ha^{-1}, produced grain yield which was greater than 50% of expected grain yield, as obtained from the plots receiving fresh S fertilizer application (Figure 13).

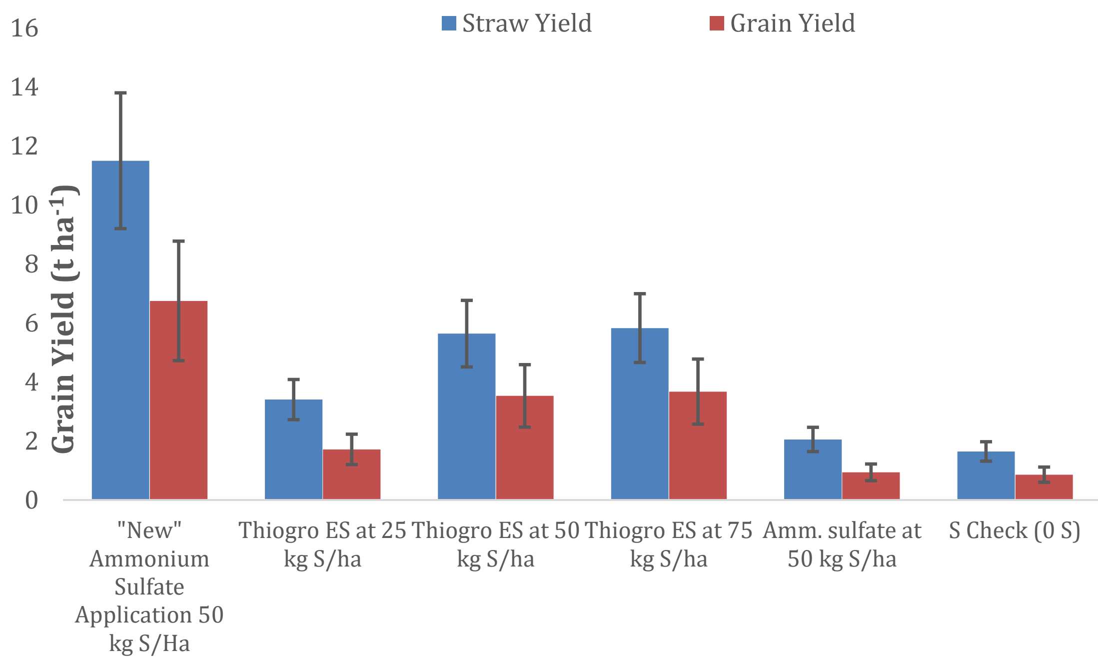


Figure 13. Straw and grain yields resulting from residual soil S from previous cropping

The combined results of the previous year's cropping with the current residual S evaluation show that the Thiogro ES product is a very effective S fertilizer product. Even at a lower application rate (25 kg S ha^{-1}), Thiogro ES produced yields that were not statistically different from the ammonium sulfate fertilizer applied at 50 kg S ha^{-1}. An economic analysis that considers the price combination of fertilizer and the value of marketable yield should be carried out to determine an economically optimal application rate for Thiogro ES fertilizer vis-à-vis the locally available sulfate fertilizer.

Zinc Borate Trials in Kenya: In partnership with US-Borax we conducted a trial on maize using zinc borate as a source for both zinc and boron in fertilizers. This trial was not entirely conclusive, given that the trial could be implemented at only one site due to COVID-19 travel restrictions. We intend to conduct this activity in Rwanda for 2021, where implementation is easier, and zinc and boron deficiencies are more prominent.

B. Balanced fertilization through secondary and micronutrients (compound fertilizers) in maize on acid-prone soils

Location: Bangladesh

Bangladesh soils are deficient in micronutrients, especially Zn, B, and molybdenum (Mo). Micronutrient deficiencies are increasing due to increased cropping intensity and production of high-yielding variety (HYV) crops. Apart from cropping intensity, low levels of organic matter in soils, little or no retention of crop residues, and limited application of animal or organic manures in soils are causing somewhat persistent micronutrient deficiencies. Improved soil testing accessibility at farmer level and fertilizer recommendations with proper micronutrient doses would be useful in attaining desired yield of crops. During fertilizer and manure application, farmers are not aware of micronutrient deficiencies, but these cause a reduction in yield. Farmer awareness of micronutrient deficiencies is crucial to resolving this prevalent problem with soils in Bangladesh. Two field experiments of balanced fertilization on maize crops have been done in 2019-2020 in the northern part of Bangladesh and in other crop (T. Aman and Rabi crops) pattern-based research initiated in T. Aman 2020, and crops have reached the reproductive stage. Maize grain yields have been reported here; however, plant sample analysis was delayed due to COVID-19. Determination of N, S, Zn, and B is currently in progress and will be reported in the next semi-annual report.

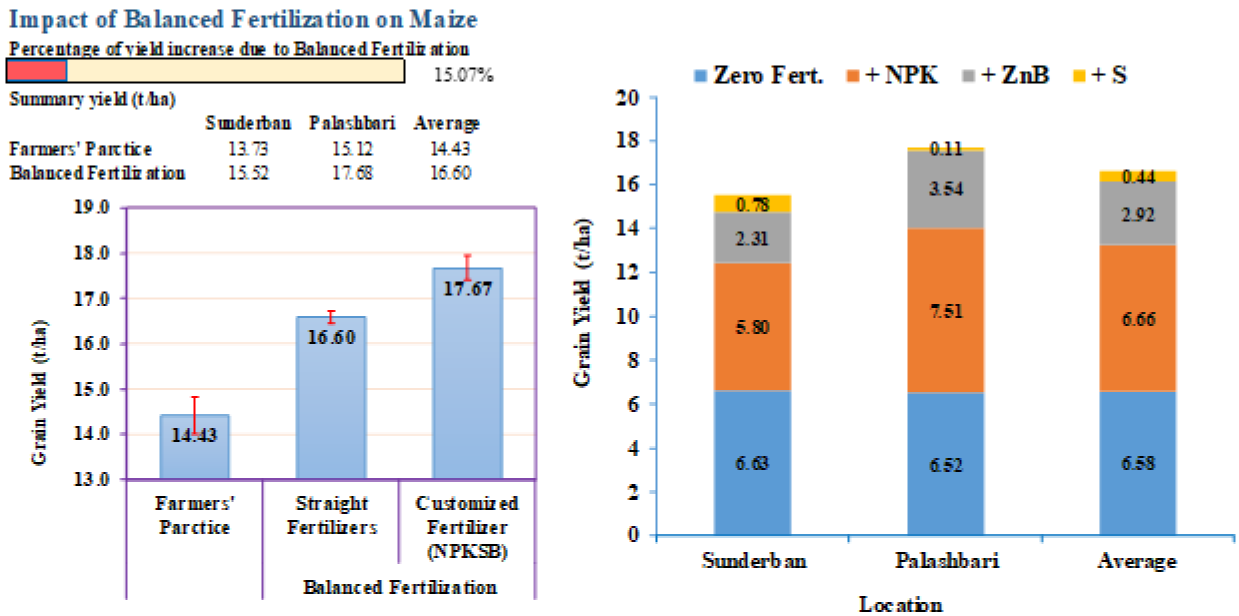


Figure 14. Effects of secondary and micronutrient fertilizers on maize grain yields in two locations of northern Bangladesh

Results showed that application of micronutrients zinc and boron increased yields by 2.92 mt ha^{-1} compared to the NPK-only treatment (Figure 14). Sulfur application in addition to the zinc and boron gives additional incremental yield of 0.44 mt ha^{-1} (Figure 14). Thus, balanced fertilization significantly increased maize yield by an average 15.07% in acidic soils, regardless of farmers' fertilizer practices.

C. Promoting the commercial and experimental use of efficient micronutrient coatings

Location: HQ

The objective of this activity is to create awareness of the most efficient strategy, in terms of cost and volume, of applying micronutrients, such that researchers apply these strategies in trials and blenders use them in their fertilizer products.

Coating Study: The objective of this ongoing activity is more efficient formulations and coating process for uniform distribution of micronutrients that leads to improved availability of nutrients from coatings and the carrier granules to crops. The optimized coating process and formulations ensure the integrity of the granules. Improved crop availability of nutrients is expected because of better physical distribution, particularly of micronutrients, and reduced chemical interactions between carrier macronutrient(s) and coated micronutrients. Commercial adhesive products and micronutrient coating sources of zinc, boron, and copper as well as mixing equipment have been procured to rapidly coat the micronutrients onto granular products. For this activity, granular urea, MAP, and DAP were coated with zinc borate and anhydrous borax products as a means of uniformly delivering appropriate amounts of the micronutrients zinc and boron along with the primary nutrients, nitrogen, and phosphorus. The substrates were coated with these micronutrient coatings with the help of corn starch, corn syrup, and calcium lignosulfonate as binders.

Physical properties were determined to assess the quality of the coatings and how they would hold up to handling and transportation. The critical relative humidity (CRH) and abrasion resistance were evaluated to measure the coating adherence. Products were chemically analyzed for total nitrogen, zinc, and boron.

A total of 62 products were coated, formulated to have nutrient ratios of 150N:2Zn:1B. Therefore, the urea-based products had a much larger coat weight than the MAP-based products. Degradation was not significantly different overall among the MAP samples. Degradation remained very low, regardless of the coating or binder. However, some products showed higher degradation than others, such as the products coated with the regular-size zinc borate and the products in which lignosulfonate was used as a binder. For the urea samples, the products in which no binder was used had higher degradation than products in which binders were used, excluding the corn starch binder.

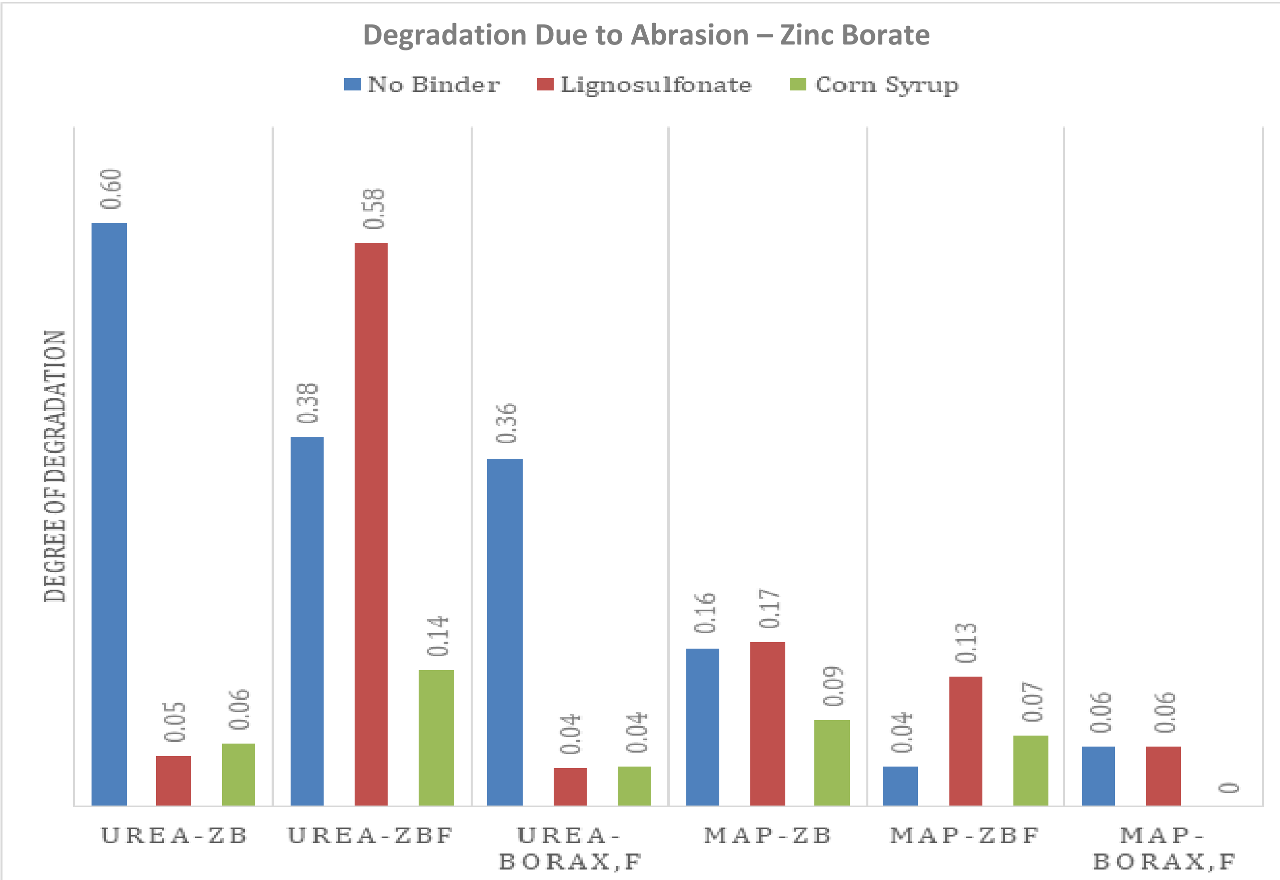


Figure 15. Degradation comparison in Zn borate and borax – regular and fine (F) MAP and urea products using different binders

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

Under this activity, data from the FTF 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 Geospatial Decision Support System for Agrotechnology Transfer (GSSAT) activity in Section 4.1.

Locations: *Ghana, Nepal, Niger, Mozambique*

Partners: SIL, Savanna Agricultural Research Institute (SARI), University for Development Studies (UDS), Ministry of Food and Agriculture (MOFA) in Ghana, Nepal Agricultural Research Council (NARC), Tribhuvan University, NSAF project, FAR Project (Mozambique), Institut National de la Recherche Agronomique du Niger (INRAN)

Outcome: Site-specific balanced fertilizer recommendations based on nutrient omission, fertilizer rate trials, and decision support tools

Progress:

A. Generate site- and crop-specific balanced fertilizer recommendations trials in Ghana

Best-Bet Trials: During FY2019-20, 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 to 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 ha^{-1}); (iv) "low" best-bet application (same NPK rates, but 50% of Zn, S, and B rates); and (v) "high" best-bet application (same NPK rates, but 125% of Zn, S, and B rates).

Across all locations, measured straw and grain yields from the check (no fertilizer) treatment produced low yields. The low yield for the check is consistent with the "very low" native soil fertility designation of the selected sites, suggesting that external fertilizer input is required for proper growth and development of the plants. Consistent with the nutrient omission trials, S, Zn, and B addition to the locally recommended NPK fertilizer significantly increased straw and grain yields, regardless of application rate. The "low" rate treatment significantly increased grain yield from an average of 4.85 mt ha^{-1} to 6.21 mt ha^{-1} relative to the NPK-only treatment. Increasing the rate to the estimated "best-bet" rate resulted in further increases in grain yield, reaching an average of 6.54 mt ha^{-1}. Further increasing the application rate to the "high" rate treatment resulted in average grain yield of 6.32 mt ha^{-1}. Although these differences in yield were not statistically significant, they were consistent across all experimental sites. These results show that applying a modest rate of S, Zn, and B (50% of the estimated "best-bet" rates) increased straw and grain yields by more than 36% and 28%, respectively, compared to the NPK-only treatment (Figure 16). The estimated "best-bet" rate, although S, Zn, and B rates were doubled from the "low" rates, did not result in a corresponding increase in straw and grain yields. A further increase in the S, Zn, and B application rate to the "high" rate (25% more than the estimated "best-bet" rate) resulted in a ~7% decrease in straw yield and 4% decrease in grain yield relative to the estimated "best-bet" rate (Figure 16).

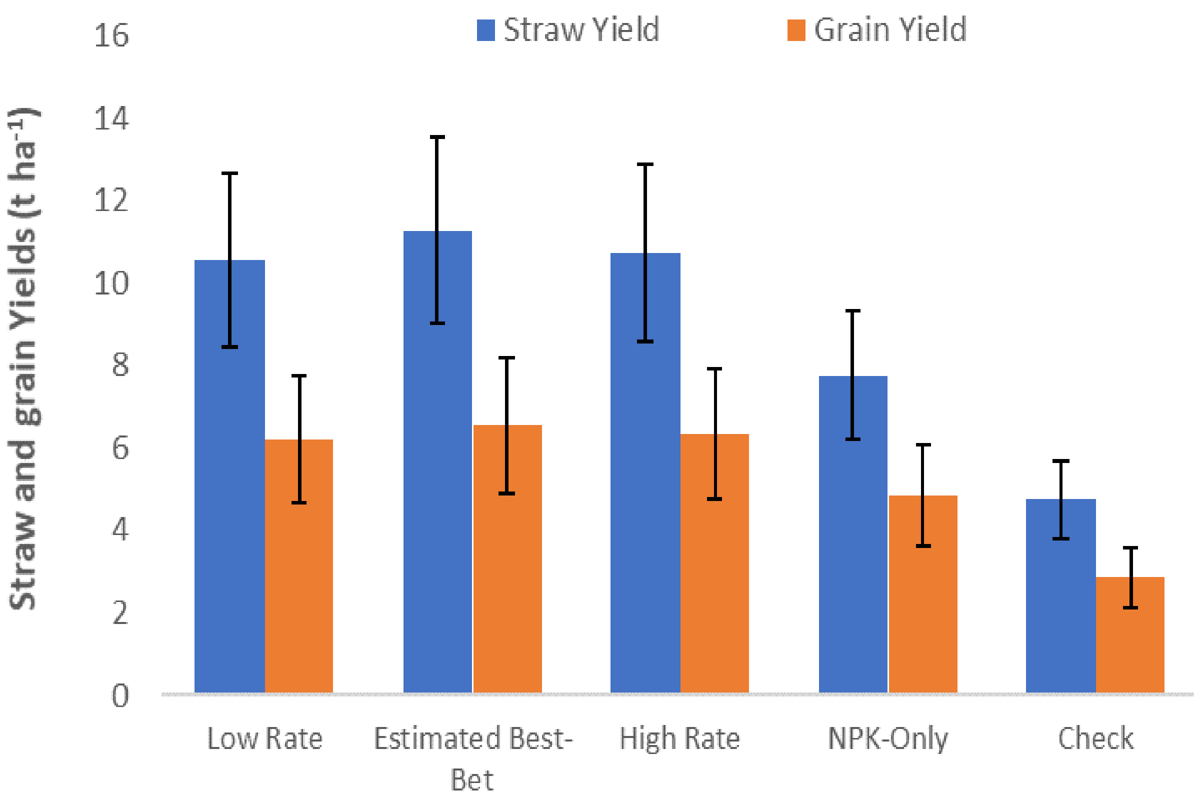
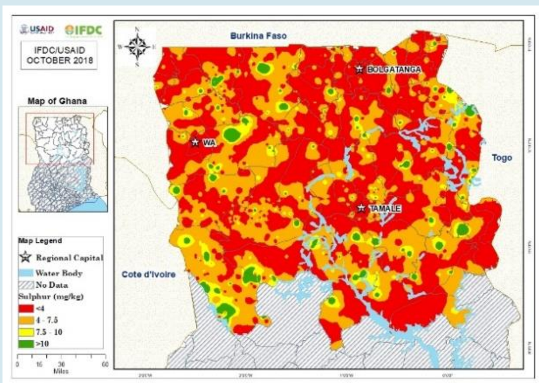


Figure 16. Effects of nutrient combinations and rates of application on maize biomass and grain yields

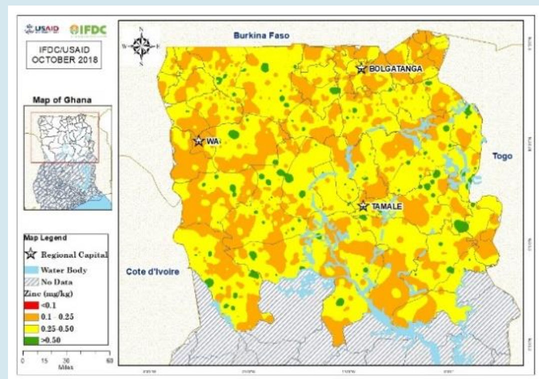
The preliminary results from the grain and straw yields suggest that applying 15 kg S ha^{-1}, 2.5 kg Zn ha^{-1}, and 0.5 kg B ha^{-1}, in addition to the locally recommended NPK rate for northern Ghana, could be the ideal fertilizer recommendation for maize production in northern Ghana. The trial is being repeated for a second year to validate the Year 1 results. The crops were harvested in October 2020, and the results are being collated. An economic analysis that considers the price combination of fertilizer and the value of marketable yield will be carried out to determine an economically optimal application rate for S, Zn, and B, in addition to the recommended NPK fertilizer, that will result in optimal profits for smallholder farmers.

