



Info Note

Accelerating Agriculture Productivity Improvement in Bangladesh:

Mitigation co-benefits of nutrient and water use efficiency

A series analyzing low emissions agricultural practices in USAID development projects

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Key messages

- Analysis of potential mitigation in the development project Accelerating Agriculture Productivity Improvement (AAPI) in Bangladesh showed a 2% reduction in greenhouse gas (GHG) emissions, driven by urea deep placement (UDP) and alternate wetting and drying (AWD) in flooded rice systems. Given high emissions associated with conventional irrigated rice production, this represents a substantial reduction in emissions.
- AAPI promotes UDP, a fertilization practice known to increase nitrogen uptake efficiency. Based on the project plan and progress of implementation, UDP adoption was anticipated on 1.1 million ha of aman rice and 700,000 ha of boro rice. UDP is an example of the absolute emission reductions that are possible when a practice is widely implemented.
- AAPI promotes AWD, an irrigation practice for rice that reduces the amount of water used and results in decreased emissions. AAPI tested AWD on a pilot scale (21,000 ha). Climate change mitigation benefits would increase dramatically if adoption of AWD were more widespread.
- Due to increased rice yields, UDP and AWD reduce the emission intensity (CO₂e emitted per kg production) from rice production by 10–48%.

About the Accelerating Agriculture Productivity Improvement project

The AAPI project, funded by the United States Agency for International Development (USAID) under the Feed the Future (FTF) initiative beginning in 2010 and carried out by the International Fertilizer Development Center (IFDC), aimed to improve food security and accelerate income growth in rural areas of southwest Bangladesh (Figure 1). In 2012, AAPI also received funding from the USAID Office of Global Climate Change to incorporate climate change considerations into existing activities, including studying GHG emission changes due to urea deep placement (UDP) in rice intensification programs.

The project, implemented by IFDC and the Bangladesh Ministry of Agriculture, collaborated with many national institutions, including the Department of Agricultural Extension. The project worked with 1.3 million farmers in 22 districts, and employed strategies around technology diffusion, capacity building, policy reform, and micro-enterprise development.

AAPI focused on increasing farmer adoption of UDP by employing demand side strategies such as farmer training, technology demonstrations, and field days, and supply side strategies that supported the development of micro-enterprises, such as production of urea briquettes, by providing business and marketing training. AAPI also included a smaller pilot study of AWD technology in flooded rice fields.

Low emission development

In the 2009 United Nations Framework Convention on Climate Change (UNFCCC) discussions, countries agreed to the Copenhagen Accord, which included recognition that “a low-emission development strategy is indispensable to sustainable development” (UNFCCC 2009). Low emission development (LED) has continued to occupy a prominent place in UNFCCC agreements. In the 2015 Paris Agreement, countries established pledges to reduce emission of GHGs that drive climate change, and many countries identified the agricultural sector as a source of intended reductions (Richards et al. 2015).

In general, LED uses information and analysis to develop strategic approaches to promote economic growth while reducing long-term GHG emission trajectories. For the agricultural sector to participate meaningfully in LED, decision makers must understand the opportunities for achieving mitigation co-benefits relevant at the scale of nations, the barriers to achieving widespread adoption of these approaches, and the methods for estimating emission reductions from interventions. When designed to yield mitigation co-benefits, agricultural development can help countries reach their development goals while contributing to the mitigation targets to which they are committed as part of the Paris Agreement, and ultimately to the global targets set forth in the Agreement.

In 2015, the USAID Office of Global Climate Change engaged the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) to examine LED options in USAID’s agriculture and food security portfolio. CCAFS conducted this analysis in collaboration with the University of Vermont’s Gund Institute for Ecological Economics and the Food and Agriculture Organization of the United Nations (FAO). The CCAFS research team partnered with USAID’s Bureau of Food Security to review projects in the FTF program. FTF works with host country governments, businesses, smallholder farmers, research institutions, and civil society organizations in 19 focus countries to promote global food security and nutrition.

As part of the broader effort to frame a strategic approach to LED in the agricultural sector, several case studies, including this one, quantify the potential climate change mitigation benefits from agricultural projects and describe the effects of low emission practices on yields and emissions. Systematic incorporation of such emission analyses into agricultural economic development initiatives could lead to meaningful reductions in GHG emissions compared to business-as-usual emissions, while continuing to meet economic development and food security objectives.