Government Introduces "Balanced Fertilizers" to Staple Food Crop Farmers in Northern Ghana

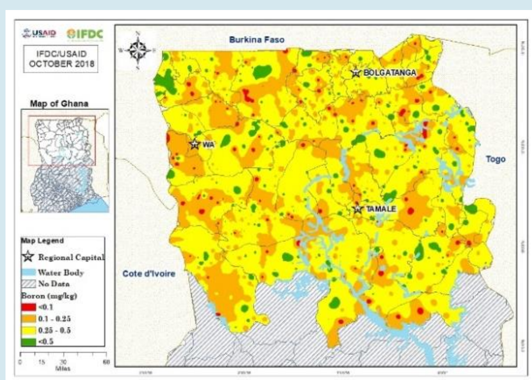
Despite a general response from cereals, such as maize, to the application of NPK fertilizers at current recommendations, the response often remains far below the potential level, especially under on-farm conditions. Continuous application of only NPK fertilizers tends to accelerate the depletion of nutrients that are not supplied, resulting in nutrient deficiencies or imbalances. Through extensive geo-referenced soil samplings and analyses, we have developed soil fertility maps for the USAID Feed the Future zone of influence (ZOI) in the five northern regions of Ghana. Results of the soil analyses show that large portions of the total land area have soils deficient in P (< 10 mg kg^{-1}), S (< 6 mg kg^{-1}), Zn (< 0.5 mg kg^{-1}), and B (< 0.5 mg kg^{-1}).



Soil sulfur concentration



Soil zinc concentration



Soil boron concentration

Maps showing spatial distribution of S, Zn, and Boron concentrations in soil within the five northern regions of Ghana

B. Updating fertilizer recommendations in Nepal for cereal and vegetable crops

Current fertilizer recommendations in Nepal are outdated (developed in the 1980s), and they are blanket country wide. The objective of the proposed activity, therefore, is to conduct knowledge-gap trials, facilitate the collection and assembling of all the available data on crop response to nutrient management in Nepal, and build a comprehensive database for use in updating fertilizer recommendations for Nepal's major crops. This is a partnership between the Nepal Agricultural Research Council (NARC) and the NSAF project on a cost-share basis.

Determination of Optimal N Rate in Rice across Different Agroecologies

Two field trials were conducted, one each at central terai region (Rupendehi District) and mid-hill district (Lamjung District) in 2020, in partnership with the Institute of Agriculture and Animal Science (IAAS), Tribhuvan University, comparing different N rates (0, 100, 120, 140, 160, and 180 kg N ha^{-1}), with the current recommended practice (100 kg N ha^{-1}) and the existing farmers' management practice. Altogether, there were seven treatments, including the efficient N product PCU.

Both trials are in maturity stage and will be harvested in November 2020. These results will be reported in the next semi-annual report (Figure 17).

The planned field trials in maize with blended fertilizers could not be conducted due to COVID-19 restrictions.

Figure 17. Field trial sites in (left) Lamjung District and (right) Rupandehi District for rice to determine the optimal N rate in two different agroecologies (mid-hill and central terai) in Nepal

Development of Guidelines for Domain-Specific Fertilizer Recommendations and Their Extrapolation using a Modeling Approach

Working in partnership with the NSAF project and NARC, support is being provided in developing guidelines for transitioning to domain-specific fertilizer recommendations based on the Soil-SMaRT approach developed by IFDC. These steps include determining targeted yield and nutrient requirement, estimating soil indigenous nutrient supply, and supplying the nutrient gap through fertilizers based on management of organic inputs and fertilizer recovery. Also, support is being provided to use a modeling approach for extrapolation of these recommendations. We are in the process of calibrating the Quantitative Evaluation of the Fertility of Tropical Soils (QUEFTS) model. NARC agreed with both approaches – domain-specific fertilizer recommendations and extrapolating using the QUEFTS model.

C. Developing soil maps for rice farming systems in Buzi

Based on results from soil analyses conducted under the FAR project in Mozambique, soil maps for 12 soil properties in digital format were developed. The maps will be distributed to public (including education institutions) and the private sector to develop crop-specific fertilizers that improve yields and economic returns compared to currently available fertilizers. An awareness creation meeting on the degree of nutrient deficiencies will be conducted with farmers, agricultural extension services, development agencies, and policymakers.

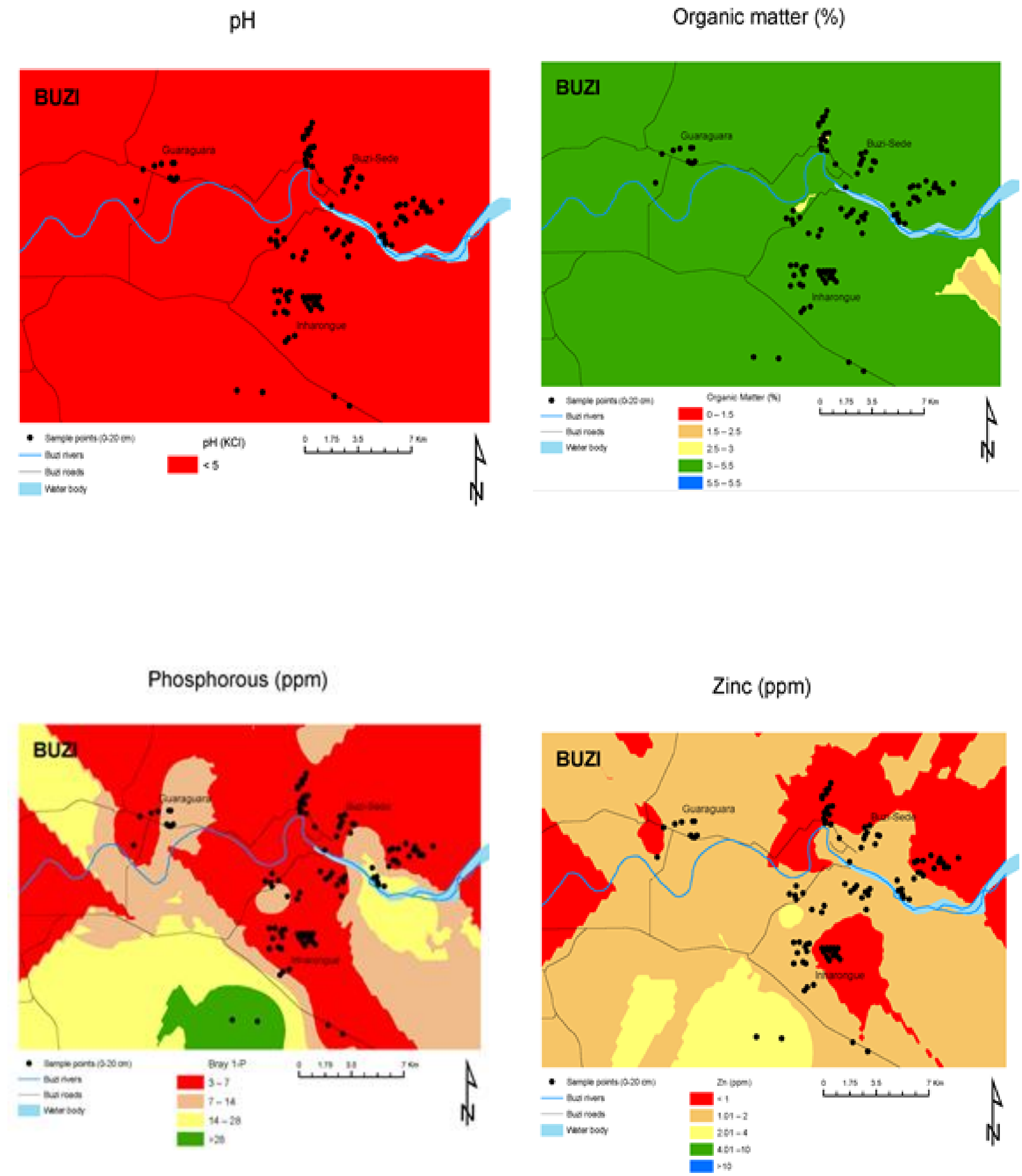


Figure 18. Selected soil properties, Buzi, Mozambique

D. Validation trials for new balanced fertilizer formulations in Niger (linked with Workstream 3)

This activity will leverage results and information generated from the ongoing soil fertility mapping project funded by the West Africa Agricultural Productivity Program (WAAPP)/World Bank in Niger and land capability classification maps generated by Land PKS decision support tool. Under the project, soil nutrient deficiencies and constraints were identified and mapped. The objective of the proposed activity, through field trials, is to verify the reported nutrient deficiencies and evaluate new balanced fertilizer formulations. Ex-ante analysis will be conducted to identify yield potential and yield gaps. The trials planned for May 2020 were delayed by the COVID-19 pandemic.

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

These activities utilize IFDC's global soil, plant, and fertilizer analyses data and crop responses to develop reliable spectral analytical procedures with high correlation to crop response and/or wet chemistry. This activity will also complement the development of N-Allyzer app (Activity 3.4.1).

Partners: Private sector (labs and equipment suppliers), fertilizer associations, Enhancing Growth through Regional Agricultural Input Systems (EnGRAIS) for West Africa project

Outcome: Improvement in fertilizer recommendations and analyses

Progress:

A. Wet chemistry-spectral analysis relationship with crop yield and nutrient response

The objective of this research is to provide the evidentiary basis for translating 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 valorized to maximum potential. This work forms the evidentiary basis for farm-specific data interpretation as well. 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 the best correlations of response for individual nutrients. X-ray fluorescence (XRF) will be used to quantify nutrients in soil, plant, and fertilizer samples. The ultimate long-term plan is to be able to use this new technology to prevent the need for hazardous chemicals and time-consuming procedures (wet chemistry) to more efficiently identify when, what, and how fertilizer should be applied. This methodology will allow farmers to conduct on-site real-time analysis without having to destroy the plants. Bruker has provided both instrument support and data sharing for this activity. At this moment, the focus is on fertilizer samples that include a wide variety of nutrients and concentrations. The goal is to develop a "global" calibration curve for XRF that performs as well as the traditional wet chemistry analysis. The results for initial correlation of the variables have been very encouraging, with R-square values ranging from as high as 0.99 for Mn and Ni to a low of 0.85 for K and Mo (Figure 19). Other elements, such as Mg, S, Cl, Ca, Cr, Fe, Co, Cu, Zn, As, Se, and Pb, were analyzed. (All of the graph comparisons are available.) Once the calibration curves were adjusted, IFDC HQ laboratories conducted several analyses on different fertilizer types, and overall, the calibrations showed very good responses. Still more work needs to be done, especially with elements that can originate from different matrixes. For example, the next step is to improve the K calibrations, taking into consideration different K sources. At this moment, Bruker is working to provide the initial calibration module in their instruments sold to the fertilizer industry.

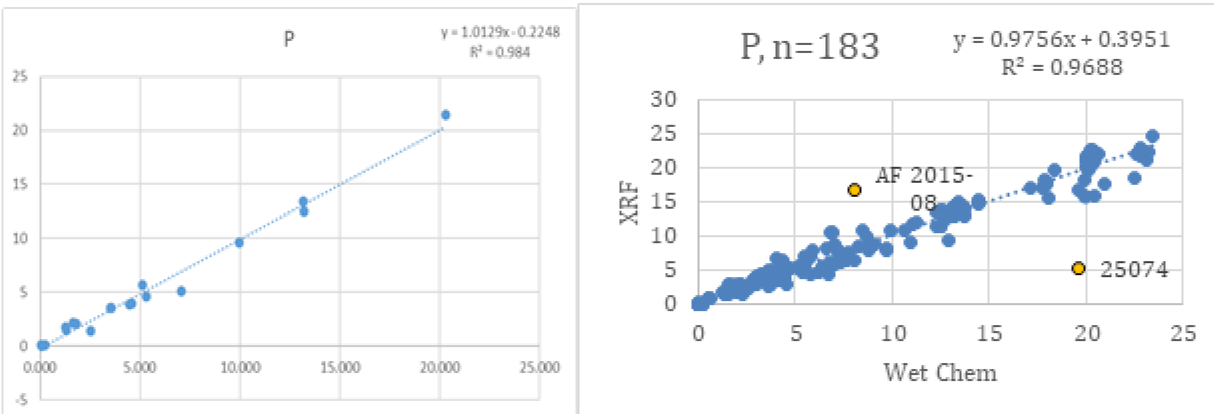


Figure 19. Result comparison analyzing a large number of samples for phosphorus

B. Evaluation of spectral and wet chemistry methods for detecting changes in soil nutrient status

While spectral analysis of soils is gaining widespread use, it does not accurately determine the availability of some nutrients, such as N and P. Further, spectral methods rely on algorithms that take several related soil properties and estimate elements in the soil. When fertilizers are applied, those related variables might not change, depending on the nutrient. A fundamental feature of the soil test is that it can recognize when a specific nutrient is applied. If spectral methods cannot recognize an increase in nutrient availability due to its application, then the test is not useful to a farmer who risks applying nutrients that are not necessary for his/her soil.

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 for fertilizer recommendations.

Four diverse soils were collected from Kenya for spiking with fertilizer nutrients. Results from this study will be presented during the next reporting cycle.

At IFDC HQ, a preliminary study was conducted with macronutrients (NPK) applied as granular fertilizers and micronutrients as liquid (solution). The sample was mixed and quickly analyzed using XRF techniques. The preliminary results showed differences between fertilizer and unfertilized soils (Figure 20). Based on these findings, a new protocol will be developed to look at different rates of application and verify whether the XRF methodology will be able to identify the changes in the amount of fertilizer application.

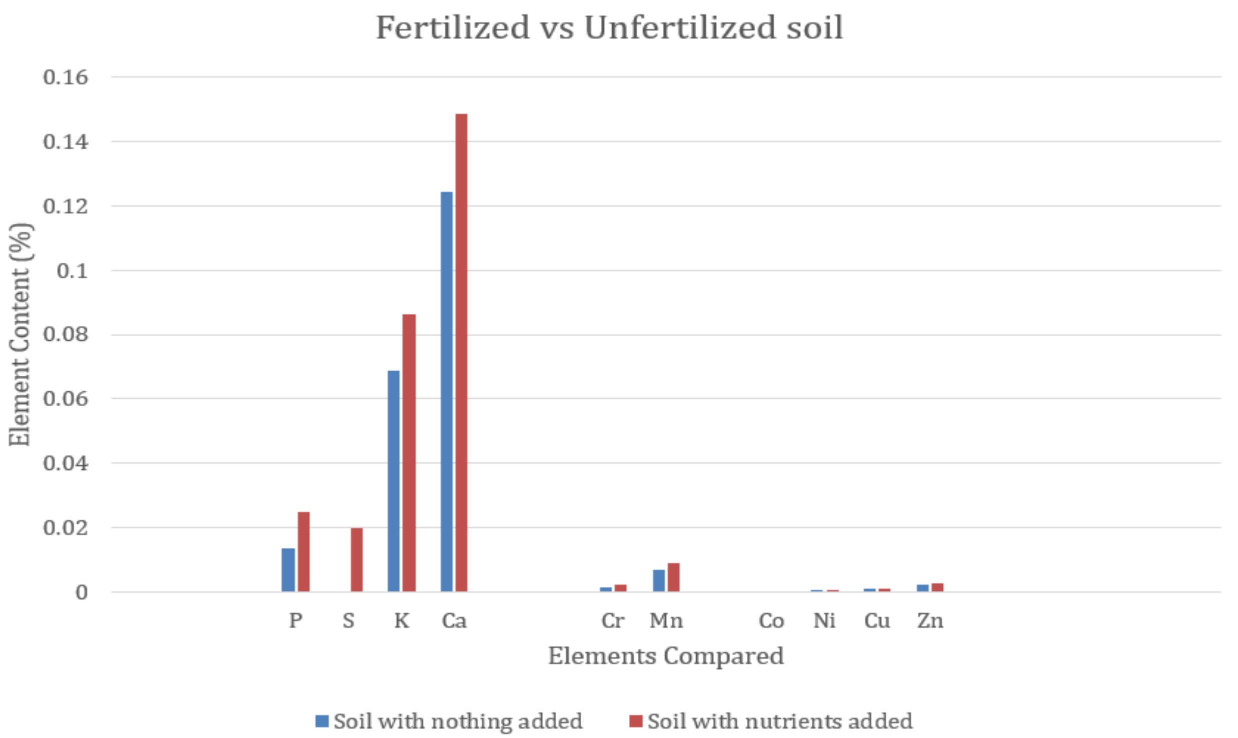


Figure 20. Comparison between elements on fertilized and unfertilized soils using XRF

C. Laboratory standards and standardized methodologies for fertilizers and amendments

Critical for fertilizer recommendation is reliable soil and plant analyses. Unfortunately, laboratories in many developing countries do not follow standard protocols, and quality assurance/quality control (QA/QC) is seldom followed or implemented. This activity addresses these issues by focusing on capacity building, developing training materials, and providing standardized soil and plant samples for QA/QC. International proficiency testing programs, such as Wageningen University and Research (WUR), BIPEA, AFPC, and Magruder, will be used or recommended for the quality control laboratories. We have assessed laboratories in five West African countries with the objective to help improve the current regional capabilities for fertilizer analyses by first focusing on the traditional mineral fertilizers and blends. Due to the COVID-19 pandemic, lab assessment was delayed for Nigeria and Ghana). Through the SOILS Consortium, this work will be expanded to improve the capacity building of the soil and fertilizer laboratories in Niger and Ethiopia with training and assistance.

With the increasing need to quantify nutrient inputs available in the market, particularly from new fertilizer materials (polymer-coated, slow-release, biofertilizers), plant biostimulants, and amendments, IFDC continues to be involved with public and private standards and regulatory organizations, such as International Organization for Standardization (ISO), International Fertilizer Association (IFA), and the Association of American Plant Food Control Officials (AAPFCO), to harmonize the methodologies, requirements, and vocabularies. This activity ensures that regulators and control officials have the available information and methodologies to verify the authenticity of the new upcoming products. As part of its involvement, IFDC is represented as the vice chair in the Magruder program and has been invited to be a member of the AOAC International method validation committee for sulfur analysis of fertilizers.

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

Poor crop residue and fallow management, excessive tillage, over-grazing, and monocropping result in soil degradation, particularly on soils inherently low in organic matter and are having severe environmental impacts in South and South-East Asia and SSA. Integrated soil fertility management (ISFM) and conservation agriculture (CA) practices can be employed to reduce and reverse this degradation and build healthy soils for improved production and environmental services. Sustainable intensification practices combine ISFM, CA, and alternative organic amendments, biofertilizers, and bio-stimulants to develop climate-smart cropping systems. The activities below combine ISFM, CA, and alternative organic amendments, biofertilizers, and biostimulants 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 and Niger (Linked with Workstream 3)

The synergistic effects of CA practices and ISFM along with activated PR as a P nutrient source is being evaluated for maize in northern Ghana. It was hypothesized that soil amendment with activated PR as a nutrient source, combined with CA and ISFM, will improve rooting and drought tolerance while reducing soil acidification.

Partners: Africa RISING project, Institut National de la Recherche Agronomique du Niger (INRAN), SOILS Consortium

Outcome: Sustainable intensification and soil health improvement as a result of CA practices combined with ISFM.

Progress:

Ghana: During FY2019-20, 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 at the locally recommended P rate; (ii) activated PR at 75% of the locally recommended P rate; (iii) DAP at the locally recommended P rate; (iv) DAP at 75% of the locally recommended P rate; (v) Togo phosphate rock at the locally recommended P rate; and (vi) control (0 P). At each location, a climate-resilient drought-tolerant maize hybrid was used as the test crop. Results showed synergistic benefits of CA and ISFM practices on maize grain yield. Generally, 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 FY2020, we repeated trials to validate the results obtained from the Year 1 trials. The trials were harvested in September and the results are being collated for analysis and reporting. Plant tissue and residual soil analyses for the previous year's trials were delayed due to the COVID-19 pandemic but are currently in progress.

Niger: The CA-ISFM millet trials that were scheduled to begin in April could not be established due to travel restrictions because of the COVID-19 pandemic. The activity has been rescheduled for FY2021.

1.4.2 Evaluation of the Role of Legumes in Rice and Maize-Based Farming Systems for Soil Fertility and Health Improvement and Income Generation in Mozambique

Since most farmers in the target areas (Beira Corridor, Mozambique) have no access to water for off-season cultivation of vegetables, the cultivation of groundnut, chickpea, or other drought-tolerant legume as an alternative crop in rice or maize rotation is being evaluated. Legumes and vegetables are profitable and can catalyze the use of fertilizers by smallholder farmers. Chickpea is a new crop for Beira farmers, requiring close collaboration with extension and research services. Since legumes respond well to P and Ca, activated PR, which provides both P and Ca, will be used as a P source. This activity complements the ongoing IFDC FAR project in Mozambique.

Partners: Yara Fertilizer Company, Agrodata co-local agro-dealers, District Economic Activities Services, and the USAID-funded Feed the Future Improved Seeds for Better Agriculture (SEMEAR) project

Outcome: Incorporation of legumes to improve soil health and income generation.

Progress:

Groundnut: We established 15 on-farm trials with farmers in Buzi to investigate the effect of P (single superphosphate) fertilizers in combination with liquid lime and gypsum products on yield of groundnut. Lime and gypsum application will increase pH (current pH < 5) and reduce salinity while supplying Ca and S – important nutrients for groundnut. Improved groundnut variety CG7 was planted November 27-30, 2019. Yield measurements have been completed. Yield of the improved variety CG7 tested is higher in a range of 30-50% than the local variety. However, yields were extremely low with no consistency across several treatments. This can be partially explained by fact that the farmers who hosted the trials took part of the produce before yield data measurements were done, which affected the quality of yield data. Though IFDC promised to offer all the produce to farmers (after the yield measurements), the farmers placed no trust in us. It should be stressed that this was the first time that IFDC worked with the groundnut farmers. In addition, this groundnut variety was new to the farmers. We held a meeting with community leaders and farmers to prevent this from being repeated in the future. We explained the importance of correct yield measurements.

Cowpea: In collaboration with the SEMEAR project, local seed production of cowpea was initiated on April 10, 2020, on 0.5 ha of land using IT16 and IT18 varieties. Harvesting and threshing of cowpea have been completed and will be followed by yield measurements.

Chickpea Performance in Crop Sequence with Rice: This activity was implemented relatively late due to the COVID-19 pandemic. Harvest is schedule for November.

On-Farm Groundnut Research and Demonstration Trials

The objective of this activity is to evaluate the role of groundnut in maize-based farming systems in Buzi District, Sofala Province, in food production, income generation, nutrient improvement, and soil health and create awareness among smallholder farmers on the performance of an improved groundnut variety. The activity was carried out in collaboration with IITA through the SEMEAR project, which works directly with 15 smallholder farmers who host the trials and indirectly with 70 smallholder farmers who attend field days. Outreach is small due to the restrictions imposed by the Government of Mozambique to prevent widespread exposure to COVID-19.

Although the data is still being analyzed, groundnut yields have increased due to the use of improved seed in combination with P fertilizers. This will have a positive impact on food security and improve smallholder income from increased grain sales. Yields of the improved variety, CG7, are higher than the local variety by 30-50%. Groundnut is one of the main sources of income in the area where the trials were established. From discussions with key informants, we estimated that about 70% of the groundnut produced by households is sold at an average price of 60 mt kg^{-1}.

While farmers showed interest in the groundnut variety, yields varied according to soil type. In sandy soils, yields were low (comparable with local variety) due to dry spells during the flowering phase. Therefore, massive on-farm trials to evaluate groundnut performance across the landscape are required to draw final conclusions. These trials should include a Spanish variety, such as Nametil, and improved cowpea varieties. To ensure the involvement of last-mile services, IFDC has already contacted Phoenix Seed Company as potential partner for improved seed provision.

1.4.3 Increasing Systems Productivity through Agronomic Biofortification with Crop Diversification and Intensification in Bangladesh

Intensive rice cultivation in Bangladesh, while helping to secure rice self-sufficiency, has resulted in pest and disease outbreak, declining soil fertility (due to imbalanced fertilization), depletion of groundwater table, etc. In addition, rice monoculture also reduces the production of non-rice crops, erodes biodiversity, and creates nutritional imbalance. Balanced fertilization and crop diversification could help to restore soil fertility and increase system productivity. Balanced fertilization and biofortified varieties can also improve grain quality and human nutrition. Diversification is also considered an effective approach to utilize scarce land and valuable water resources, and it makes agriculture sustainable and environmentally friendly. It offers comparatively high returns from crops by minimizing price and yield risk created by climatic variability and price volatility of agricultural produce while ensuring food and nutrition security, income growth, poverty alleviation, and employment generation.

Figure 21. Agronomic biofortification with crop diversification and intensification trials in northern Bangladesh

Partner: BINA

Outcome: Diversified cropping for sustainable intensification and agronomic biofortification

Progress:

To improve nutrient use efficiency, balanced crop nutrition through incorporation of secondary and micronutrients and sustainable soil intensification cropping patterns (T. Aman-mustard-maize [red amaranth or pulses as intercrop]) research was initiated in the micronutrient-deficient areas of Bangladesh, and two collaborative field experiments have been established by the BINA Soil Science Division at farmers' fields of Sundarban, Dinajpur (25°44'53.0"N 88°42'42.1"E), and Saidpur, Nilphamari (25°46'54.6"N 88°55'24.4"E), on July 18, 2020 and July 20, 2020 (Figure 21). A high-yielding T. Aman rice variety, Binadhan-17, was transplanted under 12 fertilizer treatments (Table 3). The experiments were laid out in randomized complete block design with three replications. Nutrients, i.e., N, P, K, S, and Zn, were applied based on soil and varietal recommended rate to all plots except farmers' practice. All fertilizer was applied as basal in each plot except for N, which was applied at 10, 30, and 55 DAT, respectively. Rice crops have reached the reproductive stage.

Table 3. Treatment description for crop diversification and intensification trials, 2020-21

Treatment No.	Description
1	Farmers' fertilizer practices
2*	Recommended practices (S as ES 13%)
3*	Recommended practices (S as ESS 13%)
4*	Recommended practices (S as ES 75%)
5*	Recommended practices (N as urea briquette)
6*	Recommended practices (N as PU)
7*	Recommended practices (-N)
8*	Recommended practices (-S)
9*	Recommended practices (-Zn)
10*	Recommended practices (-B)
11*	Recommended practices (-ZnB; NPKS only)
12*	Recommended practices (Compound fertilizer [NPSZn-Rice; NPKSB-Maize])

* N, P, K, S, and Zn applied at 90, 10, 50, 10, and 1.0 kg ha^{-1}, respectively.

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

The intensification of rice farming in Cambodia has generated significant increases in rice productivity but raised several questions related to the economic profitability, food quality and environmental sustainability. Rice farming is based on the principles of the green revolution with an increasing use of inorganic fertilizers, pesticides, and conventional tillage management (plough, rotovator, harrowing) inducing a continuous depletion of soil fertility. Among several factors, the improvement of soil fertility (soil organic carbon), overall soil health and use of conservation agricultural principles (minimum tillage, continuous soil cover and crop rotations) should be a central element of a sustainable intensification process. In addition, mechanization tools for various farm activities needs to be considered due to lack of availability of labor and increase the efficiency of the production systems.

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

Partners: Feed the Future Innovation Lab for Collaborative Research on Sustainable Intensification (SIIL), Kansas State University; 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; General Directorate of Agriculture (GDA), Department of Agricultural Land Resources Management (DALRM), Conservation Agriculture Service Center (CASC), Cambodia; Partnerships for Enhanced Engagement in Research (PEER) funded by 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, Agricultural Research Service, National Soil Dynamics Research Laboratory, Auburn, Alabama.

Outcome: Highly productive and sustainable CA production system for Cambodia based on yield and soil health quantification

Progress:

Since 2011, a paired-plot design, has been implemented in the Stung Chinit irrigation scheme (Santuk district, Kampong Thom province) assessing the performances of conventional tillage (CT) and conservation agriculture (CA) production systems using legume cover crops. The field experiment is located at Kampong Thom province (12°32’55” N and 105°08’47” E). The soil is characterized as sandy soil containing more than 70% of sand in 0-40 cm depth and classified as Prey Khmer group in Cambodian Agronomic Soil Classification System or Fluvisols/Arenosols in Food and Agriculture Organization of the United Nations (FAO) soil taxonomy.

The experimental plots are designed to test the effect of tillage practices (no-till and conventional tillage), cropping pattern and intensity (crop cycles and cover cropping), and fertilizer levels on the changes in soil health in lowland rice production (Table 4). Soil samples collected from 0-10 cm depth were analyzed for soil respiration, available N, available P, SOC fraction (hot-water extractable organic C and Permanganate oxidizable organic C [POXC], pH, Lamina bait, litter index, and water infiltration using the Biofunctool® approach at Soil Lab of the Royal University of Agriculture.

Table 4. Cropping systems pattern at the experimental site

Soil analysis			Paired-plot	Cropping system	Rice cycle	Fertilizer rate	2011	2012	2013	2014	2015	2016	2017	2018
Sampled and soil parameters assessed in Dec. 2014 + back up RUA	Dec. 2014	Dec. 2018	L1.1	CT	3 rice cycle	3	3 rice	3 rice	3 rice	2 rice	1 rice	1 rice	1 rice	1 rice
	Dec. 2014	Dec. 2018	L1.2	CA	3 rice cycle	3	3 rice	3 rice	3 rice	2 rice	1 rice	1 rice	1 rice	1 rice
	Dec. 2014	Dec. 2018	L4.1	CT	2 rice cycle: early wet + wet season rice	3	2 rice	2 rice	2 rice	2 rice	2 rice	1 rice	1 rice	1 rice
	Dec. 2014	Dec. 2018	L4.2	CA	2 rice cycle: early wet + wet season rice	3	2 rice	2 rice	2 rice	2 rice	2 rice	1 rice	1 rice	1 rice
	Dec. 2014	Dec. 2018	L5.1	CT	2 rice cycle: wet season rice + dry season	3	2 rice	2 rice	2 rice	2 rice	2 rice	1 rice	1 rice	1 rice
	Dec. 2014	Dec. 2018	L5.2	CA	2 rice cycle: wet season rice + dry season	3	2 rice	2 rice	2 rice	2 rice	2 rice	1 rice	1 rice	1 rice
	Dec. 2014	Dec. 2018	L6.1	CT	1 rice: wet season	3	1 rice	1 rice	1 rice	1 rice	1 rice	1 rice	1 rice	1 rice
	Dec. 2014	Dec. 2018	L6.2	CA	1 rice: wet season	3	1 rice	1 rice	1 rice	1 rice	1 rice	1 rice	1 rice	1 rice
Sampled and back up at the soil lab at RUA	Dec. 2014	Sampling can be done and quantification will be based on available funds	U5.1	CT	1 rice: wet season	3	1 rice	1 rice	1 rice	1 rice	1 rice	1 rice	1 rice	1 rice
	Dec. 2014		U5.2	CA	1 rice: wet season	3	1 rice	1 rice	1 rice	1 rice	1 rice	1 rice	1 rice	1 rice
	Dec. 2014		U6.1	CT	1 rice: wet season	3	1 rice	1 rice	1 rice	1 rice	1 rice	1 rice	1 rice	1 rice
	Dec. 2014		U6.2	CA	1 rice: wet season	3	1 rice	1 rice	1 rice	1 rice	1 rice	1 rice	1 rice	1 rice

Soil Organic Carbon Buildup and Available Nitrogen

Table 5 shows results of analysis between CA and CT systems. For all paired-plot, higher values of potassium permanganate oxidizable C (POXC) and soil respiration are observed under CA when compared with a plow-based management. Results indicate soil carbon buildup in the soil for CA compared with CT. In general, available N was higher in CA.

Table 5. Assessment of a range of soil parameters under conservation (CA), conventional tillage (CT) management, and native vegetation (NV), and rice yield (November 2019)

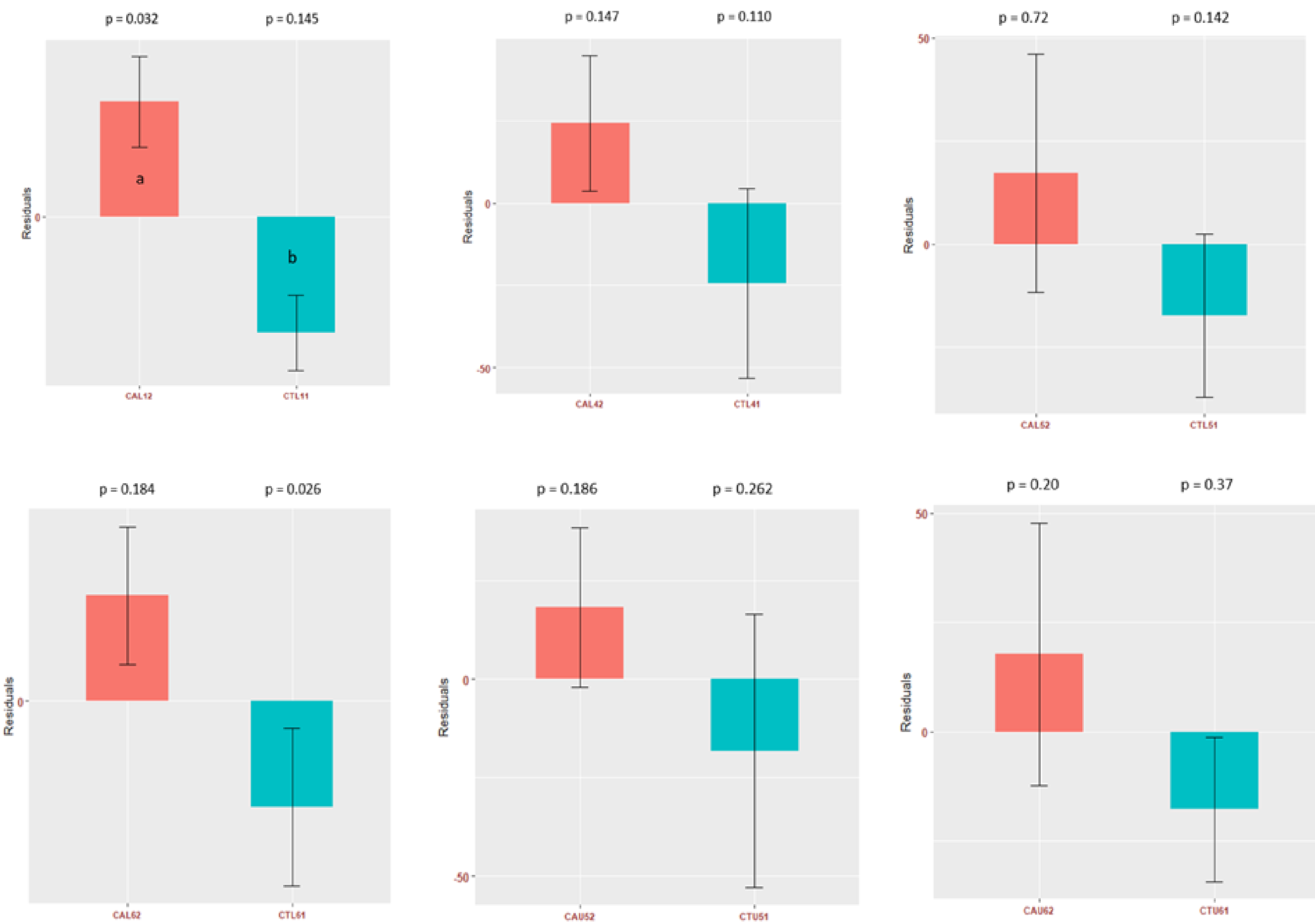
Treatment	POXC (mg/kg soil)		Available N (mg/100g)		pH-H20 (1:2.5)		P-Bray II (ppm)		Situresp Abs (T0-T24)		Rice yield 2019 (kg/ha)		
	mean	std dev	mean	std dev	mean	std dev	mean	std dev	mean	std dev	mean	std dev	Increase (kg/ha)
CT L11	721.5	37.4	36.9	6.6	5.20	0.20	26.9	14.7	0.91	0.36	898	686	
CA L12	777.5	36.7	50.9	19.3	4.88	0.23	14.6	7.5	0.88	0.31	1,447	468	549
CT L41	627.2	12.5	27.5	1.1	4.87	0.13	30.9	5.0	0.37	0.31	3,362	405	
CA L42	744.3	116.6	36.5	7.4	4.70	0.25	31.0	19.4	0.71	0.47	3,804	932	442
CT L51	627.9	31.3	35.3	10.2	4.95	0.21	21.9	6.6	0.42	0.26	4,463	717	
CA L52	672.9	64.3	33.9	8.1	4.78	0.41	35.9	8.2	0.60	0.38	4,349	335	-114
CT L61	669.5	63.9	33.9	5.5	5.03	0.29	31.5	14.1	0.69	0.31	3,107	629	
CA L62	753.8	46.8	41.4	6.5	4.73	0.29	20.9	9.1	0.92	0.20	3,630	130	524
CT U51	606.3	60.9	35.2	11.2	5.33	0.21	22.2	8.0	0.18	0.07	1,942	405	
CA U52	677.3	75.0	35.6	11.5	4.83	0.03	41.9	13.9	0.34	0.31	2,686	269	744
CT U61	644.7	42.9	36.9	13.2	5.32	0.21	25.3	16.6	0.31	0.28	3,305	553	
CA U62	761.1	57.4	39.1	10.9	4.67	0.23	26.6	10.3	0.86	0.34	3,439	837	133
NV	751.9	88.4	44.2	9.9	4.74	0.19	17.7	23.7	0.74	0.26			