The team analyzed and estimated the project’s impacts on GHG emissions and carbon sequestration using the FAO Ex-Ante Carbon Balance Tool (EX-ACT). EX-ACT is an appraisal system developed by FAO to estimate the impact of agriculture and forestry development projects, programs, and policies on net GHG emissions and carbon sequestration. In all cases, conventional agricultural practices (those employed before project implementation) provided reference points for a GHG emission baseline. The team described results as increases or reductions in net GHG emissions attributable to changes in agricultural practices as a result of the project. Methane, nitrous oxide, and carbon dioxide emissions are expressed in metric tonnes of carbon dioxide equivalent (tCO₂e). (For reference, each tCO₂e is equivalent to the emissions from 2.3 barrels of oil.) If the agricultural practices supported by the project lead to a decrease in net emissions through an increase in GHG removals (e.g., carbon sequestration, emission reductions) and/or a decrease in GHG emissions, the overall project impact is represented as a negative (–) value. Numbers presented in this analysis have not been rounded but this does not mean all digits are significant. Non-significant digits have been retained for transparency in the data set.

This rapid assessment technique is intended for contexts where aggregate data are available on agricultural land use and management practices, but where field measurements of GHG and carbon stock changes are not available. It provides an indication of the magnitude of GHG impacts and compares the strength of GHG impacts among various field activities or cropping systems. The proposed approach does not deliver plot, or season-specific estimates of GHG emissions. This method may guide future estimates of GHG impacts where data are scarce, as is characteristic of environments where organizations engage in agricultural investment planning. Actors interested in verification of changes in GHG emissions resulting from interventions could collect field measurements needed to apply process-based models.



Photo credit: AAPI, 2015.

Agricultural and environmental context: Bangladesh

Bangladesh is a nation of 148,460 km² with one of the greatest population densities in the world. Agriculture occupies 70% of the country's territory (World Bank 2014), and the average farm size is about 0.5 ha per household. More than half of rural households are classified as landless, as they own less than 0.2 ha, and 45% of rural households are classified as marginal, small, or medium landowners (i.e., owning 0.2–3.0 ha of land). Less than 2% are classified as large landowners, with more than 3.0 ha (World Bank 2010). Agriculture is the main source of rural livelihoods (Majumder et al. 2016). Southwestern Bangladesh, which hosts AAPI, has a population of 27,400,000. Forty percent of its population lives below the poverty line, slightly more than the national average of 36%. Many children in the region (38%) suffer from stunting (Ahmed et al. 2013).

In Bangladesh, rice is the dominant crop and food. It covers three-fourths of all cropland area and contributes 70% of calories consumed (Majumder et al. 2016) so rice management interventions have been a focus of food security activities. The aman (summer monsoon) rice crop grows on ~5.4 million ha (74% of net cultivated area). The boro (winter) rice crop is cultivated using irrigation on ~4.0 million ha (Magnani et al. 2015). Poor subsistence farming households in rural areas face two distinct hunger seasons: in October–November and in March–April prior to the aman and boro harvests, respectively.

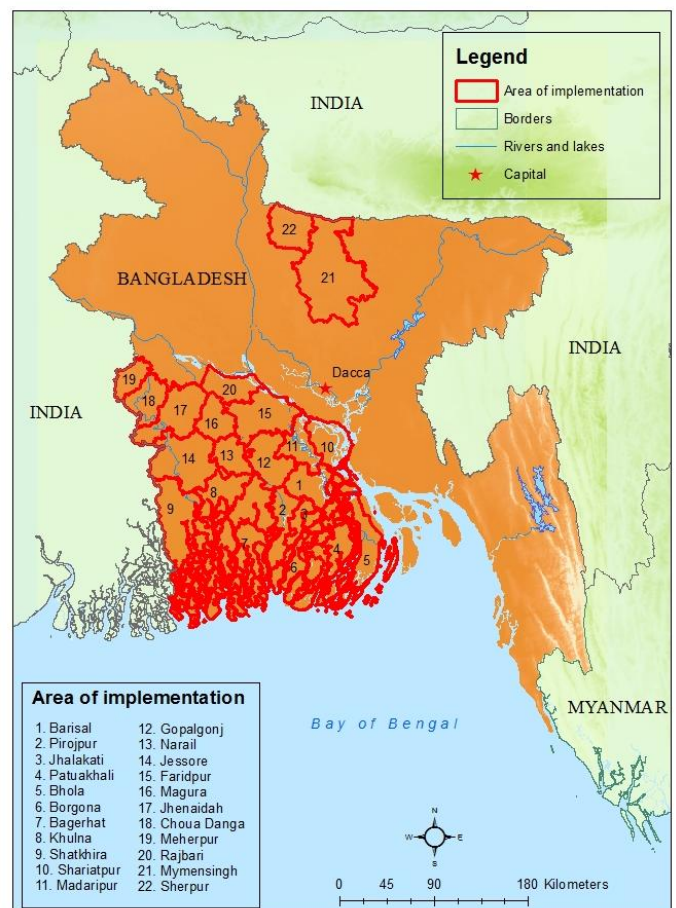
Bangladeshi farmers manage rice systems intensively and broadcast urea by hand. Nationally, farmers use ~80% of the total domestic and imported fertilizer for rice production (Rahman and Barmon 2015). Farmers typically broadcast urea in conventional systems (160 kg/ha for aman and 260 kg/ha for boro), although rates vary widely across soil types and production systems (Basak 2011; Humphreys et al. 2015). Application of fertilizers through broadcasting is imprecise, and much fertilizer is lost due to leaching, surface runoff, and volatilization (Gaihre et al. 2015). There is potential to increase nutrient use efficiency, which would reduce farm level fertilizer costs or increase income from productivity, or both. Since the government of Bangladesh provides substantial subsidies for fertilizers, any nutrient efficiency results in government subsidy savings (Mazid Miah et al. 2016).

Irrigated boro rice accounts for more than a third of the total agricultural emissions in Bangladesh (excluding land use change and forestry) (FAOSTAT 2016). Bangladesh submitted an Intended Nationally Determined Contribution (INDC) to the UNFCCC's Paris Agreement in September 2015. Though agriculture is not included in the unconditional commitments, the report specifies potential actions in livestock, fertilizer usage, and rice cultivation

(Bangladesh 2015). In addition, the report describes AWD irrigation as potential mitigation intervention (ibid.). The INDC builds on the mitigation strategy set out in the Bangladesh Climate Change Strategy and Action Plan, which outlined a pro-poor climate change strategy and includes mitigation/low carbon development as a strategy pillar (Ayers et al. 2014).

The Climate Change Vulnerability Index (2014) identified Bangladesh as the nation most vulnerable to climate change globally. Bangladesh has a tropical monsoon climate with a hot, rainy summer (aman) and a dry winter season (boro). Aman season floods are a severe threat to populations in the southern coastal belt and in the northwest. Sea level rise due to climate change is increasing soil and water salinity in the south and reducing the availability of arable land. Climate projections suggest Bangladesh will experience significant increases in average temperature and extreme weather events (e.g., heat waves), which will threaten crop and livestock production (Coirolo et al. 2013). Climate change contributes to the country's food insecurity and poverty, and represents a serious, urgent issue with the potential to reduce total agricultural crop production over the coming decades.

Figure 1. Area of implementation



Agricultural practices that impact GHG emissions and carbon sequestration

The following agricultural practices promoted by AAPI resulted in changes in GHG emissions and carbon sequestration: (1) UDP, (2) AWD, and (3) soil management improvements. A description of each follows, including a description of the intervention and its effects on the environment, the project plan for the intervention, and estimated impacts on emissions.

Urea deep placement



Urea deep placement

Background. Efficient fertilizer management includes managing the timing, type, placement, and rate of nutrients to optimize nutrient uptake by crops and minimize nutrient loss. UDP is an efficient fertilizer practice in which a urea briquette (produced by compacting commercially available solid urea) is placed about 7-10 centimeters below

the soil surface, either by hand or with an applicator. (Farmers indicate that placing urea briquettes by hand can be very physically demanding.) Improvements in nutrient use efficiency through UDP mean less fertilizer is required, thereby reducing both costs to the farmer and nitrous oxide emissions, a mitigation co-benefit.