Trend of C-Stabilization and C-Mineralization

Figure 22, based on the approach develop by Hurisso et al. (2016),[2] shows the trend of soil organic C stabilization under CA when compared with CT. However, significant difference can only be observed when comparing the paired plots L11 and L12. In addition, the plots L12 and L61 showed a significant trend of SOC stabilization and SOC mineralization, respectively, at

[2] Hurisso, T.T., S.W. Culman, W.R. Horwath, J. Wade, D. Cass, J.W. Beniston, T.M. Bowles, A.S. Grandy, A.J. Franzluebbers, M.E. Schipanski, S.T. Lucas, and C.M. Ugarte. 2016. "Comparison of permanganate-oxidizable carbon and mineralizable carbon for assessment of organic matter stabilization and mineralization," *Soil Science Society of America Journal*, 80:1352. https://doi.org/10.2136/sssaj2016.04.0106

p < 0.05. Additional data for samples collected in June 2019, show higher SOC and N contents for CA versus CT, along with higher cation exchange capacity (CEC), P and K (Table 6).



Note: The x-axis represents CA-based management – CA L12, CA L42, CA L52, CA L62, CA U52, and CA U62 – versus plow-based management – CT L11, CT L41, CT L51, CT L61, CT U51, and CT U61; regression was made between values of POXC and SituResp®. Residuals mean values below zero represent a trend of mineralizable soil organic C, values above zero reflect a trend of short-term SOC stabilization. Vertical line represents the standard error per treatment.

Figure 22. Mean values of regression residuals per treatment (n=4, y-axis "residuals")

Table 6. Changes in soil parameters (pH, P, K, Cation Exchange Capacity (CEC), Available N, Soil Organic Carbon [SOC] between Conservation Agriculture (CA) and Conventional Tillage (CT) management, Stung Chinit. Paired-plot CT L41 and CA L42

Treatment	pH $CaCl_2$	pH H_2O	P (ppm)	K (mEq/ 100g soil)	CEC (mEq/ 100 g soil)	Available N (%)	SOC (g C / kg)
CA	4.31	5.23	18.57	0.32	11.4	0.06	1.99
CT	4.37	5.32	13.85	0.29	8.8	0.03	0.95
Difference CA-CT	-0.06	-0.09	4.72	0.03	2.63	0.03	1.04

Crop Simulation Modeling – Data for Long-Term Predictions of Soil Health

The team has been parameterizing the cropping systems, soils, topography, and weather data and the corresponding yield and soil health data collected from the plots for long-term modeling using the Soil and Water Assessment Tool (SWAT), Agricultural Policy/Environmental eXtender (APEX), and Decision Support System for Agrotechnology Transfer (DSSAT) models. The training and hiring of a team of graduate students and undergraduates who will do the modeling are being done in synergy with other projects. Two abstracts have been accepted for presentation at the 2020 Annual International Meeting of the American Society of Agricultural and Biological Engineers (ASABE), Omaha, Nebraska, July 12-15, 2020, which used the data from this activity. The papers are 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." A proposal was written to Swiss Development Corporation on modeling the Tonle Sap Basin under Conservation Agriculture and Conventional Tillage Production Systems. The 2019 and 2020 rice yield data in CA and CT will be used in evaluating the performance of the APEX model.

Conservation Agriculture for Commercial Vegetable Home Garden Tools

A draft publication with descriptions and recommendations of hand tools, such as digging tools for no-till transplanting, hoes, rakes and cultivators, forks, sickles, weeding knives, shears, and scissors, for commercial vegetable home garden production system using conservation agriculture techniques been completed. A downloadable link for the publication can be found at: https://drive.google.com/file/d/1Tco_fn0hddwzZCPDxYEApVhKDN6IT11l/view

Methods of Cover Crop Crimping, Rice Seed Drilling, and Rice Harvesting

A description and recommendations of machineries in conservation agriculture production system for no-till seed drilling or broadcasting, fertilizer application, cover crop crimping, and rice harvesting will be summarized. The advantages and disadvantages of machines for CA application and their availability and cost in Cambodia are being tabulated.

Through the USAID/SIIL-funded CE SAIN, another Ph.D. scholarship was provided to Royal University of Agriculture Faculty, Lyhour Hin. He was paired with three mentors in the USA: Dr. Ted Kornecki, an agricultural engineering scientist from USDA-ARS in Auburn, Alabama; Horace Clemmons, owner of Cleber LLC, a business on open systems agricultural machinery; and Dr. Manny Reyes. Lyhour has been testing open systems agricultural machines (OSAM) that can be manufactured in Cambodia. Performance of those machines were tested (see list of presentations below). With power provided by the OSAM-Oggun tractor, Hin (2020) studied the performance of the Kornecki USDA crimper and the Kornecki USDA no-till vegetable transplanter and found promising results. In the next phase, we will evaluate the urea deep placement equipment in Cambodian conditions and test the performance of the A-Click open systems tractor and A-Click conservation agriculture implements designed and patented by the United States Department of Agriculture's Agricultural Research Service. Royal University of Agriculture is licensed to manufacture Cleber's Oggun tractors and the USDA CA implements and can provide licenses to private manufacturers in Cambodia. Performance of the Cambodian-manufactured Oggun tractor and Kornecki-USDA implements, to be called A-Click, together with the urea deep placement equipment, will be tested in Cambodia.

1.4.6 Impact of Nutrient Recycling, Biofertilizers, and Biostimulants on Yield and Soil Health

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 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.

Location: *IFDC HQ, US*

Partners: Private sector start-ups, Auburn University, farmers

Outcome: Improved monitoring of soil health and evaluation of organic fertilizers for improved productivity and soil health

Progress:

Established in 1911 to demonstrate the utility of crop rotations and cover crops, the Cullars rotation at Auburn University has long been a resource for field calibration material for soil testing resources. While 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. The objective of this project was to conduct a 14-week incubation study using selected plots from the Cullars rotation and to compare N mineralization from that predicted via the initial Solvita test. Four replicated treatments from the Cullars rotation were utilized, with soils sampled from the 0-15 cm layer in those plots: (i) no N fertilizer and a winter legume cover crop; (ii) no N fertilizer and no winter legume cover crop; (iii) complete NPK fertilization and no winter legume; and (iv) complete NPK fertilization, micronutrients, and a winter legume cover crop. Initial analyses indicate significant difference in initial nitrate-N and ammonium-N, a result of 109 years of organic matter accumulation in the cover crop and fertilized plots. The graduate student involved in this study, Annabelle McEachin, will present her finding during Annual American Society of Agronomy meeting in November 2020. The long-term study with the soils from all over Alabama is also in progress. Complete results will be presented in the next semi-annual report.

We also conducted preliminary greenhouse studies on sorghum and soybean quantifying nutrient release from organic fertilizers: (i) black soldier fly larvae manure; (ii) dried distillers' grains plus solubles (DDGS), produced by vacuum pyrolysis using corn byproduct from ethanol production; and (iii) saw-dust derived humic acid and biochar together with conventional balanced fertilization. Initial results indicate that integrated organic-inorganic products will be a more realistic choice or significantly higher quantities of organic fertilizers than used in the current greenhouse study (3 g kg^{-1}) are needed (Figure 23). Crops will be harvested in November. Complete results will be presented in the next semi-annual report.

Figure 23. Greenhouse sorghum with response to balanced NPK fertilizers

Figure 24. Field trial on soybean with organic fertilizer – DDGS

The above organic fertilizers were also evaluated under field conditions on soybean in Leighton, Alabama (Figure 24). Results from harvest at mid-season and at maturity will be presented in the next reporting cycle.

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

Under Workstream 2, IFDC conducts socio-economic research and analysis for evidence-based policies, to support reform initiatives on soil fertility management practices and technologies, including complementary agricultural inputs, toward accelerated farm yields and market systems. The activities associated with this workstream primarily focus on FTF countries; an exception can be made for a non-FTF country to be part of the policy research agenda if there are useful replicable lessons to be learned. The three broad categories under this workstream include document and advocate policy reform processes; conducting evidence-based research and analysis of soil fertility interventions; and conducting socio-economic feasibility studies on scaling up soil fertility and input-based technologies.

There are three focus areas of research under workstream 2, which includes.

(2.1) Influencing soil fertility related policy reform processes and market development.

(2.2) Impact assessment studies, and

(2.3) Economic and market research studies

A summary of research activities and accomplishments for the three focus areas under Workstream 2 follows.

2.1 Influencing Policy Reform Processes and Market Development

Activities focus on documenting country-level or regional policy support efforts that provide the necessary impetus to catalyze existing reforms in fertilizer sector. With RFS-SFT support, IFDC partners with organizations and stakeholders at various levels in countries that show high potential for policy change by: (i) engagement of stakeholders through various forums, consultations, and other advocacy modes; and (ii) production of policy briefs and background research evidence to build the capacity of stakeholders on soil fertility-related issues at the country level for wider dissemination.

Highlights for the current reporting period include:

- Continued support of fertilizer sector platform for policy advocacy and reform processes through consultations in Kenya.
- Dissemination of fertilizer policy reforms and regulations among stakeholders in Niger

2.1.1 Support Fertilizer Platform and Policy Reform Processes in Kenya

A. Stakeholder Consultations with KeFERT

Following the launch of the Kenya Fertilizer Platform (KeFERT)[3] in June 2019, IFDC was asked to serve as the advisor and coordinator for KeFERT in providing technical advice on soil heath- and fertilizer market-related issues. In this regard, regular meetings were held among the

[3] A public-private initiative to serve the interests of the stakeholders toward preparing an effective roadmap on fertilizer policy reforms and markets in Kenya (https://ifdc.org/kefert/).

stakeholders, followed by few key consultations organized to discuss the issues relevant to fertilizer stakeholders.

Progress:

KeFERT activities suffered this year from COVID-19 restrictions, as in-person events sponsored by stakeholders, which had typically consisted of half-day events in which stakeholders heard presentations by experts on relevant topics, debated and discussed, and formed action plans to address priority issues in the sector, could not be held. Instead, KeFERT hosted one virtual event August 4, 2020, on soil mapping, through a project undertaken by IFDC with OCP funding, in which an online portal containing soil information was presented by service provider Crop Nutrition Laboratory Services (CNLS).[4] The online portal will be made public once completed. The virtual event was opened by Principal Secretary Hamadi Boga of the Ministry of Agriculture, Livestock, Fisheries and Cooperatives, while KALRO presented the closing remarks and next steps. The purpose of the event was to generate enthusiasm among KeFERT stakeholders and to encourage owners of soil information to share it for the common good. A follow-up event targeting a global audience will be held in November 2020 to present the final tool. Mapping is important because it identifies regions of individual nutrient deficiencies and soil pH constraints and identifies regions of nutrient sufficiency. Mapping in Kenya is crucial for several reasons:

- To inform policymakers of the need for multi-nutrient fertilizers.
- To inform the lime industry as to where to target their products.
- To inform fertilizer manufacturers and blenders where to develop and target their products.

B. Participation in the USAID/Kenya Policy Technical Working Group 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 likewise suffered from lack of in-person field activities due to COVID-19 restrictions. The format adopted was to feature a guest speaker relevant to PTWG members. The first event after the start of COVID-19 took place in June, with Thule Lenneiye from the Ministry of Agriculture and head of the Agricultural Transformation Office speaking about the newly formed unit. All meetings were conducted virtually among the implementing partners. Three more PTWG meetings were held in July, August, and September 2020 virtually; topics discussed included:

- System strengthening and policy support to the county governments in arid and semi-arid (ASAL) areas by Kenneth Owuocha, Deputy Chief of Party, Kenya Resilient Arid Lands Partnership for Integrated Development (RAPID).
- Liaising with counties in unlocking capital and investment opportunities by Bahati Morara, Business Enabling Environment Advisor.

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[4] Report available at https://ifdc.sharepoint.com/:f:/s/Communications/El8oSZBhboZCr6og2gAzlK4By0cnCusv6ccPiFcAyMnP3Q?e=qT2fJg.

- Exploring KALRO's role in agricultural policy development in Kenya by Dr. Wellington Mulinge, Assistant Director of Social Economics and Policy Development, KALRO.

Since IFDCs intervention areas are aligned with the proposed priorities of the Kenya Mission on input policies and market systems, public and private sector capacity development, and coordination of thematic policy groups, e.g., KeFERT, the Kenya Mission further encouraged coordination with various implementing partner activities on agro-inputs in Kenya and exploration of opportunities for partnerships.

C. Dissemination of New Fertilizer Regulations in Niger

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 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 the above effort, RFS-SFT in close collaboration with the MCC-funded PARSEN project supported the large-scale dissemination of these new fertilizer regulations across the country among the stakeholders, seeking to create an enabling environment for better implementation when the regulations take effect during the end of 2020.

Opening of new fertilizer regulations validation workshop in Niamey, Niger

Progress:

The dissemination activity launched in March 2020 to raise awareness among key stakeholders on the new legal framework for fertilizer. The dissemination involved distribution of outreach materials to stakeholders and messaging through mass media channels, involving television and radio. Two types of dissemination efforts were taken up that include:

Distribution of Informative Materials:

Despite COVID-19 and the ban on large public gatherings, distribution of hard copies of the five new regulations in have been done in the remaining two regions of Niger, hence completed in all seven regions, excluding Niamey.

Meeting in Agadez with local stakeholders to discuss progress of fertilizer sector reform in Niger

Communication through Mass Media (TV and Radio):

Two short 2-minute videos and audio spots in the Zarma and Hausa languages on the regulations have been aired on both TV and radio according to the following schedule:

- National Tele Sahel and Dounia have aired the video spot six and nine times, respectively, in May.
- Thirteen radio stations in the seven regions have broadcast the audio spots on the regulations 30 times each during the months of May and June.

The major outcome expected from this fertilizer regulation dissemination activity is expected to be an improvement in the knowledge on the recently authorized new fertilizer regulations and laws among the key stakeholders in the fertilizer value chain, including farmers, to improve the functioning of the fertilizer sector in Niger.

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

Progress has been made in Bangladesh, Niger, and Nigeria on documenting key issues related to fertilizer (or inputs in general) and technology access and availability.[5] The data from rapid surveys are being analyzed and results are being documented toward final reporting in December 2020. The delays are due to the COVID-19 shutdown, during which time surveys could not be implemented among stakeholders as planned.

[5] 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.

In **Bangladesh**, initially we planned to document a policy brief identifying characteristics of fertilizer consumption, use, and access through a set of measurable indicators over the last three decades. Since the COVID-19 shutdown, we developed a quick survey to conduct remotely to document the effects of COVID-19 on input access in rural areas, market participation by farming households during the harvesting season (Boro), and plans for the next cropping period. For this purpose, a survey among 100 farmers selected randomly from 10 upazilas was conducted to determine the immediate effect of the shutdown on the farm gate prices for the harvested produce, likely issues faced by farmers in the supply chain, and farmers' cropping plans for the following season, as well as to document farmer awareness of COVID-19 and sources of information on farm-level access to information on agro-inputs, etc. A few key highlights from the results include the following:

- Yields obtained from Boro season paddy were not affected since the onset of COVID-19 and shutdown happened during the harvest time. Yet farmers faced major issues during the harvesting season coupled with shut down: (i) shortages of labor for harvesting (81% of farmers reported) and (ii) almost all of the farmers interviewed paid higher wages to laborers (as high as 20%) compared to previous years.
- Average farm-level production of Boro paddy was around 4,039 kilograms (kg), of which each farmer retained 70% for future sale. About 73% of farmers surveyed indicated higher retention for home consumption (~1,435 kg per farmer) this year vs. past years, an increase of about 30%, to ensure household food security due to uncertainty caused by COVID-19 and lower purchasing power.

The effect of the COVID-19 shutdown on the cropping pattern, access to inputs and information, and how farmers cope, along with government responses, are being documented and the final report and will be submitted in December 2020.

COVID-19 Shutdown and Its Impact on a Woman Fertilizer Briquetting Entrepreneur in Bangladesh

Salma Begum, located in Mahmudpur Bazar of Satkira District in Bangladesh, is a farmer cum entrepreneur who has been engaged in the production and sale of fertilizer briquettes of urea and NPK. Ms. Begum purchases her fertilizer for briquette making from the Bangladesh Chemical Industries Corporation (BCIC) authorized dealers and other raw materials such as diesel from local markets for her business operations.