Project plan. AAPI promoted the application of urea briquettes (called Gutis) weighing 1.8 g (aman rice) or 2.7 g (boro rice) at a density of 62,500 Gutis/ha. Based on the AAPI project plan at the time of the interview, UDP adoption was anticipated on 1.1 million ha of aman rice, 700,000 ha of boro rice, and 18,952 ha of vegetable crops. Through AAPI, urea application was reduced from 160 kg to 113 kg (aman) and from 260 kg to 169 kg (boro) per hectare, a reduction of 30 to 35% compared to conventional rates.

Impact on emissions. Nitrogen use efficiency is increased with UDP compared to broadcast urea, which is why urea application rates can be lowered without compromising yields. UDP reduces unintended losses of nitrogen through volatilization of ammonia, surface runoff, or leaching of nitrate, as well as emissions of nitrous oxide (N₂O). The IPCC Tier I guidelines for emission calculations suggest an emission factor (kg N₂O emitted per kg N fertilizer applied) of 0.003 (range: 0.000–0.006) for fertilized, flooded rice systems (IPCC 2006). Gaihre et al. (2015) measured N₂O emissions at an AAPI site in Bangladesh and calculated an emission factor of 0.00120 for rice with conventional broadcast urea and 0.00045 for rice with UDP, a two- to three-fold decrease in emissions. It should be noted that both emission factors calculated

by Gaihre et al. are within the IPCC Tier 1 range, though below the average. The FAO used the IPCC Tier I emission factor for broadcast urea as in all the country case studies. The emission factor was reduced by 50% for UDP (Gaihre et al. 2015). Given the relatively low N₂O emission factor for wetland rice (as compared to dryland crops that have emission factors of 0.01), UDP more significantly impacts emissions through the sizable reduction in fertilization rates.

Employing UDP in flooded rice results in estimated average annual GHG mitigation benefits of -0.25 tCO₂e/ha compared to conventional broadcast fertilization. Although UDP reduced emissions most in boro rice (-0.29 tCO₂e/ha/yr), emission reductions in aman rice (-0.19 tCO₂e/ha/yr) affect a larger region. Reduced fertilization rates drove the majority of emission reductions (-0.18 tCO₂e/ha/yr), while the reduced N₂O emission factor from UDP was responsible for a small reduction (-0.07 tCO₂e/ha/yr) (Figure 1). Scaled to the full area of implementation, UDP resulted in an estimated change in net GHG emissions of $-379,730$ tCO₂e/yr (Figure 2).

Alternate wetting and drying



Alternate wetting and drying

Background. AWD is a management practice in irrigated lowland rice characterized by periodic drying and reflooding of fields. Submergence of soil and organic residual material in rice paddies leads to anaerobic decomposition of organic matter that releases methane. Periodic drying events interrupt the duration of this process and

reduce methane emissions up to a half compared to continuous flooding (Richards and Sander 2014). Methane is a heat-trapping gas 34 times as potent as carbon dioxide on a 100-year time horizon (used in this study) and 86 times on a 20-year time horizon (Myhre et al. 2013). AWD reduces irrigation and associated fuel consumption while maintaining or increasing yields (Richards and Sander 2014). Because AWD depends on controlling water levels, it is practiced only during the irrigated rice season (boro rice).

Project plan. AAPI expected that farmers would adopt AWD on 21,000 ha of boro rice, affecting roughly 3% of the boro rice in the area of implementation.