Ms. Begum was trained in technical and business management aspects of fertilizer briquetting through USAID's Accelerating Agriculture Productivity Improvement (AAPI) and the Walmart Foundation project on rice and vegetable production during 2011-2016. Since 2014, Ms. Begum has been selling 50 metric tons (1,000 bags) of fertilizer briquettes to 500 rice and vegetable growers and fishponds in her village communities. She normally earns BDT 17,000-

19,000 per metric ton from the sale of briquettes per cropping season. Ms. Begum has been also providing full-time employment to two local persons (BDT 350 each day) in her shop to assist her in business operations. The COVID-19 shutdown from March to June this year impacted Ms. Begum's business operations in terms of reduced shopping time from the regular 12 hours to 6 hours. This affected her business operations with lower sales and she subsequently had to let go of the staff employed in her shop. During the COVID-19 restrictions, she only sold 3 mt of fertilizer briquettes, consisting of 2 mt of NPK for BDT 19,000 per mt and 1 mt of urea briquette at BDT 17,000 per mt. Last year during the same period, she sold 5.15 mt of fertilizer briquettes. She noted the reasons for the lower sales this year included farmers' inability to sell vegetables and crops due to a lack of buyers from metro towns, thus affecting their purchasing power to buy briquettes. Ms. Begum said, "Farmers are suffering a lot due to the very low sale price of vegetables due to the unavailability of buyers from long distances and they cannot buy a sufficient amount of fertilizer for the next crop …. That is affecting both the farmers and my business as well."

As a small entrepreneur, Ms. Begum could not extend credit to farmers to purchase briquettes as she herself is financing the business operations through credit from a money lender with very high interest rate. Since COVID-19, she has adopted several hygienic precautions in her shop, including washing her hands frequently, wearing a mask, and maintaining social distancing while dealing with customers in her shop.

Niger has been undergoing a fertilizer reform process with the assistance of MCC-Niger since FY2018. To complement this effort, stakeholder dissemination activities also have been conducted from February 2020 onward *(refer to Activity C under 2.1.1)*. Following the dissemination efforts, a feedback survey also has been implemented since September to understand the knowledge awareness and expected changes among the stakeholders and the institutions toward the functioning of fertilizer distribution and the value chain in general.

The proposed policy brief on *Does Involvement of the Private Sector Improve the Distribution Efficiency of Subsidized Fertilizers, especially through the existing parastatal CAIMA in Niger?* will be documented based on the feedback from the stakeholder survey to complement the ongoing reform processes in Niger.

Progress:

Stakeholder surveys on fertilizer regulations and the dissemination effort have been initiated since September (originally planned to begin in June and delayed due to COVID-19). For this purpose, a 211 respondents across seven regions and 21 departments, comprising 111 fertilizer dealers, 71 producers, and 29 agricultural technicians, are being interviewed to understand the awareness and knowledge on new policies and regulations in Niger. A detailed policy brief based on the results from the dissemination feedback surveys along with recommendations will be completed in December 2020.

Nigeria: A policy brief on *How do the Recent Fertilizer Bans (on Urea and NPK) Affect Fertilizer Uptake in Value Chains and Food Security Objectives?* is being documented. The activity is carried out through the involvement of IFDC's North and West Africa office in Nigeria.

Progress:

Since the concurrence from the mission was finalized during early 2020, we were able to initiate this activity during the second half of FY2020 workplan period. However, due to the COVID-19 onset, followed by the shutdown through August 2020, survey activities could only begin in

September 2020 and will be completed during Q1 of the FY2021 reporting period. Rapid key informant interviews with private suppliers/distributors and farmers in three states – Adamawa, Borno, and Yobe – in Northeastern Nigeria are planned through structured surveys. The results from the surveys and discussions will be analyzed, and a detailed policy note addressing short- and medium-term effects of the restrictions on the value chain along with constraints faced by stakeholders will be prepared. The policy note will be disseminated across the public and private sector stakeholder forums for necessary feedback for further action.

2.2 Impact Assessment Studies

To support policy reforms for the development of input markets and value chains, this sub-activity primarily focuses on producing evidence-based studies to understand the impacts or effectiveness of technologies related to soil fertility management and the related fertilizer policy reforms and other market-related interventions toward improved access to inputs for small farm households.

Progress made during the current reporting period includes:

- Advancement in the research to study the determinants of fertilizer use in Senegal among small farm households.
- Results from the assessment of the effectiveness of agro-dealer development programs on input supplier networks and improved access to and use of technologies among farmers in Rwanda.
- Headway on analyzing the economic costs to control counterfeit fertilizer products and best options and practices available for fertilizer certification in Kenya.

2.2.1 Determinants of Small Farmer Demand for Fertilizers in Senegal

This new activity was included in the FY2020 workplan as a partnership activity to complement the requirements of the newly initiated Feed the Future Senegal Dundël Suuf, which is part of the larger Feed the Future Enhancing Growth through Regional Agricultural Input Systems (EnGRAIS) Project for West Africa, and the Global Food Security Strategy.

In Senegal, despite the government subsidy programs, 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.

The main goal of this study is to understand the determinants of fertilizer use in Senegal. Specifically, this involves characterization of fertilizer consumption (including adoptions rates, profiling) based on rigorous econometric analysis of factors affecting fertilizer demand and understanding the potential yield gaps among smallholders due to inefficient fertilizer adoption methods.

Groundnut fields in the Peanut Basin

Progress:

Detailed household data have been collected from 420 small farmers located in the Senegal River Delta (SRD) region, where a national-level rice and vegetable crop-based system for self-sufficiency program is implemented through irrigation, and in the Peanut Basin (PB), where other high fertilizer consumption crops (peanut, maize, cotton) are grown, mostly under rainfed systems. These farmers come from five departments (Dagana and Podor in the SRD and Kaolack, Nioro, Kaffrine and Fatick in the PB) and 60 villages. The study is conducted by Bureau d'Analyses Macro-Économiques (BAME) researchers and graduate students, with advice and participation from the IFDC North and West Africa Regional Economist based in Senegal.

Rural household sampling and field surveys have been completed. Data analysis is being carried out and the results will be reported during the Q1 of FY2021. The final set of outputs from this research include:

- Research report based on qualitative and quantitative analysis.
- Policy brief identifying factors that enhance programs promoting fertilizer use in small-scale farms.
- A clean and complete farm household database will be generated.

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

This activity was initiated with the Agribusiness-Focused Partnership Organization (AGRIFOP), a local Rwandan civil society organization, and in partnership with the Alliance for a Green Revolution in Africa (AGRA)-Rwanda, involving capacity building of agro-dealer programs in Rwanda. The purpose of the assessment is to profile and document the contribution of agro-dealer development programs toward establishing sustained agricultural input networks and making inputs available, accessible, and affordable to smallholder farmers in Rwanda since 2010.

Progress:

For this assessment, 150 agro-dealers from 10 districts in all four provinces (East, West, North, and South) were sampled based on their participation in to various agro-dealer capacity building initiatives provided by donor programs (COMESA Regional Agricultural Inputs Programme [COMRAP], AGRA, USAID); it includes those who are still in business, those who never received any such skills training, and those who left the input business operations despite training. Ten focus group discussions among 210 farmers were also held to determine farmers' access to inputs through agro-dealers and the knowledge gained through such channels.

Analysis of our survey results indicates that the demand for agro-inputs has increased in Rwanda due to agro-dealer networks and strengthening through programs. There are currently more than 1,500 agro-dealers supplying inputs throughout the country; of those, 60% are trained and are still in business. The average distances traveled by the farmers to agro-dealer shops has decreased from 20 km (in 2009-10) to less than 3 km. The effect of financial institutions on credit delivery also has increased. The focus group discussions also indicate reduced transaction costs with the increased number of dealers and access to improved technologies, especially new varieties of seeds and fertilizers.

In our survey, we compared the effectiveness of input retailers reach to farmers by comparing two groups of retailers, i.e., retailers who have received and participated successfully in the agro-dealer development capacity building programs (trained) vs. dealers who have never received any kind of capacity building to improve their technical knowledge, management practices, etc. (non-trained). The results from our analysis indicate (Table 7) there are significant differences in the engagement of retailers with farmers in terms of extending technologies, accessibility or reach and sustained business operations and participation in market-related interventions between the groups. The trained agro-dealers have been engaged actively in the retailing business operations, compared to the non-trained dealers, with an increase in sales due to involvement in technology transfers.

The data from the surveys have been further analyzed to understand the extent of the agro-dealer development program effectiveness in Rwanda toward improving the efficiency and delivery of agro-inputs and in dissemination of inputs knowledge among farmers, how sustainable are these agro-input businesses, and what are the factors that ensure the delivery of agro-inputs to smallholders.

A final analytical report along with policy implications will be submitted in December 2020. This will be followed by a dissemination workshop to share the findings of the assessment, which is planned during FY2021.

Table 7. Comparison of trained vs. non-trained agro-dealers in Rwanda

Agro-Dealer Characteristics (mean values)	Trained (n=102)	Non-Trained (n=26)
Agro-dealer by gender		
Male (%)	73	46
Female (%)	27	54
Employees/shop (#)	2	1
Micro retailers (#)	2	
Years in business (#)	9.7	3.4
Initial investment (U.S. $)	2,611	1,083
Current sales value of inputs (U.S. $) **(fertilizers and CPPs only)	30,238	8,460
Radius of business coverage (km)	3.5	5.1
Villages covered (#)	19	14
Conducted farm demonstrations (%)	82	31
Received loan from financial institution (%)	76	50
Extends inputs credit to farmers (%)	78	69
Receives credit from input suppliers (%)	21	27
Participated in input voucher program (%)	85	38
Number of vouchers distributed per year (#)	3,598	1,400
Involved in output commodities trading (%)	12	4

Source: Agro-dealer survey results, 2019-20.

2.2.3 Analyze Impact of Counterfeit Fertilizer Products and Options for Fertilizer Certification in Kenya

Counterfeit fertilizers not only result in an inferior product to 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 was the presence of counterfeit fertilizers. These 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.

Progress:

Due to the COVID-19 shutdown in Kenya, we could not initiate the survey among the stakeholders until September.

- Currently, the interviews are being conducted among fertilizer value chain actors and Kenya fertilizer industry-related public sector regulators, such as the Kenya Fertilizer Board, Kenya Bureau of Standards and Ministry of Agriculture officials.
- A detailed literature review along with best practice options or successful models implemented in other countries across different agro-inputs, including the pharmaceutical industry (such as seeds and animal and human health-related), will be documented. This will allow us to undertake a detailed economic analysis of the extent and costs of fertilizer counterfeits, particularly to the Kenyan economy, and suggest options for fertilizer certification involving private and public sector entities using best practices approaches for counterfeits.
- A draft report will be submitted during the semi-annual reporting period of FY2021 and will be disseminated through a webinar or presentation through KeFERT to obtain the necessary feedback.

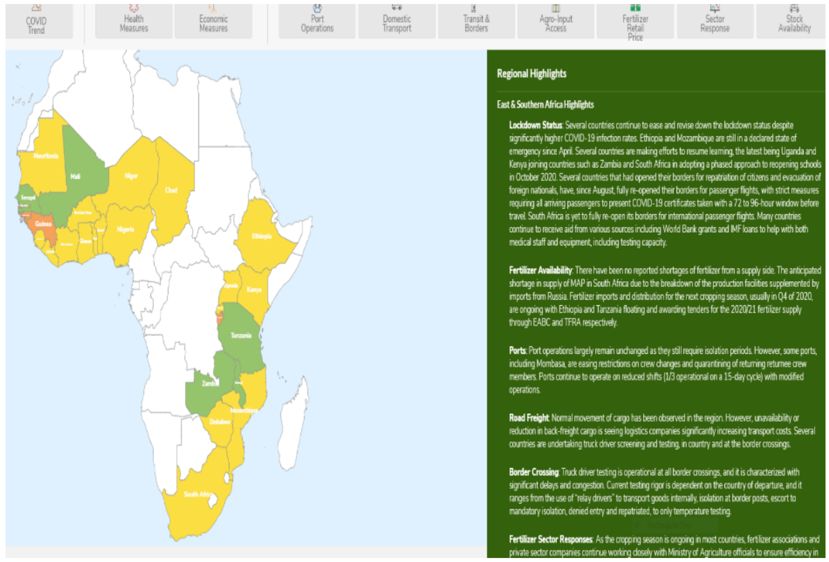
2.3 Economic and Market Studies

IFDC's economic studies include: evaluation of various soil fertility-enhancing technologies in terms of economic returns and also financial returns toward scaling; 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.

The activities planned in the FY2020 workplan were initiated in March 2020 and are currently under various stages of implementation. We have also made modifications to accommodate studying the various impacts of the COVID-19 pandemic shutdown in selected Asian and SSA countries. Activities that are currently in progress include:

- Initiated weekly updates with the *Fertilizer Watch* in the East and Southern Africa region due to the COVID-19 shutdown with collaboration from the IFDC-AfricaFertilizer.org (AFO) partnership.

2.3.1 Fertilizer Watch Reports in East and Southern Africa



As an immediate response to the COVID-19 pandemic, IFDC and our ongoing fertilizer marketing initiative, AfricaFertilizer.org (AFO) launched a weekly East and Southern Africa *COVID-19 Fertilizer Watch* starting Thursday, April 23. This weekly one-page document tracks the impact of COVID-19 interventions on the delivery and use of fertilizers in African countries and, in doing so, allows public and private sectors and development partners to monitor agricultural production and food security in the region. IFDC had already launched the COVID-19 Fertilizer Watch in West Africa and has launched an Africa-wide Watch as well. The weekly Fertilizer Watch has provided updates, with a mix of quantitative and qualitative data on nine indicators in 28 countries in Africa to date. The watch has attracted a lot of interest from various stakeholders, including the Africa Union and other regional economic communities, including the Economic Community of West African States, East African Community, and others.

Africa COVID-19 Watch Indicators

1. Magnitude of COVID-19 in Africa:
   - Number of COVID-19 cases recorded as of date of release.
   - Rate of increase in COVID-19 cases compared to the previous month.
2. Public health and economic measures:
   - Public health measures, such quarantine, social distancing, curfews, and state of emergency status.
   - Economic measures, such as business operations, financial incentives, and waivers.
3. Measures with a direct impact on fertilizers along the supply chain:
   - Port operations – discharge rates, congestion/delays, prioritizing of vessels, labor and shifts, initiatives.
   - Domestic transport – free movement of local and transit cargo, classification of movement of essential goods, restrictions, delays, initiatives.
   - Border crossing – restrictions (cargo), congestion/delays, closure.
   - Agro-dealers – Allowed to operate, restrictions, access to product, price changes.

Progress:

The Africa Fertilizer Watch has been greatly appreciated by private sector businesses all along the value chain, public sector and development partners responsible for policy and food security interventions, including Government Ministries, Regional Economic Communities, IFA, and the

African Union, as a valuable tool to monitor actions and analyze data to help in decision-making related to fertilizer availability and use.

Through this weekly Fertilizer Watch and for the coming months, IFDC wants to ensure that fertilizers are moving freely across the region, from ports and plants to farms, and that sufficient fertilizers are reaching the farmers in time for planting so that productivity and food security needs are met. We expect that, as the agricultural season evolves, other related indicators and data will need to be tracked and we will update the Fertilizer Watch accordingly. The East and Southern Africa COVID-19 Fertilizer Watch will pertain to the following countries: Ethiopia, Kenya, Uganda, Rwanda, Burundi, Tanzania, Mozambique, Zambia, Zimbabwe, Malawi, and South Africa, covering the major consuming countries and fertilizer trade corridors in the region. The weekly reports on fertilizer access-related measures will be collected from stakeholders in the fertilizer value chain and documented for wider public outreach.

The outputs from the COVID-19 Fertilizer Watch included:

- Bi-weekly one-page regional highlight of the impact of COVID-19 on the fertilizer sector for 11 East and Southern African countries and a detailed country write-up of each indicator by country. https://ifdc.org/2020/08/06/measuring-covid-19s-impact-on-the-fertilizer-sector-in-sub-saharan-africa/
- Development Gateway developed an interactive page for the COVID-19 Fertilizer Watch hosted on an independent site/AFO website for the July to September monthly publications.
- Fertilizer stakeholders interested and/or active in the East and Southern African market have an up-to-date comprehensive view of the impact of COVID-19 on the fertilizer market, which will be extended through December 2020.

2.3.2 Women's Access to and Use of Fertilizers in Field Crops and Vegetables – Case of Input Retailers in Uganda and Mozambique

For various reasons, female farmers use less fertilizer than male farmers. Studies show that female farmers are as efficient as male farmers, but they produce less because they control less land, use fewer inputs, and have less access to important services, such as extension advice. The outcome of this effort is to generate a series of country-level case studies that offer best practices for IFDC and others, incorporating technologies that are "gender neutral" to those that are "gender aware" and eventually "gender transformative."

Progress:

- Discussions were held with IFDC colleagues in Uganda in February about conducting a case study on the role of last-mile women input suppliers in improved access to fertilizers in the southeastern region of Uganda. The activity will be carried out in collaboration with the Uganda National Agro-Input Dealer Association (UNADA).
- However, due to the extended shut down until August and with the beginning of the rainy season (planting season), we could not finalize the sampling among farmers and input dealers before the end of September.
- We further plan to initiate the activity in Uganda and in Mozambique during Q1 and Q2 of FY2021 and generate two case studies documenting the gender access to and use of fertilizers.

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

Coordination and alignment of activities have been a significant component to the work plan of the SOILS Consortium. Research activities have been developed and are underway in Niger and Ethiopia.

The research activities in Niger (3.1) focus on enhancing resilience to food insecurity and conflict through land-use planning, soil rehabilitation strategies that involve developing the capacities of in-country research institutions, and collaboration through effective partnerships in producing research evidence.

The activities to be implemented in Ethiopia (3.2) focus on developing improved soil fertility-enhancing tools and management practice to address productivity issues associated with key cereals and legumes with national and international agricultural research partners for effective scaling.

The activities and accomplishments outlined in the following sections below fit within a unified agenda that was developed in collaboration with lead soil fertility partners. As each of these activities was developed, significant input was also received from the other partners to either collaborate with these activities or to align plans by donors.

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

Five related research activities have been developed and are underway in Niger. These activities are applicable to regional aspects of soil fertility management and land-use planning.

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 (LCCs) 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.

Partners: Jason Neff, University of Colorado; Jeff Herrick, USDA Agricultural Research Service (ARS)

Outcome: Land Use Management Decision Support Tool (version 1.0) developed for further validation and improvement

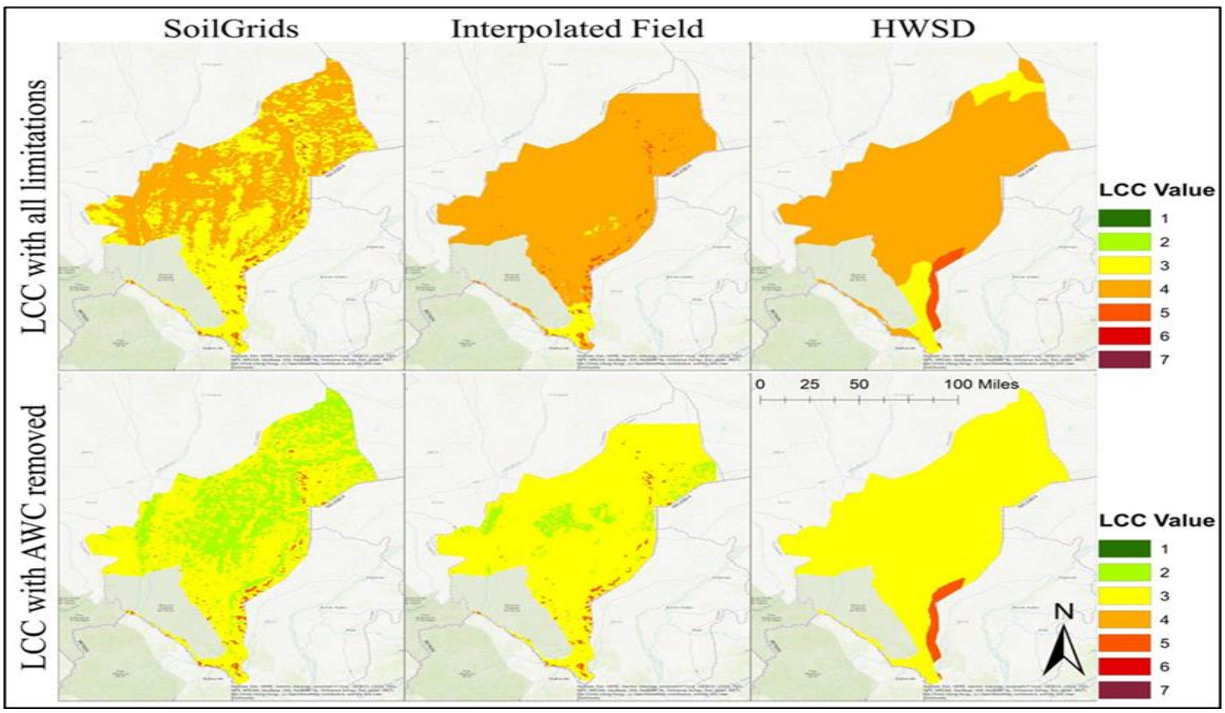
Progress:
Mapping of LCCs for the Dosso Region, Niger, has been completed and presented to stakeholders. There are three maps based on the Harmonized World Soil Database (HWSD) soil product, the ISRIC Soil Grids product, and a final map based on field sampling of over 1,100 sites by IFDC. The maps have been shared through an interim report, short presentation and recording, and a manuscript has been developed, circulated for a first review by authors, and

submitted (October 2020). The shape files for the LCC products are with the Millennium Challenge Corporation (MCC) technical team for feedback and evaluation of the potential for use at the commune level. These first stage products are nearing completion and represent the current state of our understanding of land capability given the data products available to us.

This project will continue until January 2021. In that time period, an initial assessment of the Normalized Difference Vegetation Index (NDVI) time series on 30-plus IFDC plots will be completed and, pending the results of that assessment, this effort will be expanded to a larger group of field sites. The intent with the NDVI work is to determine whether we can capture the effects of soil moisture limitations (such as available water content) in the annual time series of crops. If we can, we can further test the LCC map, but more importantly, we will have a new approach to mapping drought vulnerability. Our current focus is on evaluation of the slope of the greenup phase, peak biomass period, and rate of vegetation greenness loss after peak biomass. We hope this work will result in a proof-of-concept paper by the end of 2020/early 2021, but that will depend upon the outcome of the study. The first round of results were promising, so we are cautiously optimistic.

Impact of COVID-19:

- Field visits for validation were postponed, and the meeting to obtain feedback from Nigerien stakeholders was held virtually. All deliverables are on track.



Note: LCC ranges from 1 to 8 (lower is better) and is calculated on a per pixel basis. Removing available water content (AWC) as a constraint improves the LCC values.

Figure 25. Land capability classification (LCC) maps for SoilGrids, field data, and harmonized world soil database (HWSD)

3.1.2 Remote Sensing and Improved Use of Soil Data, Niger

The objective of this activity is the use of remote sensing to aid in the identification of at-risk soil areas and selection of agronomic methods best suited for the soils.

Specific activities include:

- Ground truthing to calibrate LandPKS (delayed due to COVID-19).
- Socio-economic analysis using Niger Living Standards Measurement Study – Integrated Surveys on Agriculture (LSMS-ISA) data (available from World Bank).
- Household survey preparation and data collection (delayed due to COVID-19).
- Household survey analysis.
- Training workshop (changed to virtual due to COVID-19).
- 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

Outcome: Use of LandPKS and remote sensing as tools for decision-making.

Progress:

MSU-ICRISAT-LandPKS: The LandPKS training workshop was planned for virtual implementation in April; however, due to connectivity issues, PowerPoint presentations will be shared with the trainees, followed by a virtual meeting in May. The subsequent ground survey in Dosso, Niger, is planned for late June/early July following the incorporation of IFDC's Supported Crop Fertilization for Sustainable Agriculture in Niger (AFRAD) project data. By the end of April, there will be a training workshop report (sensitizing Nigerien scientists [INRAN et al.] and extension on the use of LandPKS and draft soil hardness maps with ICRISAT). INRAN scientists will have a major role in this training and field data collection as well.

MSU Economic Profitability Assessment: The economic profitability assessment based on the Niger LSMS (a panel survey conducted by Niger/World Bank; thus, data has already been collected) is currently in preparation for analysis. Insights on technology profitability will be derived from this survey in June/July. There will be some preliminary insights on the prevalence of factors associated with farmers' use of various soil fertility management and soil-water conservation practices by late April.

Impact of COVID-19:

- The in-person training has been changed to a virtual training, and the planned field study and household survey have been delayed.

Note: This activity is also linked with Validation Trials for New Balanced Fertilizer Formulations in Workstream 1.3.2.

3.1.3 LandPKS Collaboration with Auburn University

This activity provides general support of the LandPKS platform. The goal is to improve the soil taxonomic unit descriptions and subsequent management information, with a focus on lateritic soils, for the LandPKS app to support the Niger activities and the use of LandPKS more broadly.

Partnership: Joey Shaw and Beth Guertal, Auburn University

Deliverables:

While the basics of the LandPKS soil inventory program are already developed, FAO and World Reference Base (WRB) databases are being used to improve soil taxonomic unit descriptions of the soils of Niger and other regions. These taxonomic descriptions are correlated to map units that provide a foundation to LandPKS. Once these descriptions are developed, the specific soil characteristics and properties will be described to improve the inventory and interpretive value of the taxonomic descriptions. Specifically, there is a need to create unique descriptions for each of the ~170 group/sub-group combinations. Given the not-infrequent contradictions between FAO's group and sub-group descriptions, this will require a fair bit of careful expert consideration. Significant progress has been made in updating these descriptions to date.

In the second portion, existing data is being evaluated (FAO, WRB, Soil Taxonomy, peer-reviewed literature, etc.) to further develop management considerations and strategies for the soil taxonomic units. LandPKS also needs to have continued editing to improve the readability (for target audiences – extension and farmers with some education in the developing world) and information value. This editing is designed to provide a strong link between the soil information obtained from the LandPKS program (what the farmer or extension professional sees on their phone) and how that translates to agronomic and land management information for the grower. This could include, but is not limited to, specific cropping system, tillage, soil fertility, or crop selection recommendations.

Progress:

FAO and WRB databases have been used to improve soil taxonomic unit descriptions of the soils of Niger and other regions in the LandPKS app.

Editing has been provided to the LandPKS app to link soil classifications to land management information.

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

The objective of this study is to provide insights and recommendations on how the SOILS Consortium and its implementing partners can better utilize digital extension tools, platforms, approaches, and services to increase the reach and success of their activities and thereby help strengthen resilience. This will take into account the country's challenges with literacy, gender, and connectivity, as well as USAID's priority to integrate activities in ways that can enhance resilience in Niger.

The Feed the Future Developing Local Extension Capacity (DLEC) project and the SOILS Consortium are conducting a study in Niger to support iREACH to use the most appropriate extension platform, tools, approaches, and services, particularly digital as they establish Technology Parks.

Specific activities will include:

- Conduct an extension and digital extension landscape analysis in Niger, including:
    - The digital ecosystem of Niger, including mobile and internet usage, trends, and regional comparisons.

  - Public and private extension systems, taking into consideration the access, quality, and sustainability of these systems (including engagement of youth and women and support for overall livelihood strategies of farmers).
  - Gender and literacy challenges in Niger, specifically those related to the use of digital tools and services.
- Using expert opinion, farmer feedback, and secondary sources, analyze the effectiveness of the extension platforms, tools, approaches, and services in providing information to farmers in Niger.
- Using the digital extension typology, provide recommendations to strengthen digital extension platforms, tools, approaches, and services in Niger.
- Provide recommendations for the most appropriate extension platforms, tools, approaches, and services for iREACH to share soils, agronomy, and livelihood information in Niger, as well as recommend potential partners and stakeholders who can support the SOILS Consortium to build capacity and implement digital solutions. The report will focus on Niger, but generalizable recommendations for the other iREACH West African countries will also be valuable.

Partnership: DLEC, SOILS Consortium, INRAN, IFDC-Niger

Outcomes: This study will influence the SOILS Consortium work in Niger as it establishes a Technology Park in Niger. This study focusing on Niger will allow the SOILS Consortium to apply approaches that can be replicated across other Technology Parks in West Africa.

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 and is currently in progress as outlined below. Greenhouse trials were initiated in March-April 2020 to generate critical data for evaluation of the teff model.

3.2.1 Targeting Fertilizer Source and Rate in Ethiopia

The goal of this activity is to produce a model for prediction of responses to different nutrient combinations and rates, with emphasis on K, S, Zn, and B, that 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 link to crop response. The intended use of the model is within a dedicated decision support tool (DST) 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.

Progress:

A unified Fertilizer Trial Protocol has been developed with the Ethiopian Institute of Agricultural Research (EIAR). However, due to COVID-19, only the trials implemented by the

SOILS Consortium were conducted. More than 300 trial sites have been established for wheat, sorghum, and teff crops at three landscape positions in four regional states of Ethiopia. Field supervisions were conducted through a collaboration of the ICRISAT and IFDC teams, and 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 are conducted virtually.

The trials are progressing well, and the required data is being collected on time. Teff harvesting will start in October from trial sites located at low to medium rainfall areas. Data on yield and yield components will be collected and reported after all the sites have been harvested. Soil samples were collected from all trial sites at two depths (0-20 and 20-60/40 cm) and are under preparation at the National Soil Testing Center, Addis Ababa, Ethiopia. Soil samples will be analyzed at IFDC HQ laboratory in Muscle Shoals, Alabama. Spectral determination of the soil samples will be performed in Ethiopia and at the IFDC lab.

Data compilation has begun, with the historical IFDC and ICRISAT data currently being combined and cleaned.

Partnership: ICRISAT, IFDC, SOILS Consortium, EIAR, Regional Agricultural Research Institutes (RARIs)

Progress:

A unified fertilizer trial protocol that includes core fertilizer treatments and minimum supporting parameters. The collaborative model and joint planning with the national system on common protocols will provide access to large datasets coming from the various institutions, including EIAR, the four RARIs, universities, CGIAR centers, large donor-funded projects including Capacity Building for Scaling up of Evidence-based Best Practices in Agricultural Production of Ethiopia (CASCAPE), and SOILS Consortium investments. Moreover, the Excellence in Agronomy (EiA) team is now considering the Ethiopian fertilizer research as a use case to test broader concepts and investments. Targeted and gap-filling field trials on teff (175 sites), wheat (75 sites), and sorghum (50 sites). These trials are currently in the field and regular field visits have been conducted to track progress.

Historical data from fertilizer response trials relevant to the objectives of this research will also be reviewed with the intent of integrating such data into our model. Special attention will be paid to collecting data from EthioSIS, EIAR, RARIs, universities, and CGIAR centers that have a set of minimum characteristics that would allow integration. 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.

Impact of COVID-19:

No delay has occurred; however, movement of goods and personnel to some districts reduced the target number of trials from 400 to just over 300.

Figure 26. Ongoing field trials on teff, wheat, and sorghum

3.2.2 Decision Support Systems for Improved Access to Information and Farming Practices

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. Mulugeta Demiss, Visiting Scientist from the Ethiopian Agricultural Transformation Agency (until April 30, 2020) and then SOILS Consortium post-doc (since May 2020), has been developing a teff model, which will be included within the DSSAT suite of crop models.

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.

Progress:

Greenhouse trials to quantify the effects of N response, plant population, and flooding/waterlogging on teff was initiated in March-May 2020. Data from N response trials were collected at heading stage (April 27) and at final harvest (June 23). Data from all other trials were collected at final harvest. An interesting result – and not reported by anyone previously – showed that teff, just like rice, can be grown from transplanting to maturity under flooded conditions.

Figure 27. Effect of N fertilizer rates on teff

Figure 28. Teff grown under fully upland to fully flooded conditions

Collection of additional data for model validation and application from the 175 teff field trials is planned under the “Targeting Fertilizer Source and Rate in Ethiopia” activity.

Partnership: SOILS Consortium, NARCS, universities

Impact of COVID-19:

Analysis and reporting of the greenhouse trials have been delayed because Mulugeta Demiss traveled to Ethiopia in July 2020, prompted by COVID-19, to assist with Activity 3.2.1 – Targeting Fertilizer Source and Rate in Ethiopia.

3.2.3 Quantifying Effect of Rainfall and Fertilizer Use on Crop Production in Ethiopia

Water and nutrients are 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 is affected by rainfall pattern and amount, amount of fertilizer used, and their interaction. 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 is under review.

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

4.1 Centralized Database and Improving Decision-Making Tools for Soil Sustainability Processes

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). Within this partnership we are also improving the existing soil dynamics model in the DSSAT Cropping System Model using the soil and agronomic data generated by IFDC over past years. The database and decision support tools will help in making timely and reliable recommendations on fertilizers, sowing dates, and other management inputs covering a wide range of biophysical and socioeconomic conditions.

Accomplishments:

- A centralized database platform has been established and a total of 4,176 experiments (29,122 records) from Bangladesh, Myanmar, Northern Ghana, and the United States are available on the platform (http://database.ifdc.org:9000/cropsitedb) (Figure 29).
- Platform was redesigned and expanded, providing new features to import, export, search, visualize, and maintain various kinds of data (AgMIP's data format, raw data, papers, documents, manuals, photos, and weather data).
- Improvements to the DSSAT Cropping System Model include: (i) soil carbon (C) balance precisely tracks all soil C and N state variables during computation of organic matter decomposition processes (including emissions of CO_2), organic matter application events, and tillage events; (ii) evaluation of nitrous oxide emission; and (iii) a generic fertilizer routine allowing users to create custom blends of fertilizers and evaluate the effect of urease and nitrification inhibitors and controlled-release fertilizers.

4.1.1 Develop IFDC Centralized Database Using AgMIP Database Template

The objective of this center-wide initiative is to collect all research and development data in standard accessible formats, collate all data and analyses, and make these available through the IFDC website. The IFDC data management and sharing services will be organized based on the principles of FAIR, i.e., easily findable, accessible, interoperable (compatibility of systems), and reusable. The IFDC database will be compatible with CGIAR and USDA data platforms. Data interoperability will also allow capture of older datasets, which are often archived in distributed locations and diverse formats and do not use a consistent vocabulary. IFDC envisages that this approach will also facilitate the reuse of these data for quantitative analyses, including for in modeling activities and synthesis for recommendations and policy reforms. This effort will avoid poor documentation and even loss of data due to a lack of a centralized system.

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

Outcome: Improve storage, analyses, and sharing of data within IFDC and full public access to all non-confidential data and results.

Progress:

During April-September 2020, 122 experiments carried out in Myanmar between 2014 and 2019 and three nano-technology experiments carried out at IFDC HQ between 2018 and 2020 were uploaded to the IFDC database. The VMapper tool developed by the University of Florida was used for data preparation prior to uploading.

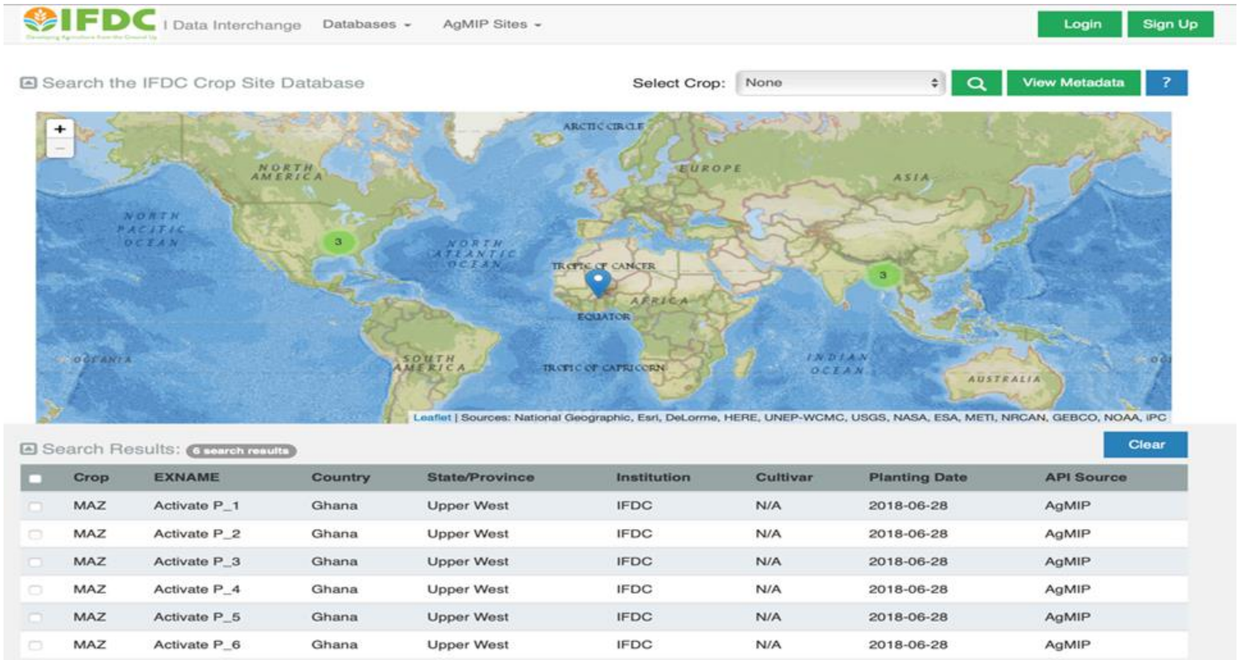


Figure 29. IFDC Crop Site Database

During 2020 the platform was redesigned and expanded, providing new features to import, export, search, visualize, and maintain different kinds of data (AgMIP's data format, raw data, papers, documents, manuals, photos, and weather data). In addition to other technologies, Containers, Docker, and Kubernetes are being used to improve the system for automatic deployment, scaling, and management. The current software was transformed into microservices and containers, making the platform expandable and replicable (Figure 30). The centralized platform will allow the integration between IFDC and partners' different solutions, such as Phosphate Rock Decision Support System (PRDSS), GSSAT, Pythia (parallel crop simulation computing), Field Data Acquisition System, and DSSAT.

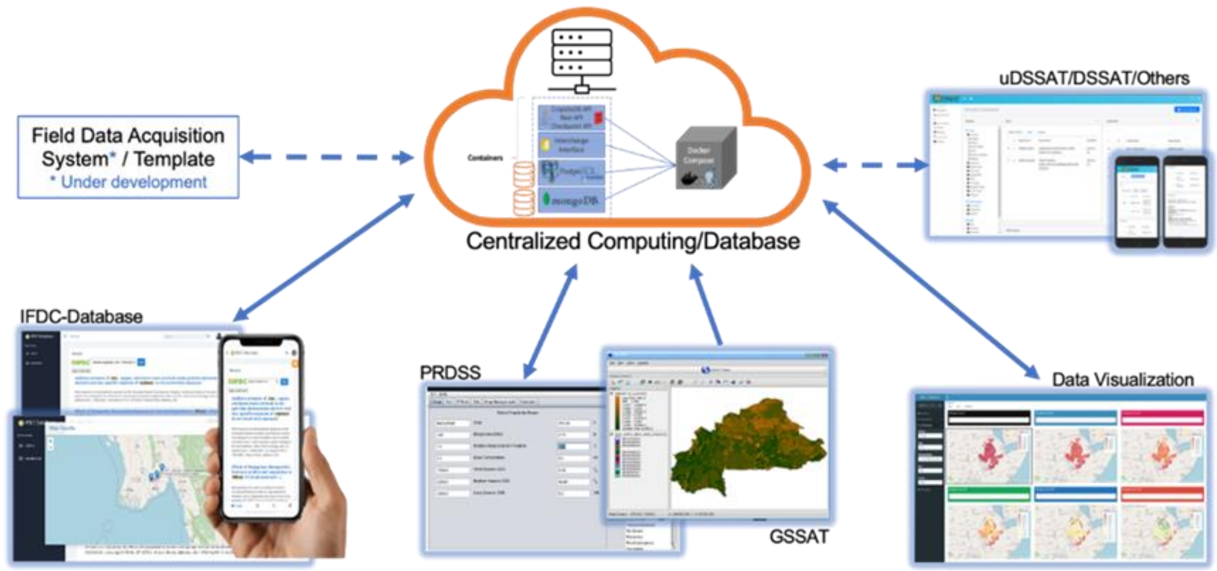


Figure 30. Centralized platform, Docker solution, and implementation architecture

Based on the FAIR principles (findable, accessible, interoperable, and reusable), the system is being developed and adapted to support data interchange between different and heterogeneous projects and institutions. For the database interface and access, a new responsive and user-friendly interface is being implemented to make data uploading far more agile, so that the database 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 31) allows users to search the text data uploaded to the database and, in the near future, to search through all PDFs, documents, pictures, and spreadsheet files also stored. Public and global weather data acquisition will be facilitated for IFDC researchers, who will provide the location or areas of interest. Crop simulations will be facilitated by the interface, using the data stored in the database or accessible through many organizations' platforms, with the option to present the results in friendly geographical interfaces.

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

Outcome: Improve storage, analyses, and sharing of data within IFDC and allow full public access to all non-confidential data and results

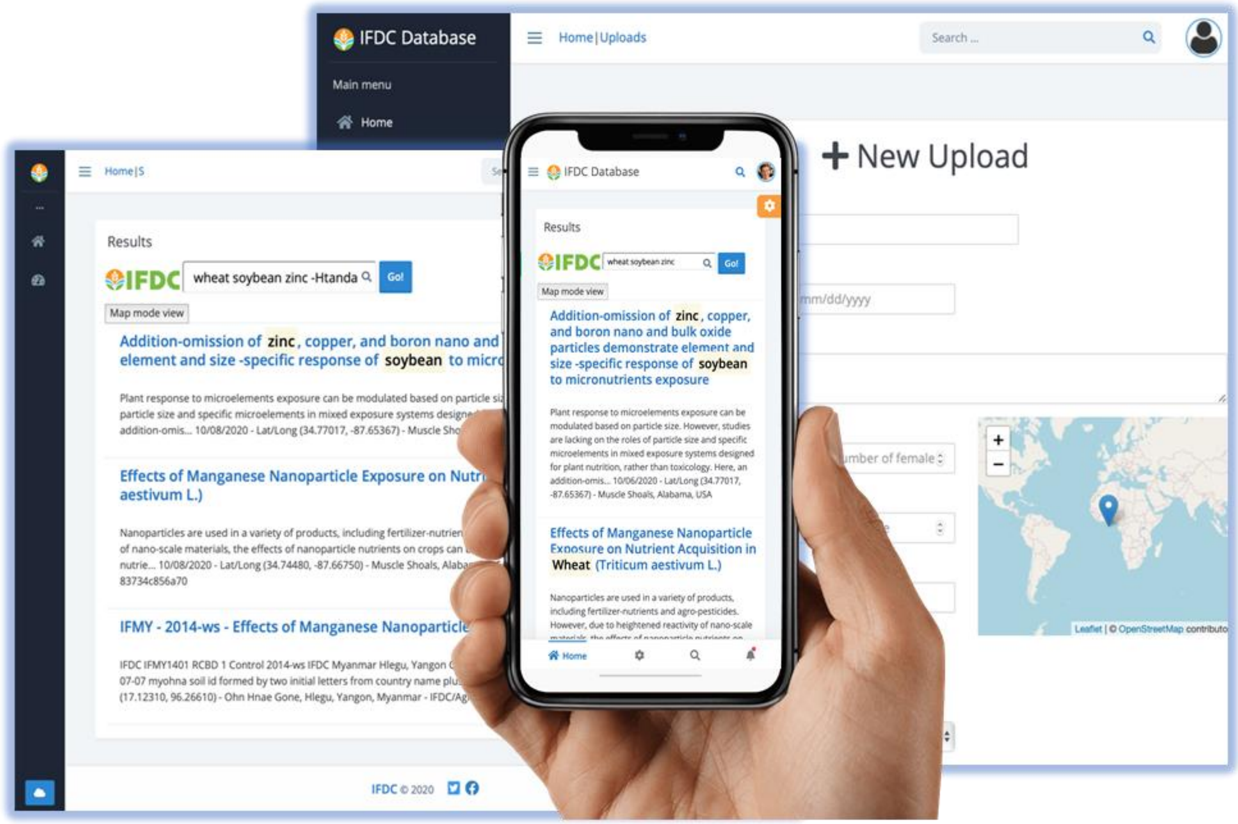


Figure 31. New user-friendly search interface

4.1.2 DSSAT Cropping System Model Improvement and Application

Crop simulation models are widely used for fertilizer recommendations, yield gap analysis, and climate change impact, adaptation, and mitigation. However, the performance of models can be questionable in low fertility soils with low soil organic matter content and multiple nutrient deficiencies. The University of Florida is collaborating with IFDC to improve our ability to model impacts of fertilizers and soil fertility on environmental and agronomic outcomes. Model improvements as part of this collaboration were done using the Decision Support System for Agrotechnology Transfer (DSSAT, dssat.net). In addition, the GSSAT (GIS-based DSSAT) was updated to use the most recent DSSAT software and the database expanded to include more georeferenced data from IFDC projects.

Partners: University of Florida, SOILS Consortium partners in Ethiopia and Niger, the International Maize and Wheat Improvement Center (CIMMYT) and Optionline, Brazil (Inspire Challenge with CGIAR funding)

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

Progress:

1. University of Florida and IFDC are collaborating on improvements to GSSAT, a gridded DSSAT modeling platform developed by IFDC that computes yield forecasts on a regional to country-level scale. GSSAT is one of the tools that will be used by SOILS Consortium partners.
2. GSSAT and other modeling tools also complement the land capability classification approach being developed in Niger using Land PKS app, ground data, and remote-sensing information (Section 3.1.1).
3. The teff model (Section 3.2.2), once evaluated, will be part of the DSSAT suite of crop models.

Development of a Teff Model for Ethiopia

During the COVID-19 pandemic, IFDC and partners from Ethiopia organized and prepared weather, soil, harvesting area, and management data in a grid format and used GSSAT to run spatial simulations based on present coordinates and are presenting the results in a GIS web-based interface. The data sources for this project were:

- Weather from NASA Power.
- Soils from Global High-Resolution Soil Profile Database for Crop Modeling Applications.
- Sowing areas from Global Spatially Disaggregated Crop Production Statistics Data for 2010 Version 2.0.

The strategy used for treatment organization and run (4,174,800 simulation runs) was based on: (a) five planting windows (15 days) starting 15 days prior the official planting date; (b) fertilizer levels (nitrogen): 0, 30, 60, 90, 120, and 150; (c) rainfed experiments; and (d) 35 years of simulation for each point (1984-2018). The computational resources used/developed were: (a) DSSAT Cropping System Model v4.7.5; (b) DSSAT-Pythia; and (c) COVID-19 Shiny App (a visual user-friendly interface for simulation results visualization: https://wpavan.shinyapps.io/COVID19-App-Mulugeta) (Figure 32).

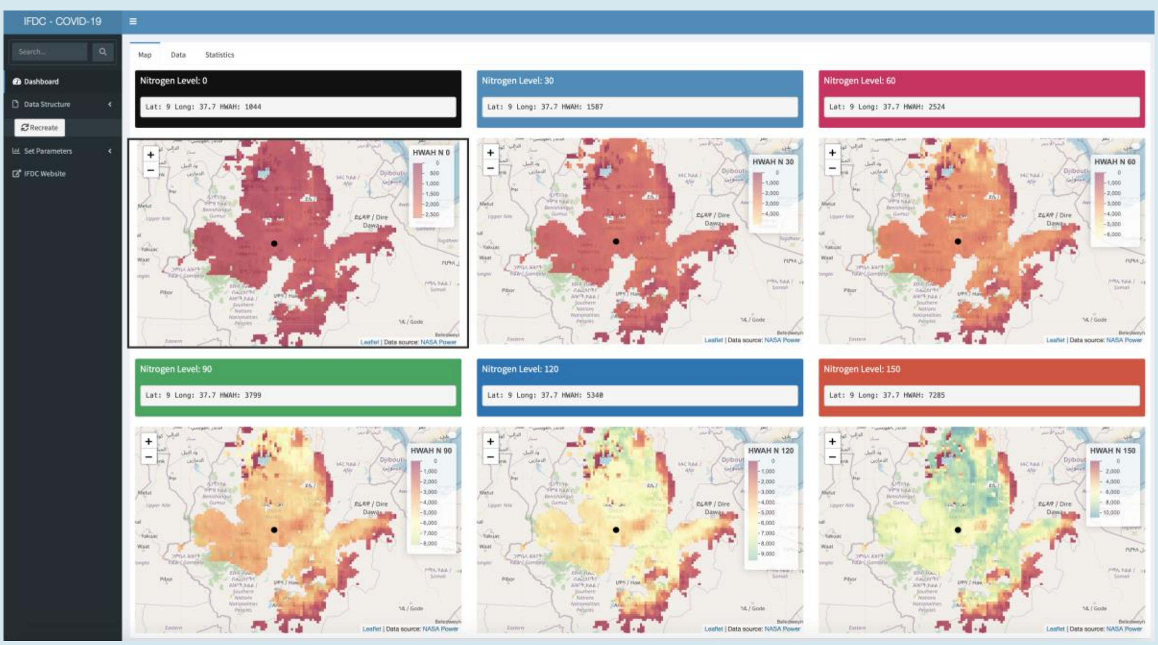


Figure 32. Ethiopia COVID-19 study – planting date and fertilizer effect

4. With support from CGIAR under the Inspire Challenge, IFDC, in partnership with CIMMYT and Optionline, is working on a smartphone app, N-ALLyzer, that combines machine learning/artificial intelligence and modeling with leaf image for fertilizer recommendation. Leaf N level and optimal N ratio to other nutrients are the key components of the system. The initial version is designed for maize and wheat.

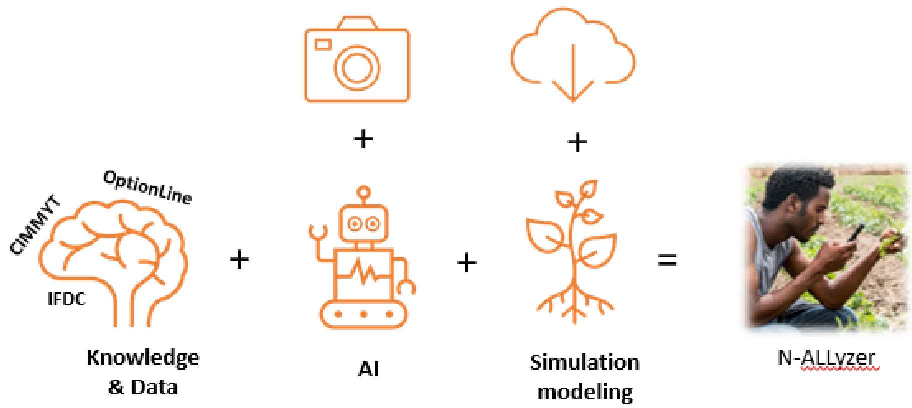
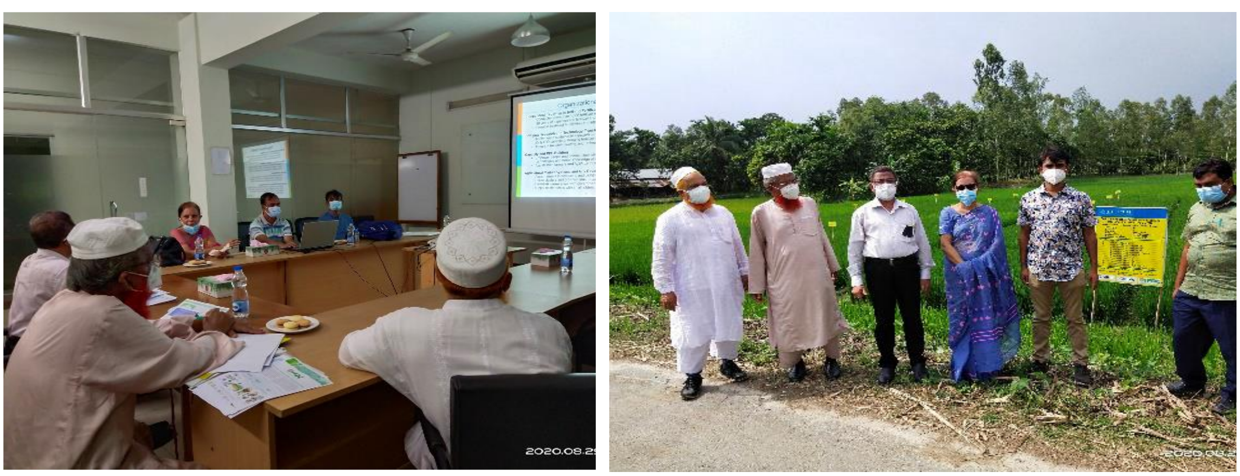


Figure 33. N-ALLyzer app for field-based fertilizer recommendations

4.2 Workstream 2: Cross-Cutting Activities

A. IFDC-SFT Meetings with the Partner Institutions

1. *Meeting and Field Visit with the Director General, Bangladesh Institute of Nuclear Agriculture (BINA), RFS-SFT Field Trials in Rangpur Dinajpur Nilphamari Districts, Bangladesh, August 29-30, 2020*: Ishrat Jahan and Abdullah Mohammed conducted a joint field visit with the Director General of BINA and made a presentation on the "Status and Update of the Soil Fertility Technology Adoption, Policy Reform, and Knowledge Management Activity in Bangladesh."



Presentation and field visits on RFS-SFT research trials with BINA scientists in Bangladesh, August 29-30, 2020

The objective was to further strengthen the collaborative partnership between BINA and IFDC research through RFS-SFT project on the soil fertility technologies in Bangladesh that need further evaluation and technologies that have significant scaling potential with the private sector. The ongoing RFS-SFT research trials are conducted in partnership with BINA and BRRI in Bangladesh.

2. The following meetings with stakeholders and partners held in Nepal about RFS-SFT activities

Date	Meetings Held	Purpose
August 30, 2020	Agriculture Specialist, USAID-Nepal	Improvement of fertilizer supply system, policy support to MoALD
September 27, 2020	Task force led by Mr. Kanchan Pandey, Joint Secretary, Agriculture Development Division of MoALD	Improvement of fertilizer supply system in Nepal
September 28, 2020	Private sector stakeholders in fertilizer value chain	Private sector’s role to improve fertilizer supply in Nepal – issues, challenges, and prospects

4.3 Workstream 3: Cross-Cutting Activities

A. Recruitment of SOILS Consortium Post-Doctoral Fellow, Muscle Shoals

SOILS Consortium post-doctorate position was filled by Dr. Mulugeta Demiss from Ethiopia on May 1, 2020.

B. Virtual Niger Stakeholders Meeting with Niger Mission, Millennium Challenge Corporation, World Bank, and INRAN

On September 21, a virtual stakeholders meeting was held with Niger partners to share progress on SOILS Consortium activities and to receive feedback on the next steps. From this meeting, proposed next steps were drafted and a proposal is being developed to: (i) create a second parallel layer to the LCC assessment focused on soil fertility and (ii) downscale the results to the level in which commune decisions are made and incorporate additional remote-sensing data streams into the product in large part to support this downscaling and localization effort. We envisage that the downscaling the existing maps in key areas will be led by local organizations with a focus on high-density sampling in areas of interest for ongoing MCC activities. This would be an intentional co-design effort in which we pull the remote-sensing information into the products and share the preliminary data streams with the local teams, who then would test and suggest revisions to the product to make it more usable at the local scale and more useful in general.

C. Cross-Cutting Activities with Workstreams 1 and 2

Specific activities include:

- **Improve capacity of farmers, research and extension actors, and other organizations** by: (i) establishing research and technology parks to empower farmers and researchers;

(ii) creating a Center of Excellence (CoE) at local organizations to build institutional capacity (one of the major limitations for the NARES and universities is the lack of human and institutional capacity to lead, coordinate, and enhance networking and collaboration with key stakeholders, implementing partners, and donors); (iii) enhancing human resources via training technicians as well as undergraduate and postgraduate students (engagement of youth in agricultural science to build the next generation of scholars is critical); and (iv) strengthening curricula at schools and universities (science continues to improve our understanding of both basic and applied principles and it is critical to keep curricula current).

- **Enhance knowledge sharing and data management** by: (i) facilitating coordination of activities funded by the international donor community, including World Bank, MCC, and USAID (central and regional); (ii) providing a platform for networking opportunities among all actors (there are multiple partners engaged in Niger but they lack a common platform to come together, engage, and share knowledge and information); and (iii) developing data curation and storage opportunities (efficient data management and curation are critical components in quantifying the impact and attributions beyond the project period).

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

Outcome: Promote nutrition-smart agriculture through crop-livestock diversification and agronomic and genetic biofortification

Table 8. Workstream 1: Developing and Validating Technologies, Approaches, and Practices (RFS-SFT/FY2020)

Workstream 1		Country	Activity Summary	Progress	Partnership
1.1	**Improving Nitrogen Use Efficiency**				
1.1.1	Development and Evaluation of Enhanced Efficiency N Fertilizers	Global	1. Developing enhanced efficiency N fertilizers using Zn (nano and bulk), as coating material for urea. Coated products formulated, characterized, and evaluated under greenhouse conditions.	New products for field evaluation. New-capped products under greenhouse evaluation. Publication in progress.	University of Central Florida, TERI (cost shared)
		Bangladesh, Ghana, Nepal, Myanmar (FY2018 Funds)	2. Field evaluation of existing enhanced efficiency N fertilizers (urea briquette, urea with elemental S) for improved yield, reduced N pollution	Field trials (completed in Ghana, Myanmar and ongoing in Nepal, Bangladesh). Reports/publications are in progress	BARI, Africa Rising, cost shared (OCP, NSAF, Shell)
1.1.2	Scaling Fertilizer Deep Placement Technology for Granular and Briquette Fertilizers	Kenya, HQ,	Developing fast and flexible mechanized/manual applicators for fertilizer deep placement for upland and lowland conditions with the option of combined planting.	Field evaluation delayed due to COVID-19 in Kenya. Feedback to manufacturers (MSU) and evaluation in progress.	Private sector, BRRI, Mississippi State University
1.1.3	Climate Resilience and Mitigating GHG Emissions (Crosscutting with Knowledge Management)	Bangladesh	1. Mitigating GHG emissions from rice-based cropping systems through efficient fertilizer and water management.	Publications and modeling data from past trials in progress.	Krishi Gobeshona Foundation, IRRI, BAU, BRRI
		Bangladesh	2. Increasing fertilizer use efficiency and resilience in saline soils for rice.	Rice at ripening stage. Lab analysis in progress for publication.	BRRI, Khulna Agricultural University, SRDI
		Burkina Faso	3. Adapting balanced subsurface fertilizer management (NP, NPK briquette) to intensive rice cropping systems (SRI).	AWD-SRI and multi-nutrient briquette results in progress – delayed due to flooding issues.	NARES

Workstream 1		Country	Activity Summary	Progress	Partnership
1.2	**Improving Efficiency of Phosphatic Fertilizers**				
1.2.1	Activated Phosphate Rock Trials Under Greenhouse and Field Conditions	Ghana, Kenya, HQ	Activated PR evaluated under greenhouse and field conditions.	Yield results reported in Ghana; final analysis and journal publication in progress (Ghana). Kenya – delayed due to COVID-19.	Private sector, UDS, SARI, and local agricultural extension agents
1.2.2	Validating and Promoting Activated PR Using Local PR Sources and Producers (Crosscutting with Workstream 3)	Ghana, Niger,	PR and activated PR demonstrations conducted on soils of varying pH to further validate the role of activated PR as an alternative to WSP fertilizers.	Seven on-farm demos completed in Ghana with three field days for each location. Analysis and reporting in progress. . Niger planting delayed by COVID-19.	Private sector, NARES
1.2.3	Alternative Activation Process for Enhanced Efficiency P Fertilizers	HQ	Alternatives to water-soluble P fertilizers with beneficiation by calcination and grinding.	Range of calcined and ground products prepared. Lab characterization in progress.	Private sector
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	Kenya, Ghana, HQ	1. Micronutrient rates, sources (S, Zn, B, Cu), and nutrient omission trials in cereals and vegetables - crop yields and nutrient acquisition.	GH trial on Zn and organic manure completed and published. Zn, and B trials completed and reported for Western Kenya (SAR 1) Ghana residual S trials completed. Analysis in progress.	KALRO (in kind), NARC (in kind), SARI
		Bangladesh	2. Balanced fertilization through secondary and micronutrients (compound fertilizers) in maize (acid-prone area).	Two maize trials planted in 12/2019: harvesting done and analysis in progress – reporting preliminary results.	BARI, SRDI
		HQ, Kenya	3. Promoting the commercial and experimental use of efficient micronutrient coatings.	Products for characterization. Greenhouse study completed and reported. Journal publication in progress.	NARES, private sector, university partners

Workstream 1	Country	Activity Summary	Progress	Partnership
	Mozambique	4. Repeat on-farm omission trials (severely affected by cyclone Idai) in Buzi district to quantify the effect of key nutrients, including secondary and micronutrients, to close rice yield gaps.	360 plots in 40 farmer-fields established. Due to February 2020 flooding; continued with only 15 fields. Conducted field days incorporating COVID-19 measures.	FAR project, Yara, farmers' associations, agro-dealers, District Economic Activities Services
1.3.2 Facilitate Site- and Crop-Specific Fertilizer Recommendations for Increased Economic and Environmental Benefits from Fertilizer Use	Ghana	1. Generate site- and crop-specific balanced fertilizer recommendations – nutrient omission trials in Ghana	115 maize trials completed. Analyses of harvest data in progress. Journal publication.	Soybean Innovation Lab (SIL) - University of Illinois, UDS, Shell
	Nepal	2. Update fertilizer recommendations for cereals and vegetables in Nepal.	Maize and cauliflower trials completed and reported. Publication in progress.	NSAF Project (cost shared), NARC
	Mozambique	3. Develop soil maps for rice farming systems in Buzi.	Preparation of maps completed.	FAR Project
	Niger	4. Validation trials for new balanced fertilizer formulations (cross-cutting with Workstream 3).	Ex-ante data collection – delayed COVID-19.	NARES, SOILS Consortium
1.3.3 Wet Chemistry-Spectral Analysis Relationship for Rapid and Reliable Fertilizer, Soil, and Plant Analyses	Global	1. Wet chemistry-spectral analysis relationship to crop yield and nutrient response. Current activity focused on fertilizer samples a wide variety of nutrients and concentrations.	Calibration curves for XRF vs. wet chemistry 18 elements (excluding N and P) developed. Reporting in progress.	Bruker (equipment), NARES
	Kenya, HQ	2. Evaluation of spectral and wet chemistry methods for detecting changes in soil nutrient status.	Soil samples collected and analysis in progress.	Local labs
	HQ/Global	3. Working with partner organizations to improve methodologies and lab standards for fertilizers and amendments.	24 lab assessments in 5 West African countries. Staff training. Delays due to COVID-19.	ISO, IFA, AAPFCO

Workstream 1		Country	Activity Summary	Progress	Partnership
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, Niger	Performance maize (Ghana) and millet (Niger) under CA versus non-CA and amendments – activated PR.	8 trails in Northern Ghana completed and yields reported. Research publication in progress (Ghana). Establishment of Niger trials delayed due to COVID-19.	Africa RISING, NARES
1.4.2	Evaluation of the role of Legumes in Rice-Based Farming Systems in Mozambique for Nutrient Improvement, Soil Health, and Income Generation	Mozambique	Promoting beans and vegetables in crop sequences with maize to improve farmer income and catalyze the use of fertilizers by smallholder farmers.	Established 15 on-farm trials. Field days conducted.	FAR Project, USAID-SEMEAR project, Yara Fertilizer Company
1.4.3	Increasing System Productivity Through Agronomic Biofortification with Crop Diversification and Intensification	Bangladesh	Increasing system productivity through agronomic biofortification with crop diversification and intensification.	S nutrition trials completed. Analysis and reporting in progress.	BARI, BAU, BRRI, SRDI.
1.4.4	Developing a Highly Productive and Sustainable Conservation Agriculture Production System for Cambodia	Cambodia	Assessing changes in soil organic C and N stocks and soil functions of sandy paddy fields under conventional tillage and conservation agriculture production systems.	Soil health parameters analyzed and reported. Impact on rice yield quantified. Data prep for modeling. Final reporting Q1 FY2021.	RUA-CE SAIN, GDA, DALRM, CASC, CIRAD, SIIL-KSU (university partnership)
1.4.5.	Integrating Best Management Practices for Climate Resilience in Rice-Cereal-Legume System in Nepal	Nepal	Improving crop performance through balanced fertilization using customized compound fertilizers in rice-cereal-legume system.	Four maize demo plots established and harvested. Analysis and reporting in progress.	NARC, AFU
1.4.6	Impact of Nutrient Recycling, Biofertilizers, and Bio-stimulants on Yield and Soil Health	Global, HQ	Effective recycling of nutrients using biological, chemical, and physical processes for improving soil fertility, soil health, crop yield, and nutrient use.	Representative soil samples collected. Characterized organic amendment. Analysis in progress.	Private sector, Auburn University, farmers

Table 9. Workstream 2: Supporting Policy Reform Processes, Advocacy, and Market Development (RFS-SFT/FY2018)

Title/Activities		Country	Progress	Partnership
2.1	**Document Policy Reforms and Market Development**			
2.1.1	Kenya Fertilizer Platform (KeFERT) Public-Private Dialogue and Coordination	Kenya	Participation in USAID-Kenya Mission on Policy Working Group; continued advocacy work through KeFERT.	MoA, FAK, AGRA, private firms, KMT, One Acre Fund, Tegemeo, AFAP
2.1.2	Policy Briefs on Fertilizer Policies, Reforms, and Market Development	Global	• Niger: Data analysis in progress – to be completed in Q1 FY2021. • Nigeria: Survey in progress and draft report due Q1 FY2021. • Bangladesh: COVID-19 surveys and preliminary reporting completed – final report due Q1 FY2021.	PARSEN, MCA-Niger, EnGRAIS
2.2	**Impact Assessment Studies**			
2.2.1	Determinants of small farmer use of fertilizers in Senegal	Senegal	• Surveys completed and analysis and reporting in progress – due Q1 FY2021. • Delayed due to COVID-19.	EnGRAIS, ISRA-BAME
2.2.2	Impact of Agro-Dealer Development in Technology Transfer and Input Use and Access	Rwanda	• Data analysis completed and draft reporting in progress – due by Q1 FY2021. • Rapid assessment on effect of COVID-19 lockdown on last-mile actors carried out.	AGRIFOP, AGRA-Rwanda
2.2.3	Analyze the Impact of Counterfeit Fertilizer Products and Options for Fertilizer Certification in Kenya	Kenya	• Interviews initiated in September (delayed due to COVID-19) – in progress. • Draft report due Q2 FY2021.	KeFERT platform members, OCP-Kenya
2.3	**Economic Studies**			
2.3.1	***Fertilizer Watch*** for East and Southern Africa – as part of the COVID-19 response	East and Southern Africa and SSA wide	• Analytical reports – *Fertilizer Watch* in East and Southern Africa since April 2020 and will continue until December 2020 – in progress. • Weekly report publication – in progress since April 2020.	IFDC-AFO, EnGRAIS, AFAP

Title/Activities		Country	Progress	Partnership
2.3.2	Gender Series on Women's Access and Use of Fertilizers: Case in Uganda – documenting women entrepreneurs (input suppliers and women farmers in Uganda)	Global	• Preliminary discussions held in February with REACH project in Uganda and sampling and surveys to be completed in Q1 FY2021. • To be initiated in Q2 FY2021 in Uganda and Mozambique.	IFDC projects and interventions in Uganda and Mozambique

Table 10. Workstream 3: Sustainable Opportunities for Improving Livelihoods with Soils (SOILS) Consortium

Workstream 3		Country	Activity Summary	Progress	Partnership
3.1	**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	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.	University, Colorado, USDA-ARS, IFDC Niger, INRAN, SOILS Consortium
3.1.2	Remote Sensing and Improved Use of Soil Data	Niger	• Ground truthing to calibrate LandPKS. • Socio-economic analysis using Niger LSMS-ISA data. • Household survey preparation and data collection. • Household survey analysis. • Training workshop. • 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 to be identified. COVID-19 delays.	Michigan State University, Colorado University, Auburn University, ICRISAT-Niger, INRAN, SOILS Consortium, IFDC-Niger
3.1.3	Land PKS Collaboration with Auburn University	Niger	Provide general support of the LandPKS Platform and improve the soil taxonomic unit descriptions and subsequent management information, with focus on lateritic soils, for the LandPKS app to support the Niger activities and the use of LandPKS more broadly.	FAO and WRB databases have been used to improve soil taxonomic unit descriptions of the soils of Niger and other regions in the LandPKS app. LandPKS app to link soil classifications to land management information.	Auburn University

Workstream 3		Country	Activity Summary	Progress	Partnership
3.1.4	Cross-Cutting Activities with Workstreams 1 and 2	Niger	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, CORAF/WECARD, IFDC, SIIL, , U.S. land-grant universities, USAID, MCC, World Bank
3.1.5	Analysis of Digital Extension Platforms, Tools, Approaches and Services in Niger	Niger	• Conduct an extension and digital extension landscape analysis in Niger. • Analyze effectiveness of the extension platforms, tools, approaches, and services in providing information to farmers in Niger. • 3. Recommendations to strengthen digital extension platforms, tools, approaches and services in Niger.	• Draft report for DLEC and SOILS Consortium review due by December 15, 2020. • Final report incorporating comments due by January 30, 2021.	DLEC, SOILS Consortium, INRAN, IFDC-Niger
3.2	**Enhancing Productivity and Food Security in Ethiopia through Improved Soil Fertility Management**				
3.2.1	Targeting Fertilizer Source and Rate in Ethiopia	Ethiopia	Produce a model for prediction of responses to different nutrient combinations and rates, with emphasis on K, S, Zn, and B, that improves upon current fertilizer targeting using soil critical values only	• A unified Fertilizer Trial Protocol has been developed with the Ethiopian Institute of Agricultural Research (EIAR). • Field trials are being implemented across Ethiopian farming systems and are currently underway. • Data compiling has begun with the historical IFDC and ICRISAT currently being combined and cleaned.	ICRISAT, IFDC-Ministry of Agriculture-Soils Directorate, Ethiopian Agriculture Research Council Secretariat (EARCS), Ethiopian Institute of Agricultural Research (EIAR), Regional

Workstream 3		Country	Activity Summary	Progress	Partnership
					Agricultural Research Institutes of Amhara, Tigrai, Oromia and Southern Regions, CASCAPE (GIZ ISFM+) Ethiopia, and (CIAT).
3.2.2	Decision Support Systems for Improved Access to Soil Fertility Information and Farming Practices	Ethiopia	During December 2019 to April 2020, the teff model was developed, with ongoing testing with independent data in progress (Figure 27). Teff model to be released with the next DSSAT version. Greenhouse trials are quantifying the effects of N response, plant population, and flooding/waterlogging on growth, development, and nutrient status of teff (Figure 28).	A teff model that simulates effect of soils, weather, genotype, water management, fertilizer rates and sources, and effect of such management factors as plant population and sowing date has been developed.	IFDC-SOILS Consortium), NARCS, universities
3.2.3	Quantifying Effect of Rainfall and Fertilizer Use on Crop Production in Ethiopia	Ethiopia	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	15 years of data on crop production, fertilizer use, and weather compiled, analyzed, and interpreted. Manuscript prepared.	SOILS Consortium IFDC

Table 11. Cross-Cutting Activities: University Partnerships, Workshops, and Trainings FY2020

Theme/Activities	Countries	Partnership	Progress
I. Collaboration with U.S. Land-Grant Universities*			
1.1.1 Developing Enhanced Efficiency N Fertilizers	Global	University of Central Florida	Dual-capped Zn nanoparticle coatings were formulated, characterized, and sent to IFDC for coating with urea.
1.1.2 Scaling Fertilizer Deep Placement (FDP) Technology for Granular and Briquette Fertilizers	Global	Mississippi State University	Prototype developed combined with rice transplanter. Delayed due to COVID-19.
1.2.1 Activated Phosphate Rock Trials under Greenhouse and Field Conditions	Northern Ghana	Soybean Innovation Lab, University of Illinois	Soybean field trials established on near-neutral soils and harvested.
1.4.4 Developing a Highly Productive and Sustainable Conservation Agriculture Production System for Cambodia	Cambodia	Kansas State University	Soil health parameters analyzed and reported. Impact on rice yield quantified. Data preparation for modeling.
1.4.6 Impact of Nutrient Recycling, Biofertilizers, and Bio-Stimulants on Yield and Soil Health	Global	Auburn University	Representative soil samples collected. Student involvement delayed. Cotton field trials begin this summer.
1.5.1 Develop IFDC Centralized Database Using AgMIP Database Template	Global	University of Florida	Database established and data uploaded. http://database.ifdc.org:9000/cropsitedb Platform expansion to include new features.
1.5.2 DSSAT Cropping System Model Improvement and Application	Global	University of Florida	Carbon balance and generic fertilizer module completed. Evaluating GHG emission model with IFDC and LTAR datasets. Training program postponed due to COVID-19.

Theme/Activities	Countries	Partnership	Progress
Workstreams 1 and 2: Strengthening MELS Capacity in IFDC – Ph.D. Training for an IFDC M&E Field Staff Member	Global	University of Georgia	In progress
3.1.1 Remote and On-the-Ground Land-Use Suitability Analysis to Guide Decision-Making in Niger	Niger	Colorado University	Revised high-resolution base maps at 12.5 M resolution have been developed.
3.1.2 Remote Sensing and Improved Use of Soil Data, Niger	Niger	Michigan State University	Training workshop on LandPKS postponed to May. Economic profitability assessment based on the Niger LSMS is currently in preparation for analysis.
3.1.3 LandPKS Collaboration with Auburn University	Niger	Auburn University	FAO and WRB databases have been used to improve soil taxonomic unit descriptions of the soils of Niger and other regions in the LandPKS app.
**Note: All university partnerships involve graduate students/post-doctoral fellows and faculty expertise.*			
II. Outreach: Trainings/Workshops			
A. Workshops			
2.1.1 Support for Policy Reform Processes in Kenya – KeFERT Consultations and Meeting	Kenya	BFS/MoA/AFAP	August 2020
B. Training Programs			
International Training Program on Technology Advances in Agricultural Production, Water and Nutrient Management	USA	IFDC, BFS	Postponed to 2021
International Training Program on Assessing Crop Production, Nutrient Management, Climatic Risk and Environmental Sustainability with Simulation Models	University of Georgia	University of Florida, University of Georgia, DSSAT Foundation	Postponed to May 17-22, 2021
GSSAT Training (Job Fugice, Upendra Singh, Sampson Agyin-Birikorang, John Wendt, Willingthon Pavan)	West Africa	NARES, University of Florida, local universities	Postponed to 2021

Annex

Publications

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Training

Farm-level trainings on “Urea-S” and one “Crop Diversification and System Intensification” research trial conducted December 26, 2019, December 29, 2020 and July 17, 2020 in Bangladesh.

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