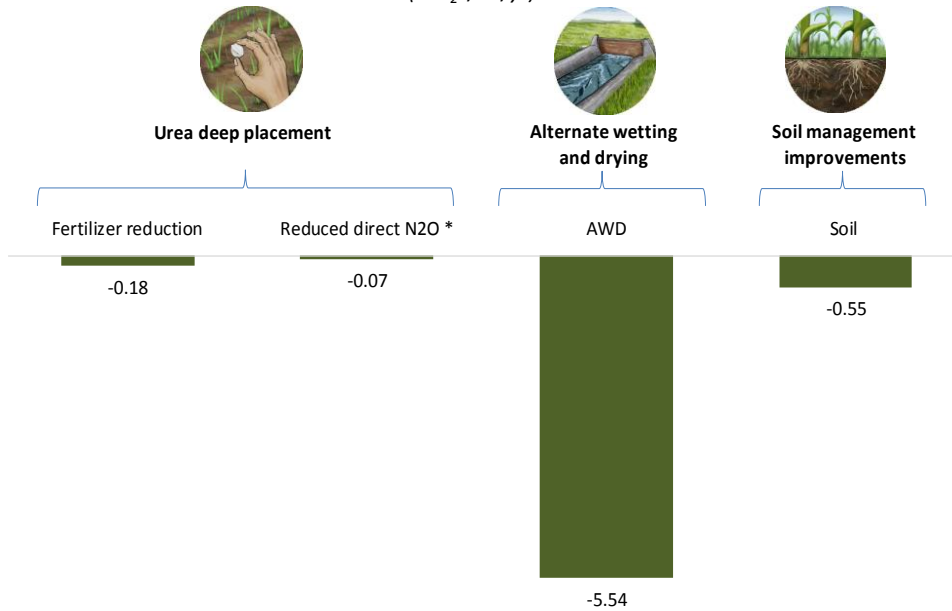
Impact on emissions. In AAPI, AWD practices mitigated -5.54 tCO₂e/ha/yr (Figure 1) or $-116,396$ tCO₂e/ha/yr when scaled to the full area of implementation (Figure 2). Estimates of reductions in methane emissions are based on a robust body of evidence describing the impact of

Summary of projected GHG emission and carbon sequestration co-benefits

Total decreases in emissions due to AAPI's interventions were approximately 2% per year (-506,550 tCO₂e/yr). The largest net decrease in GHG impact by area was AWD (-5.54 tCO₂e/ha/yr); UDP and soil management also resulted in emission reductions (Figure 2). AAPI anticipated that AWD would be adopted on 21,000 ha, which would result in an annual estimated GHG impact of -116,396 tCO₂e/yr (Figure 3). Given the estimate by AAPI that farmers would adopt UDP on over 1.7 million ha,

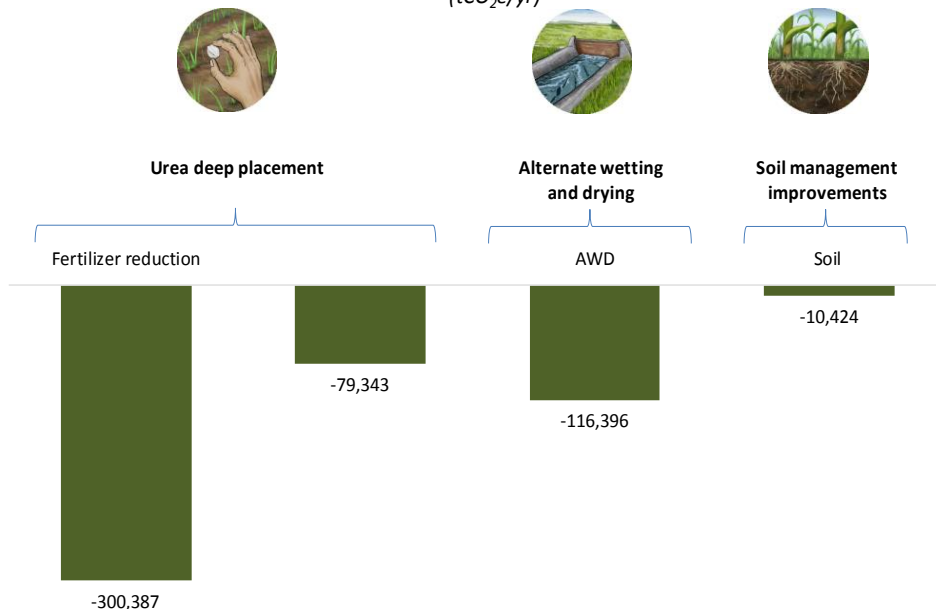
UDP had an annual net emission impact of -300,387 tCO₂e/yr due to reduced urea application and -79,343 tCO₂e/yr due to decreased direct N₂O emissions (Figure 2). The scale of implementation of the agricultural practices, rather than per area emissions, was the predominant driver of the net GHG emission impact of AAPI (Figures 2 and 3). Climate change mitigation benefits at the project level would increase dramatically if AWD were adopted over even larger areas.

**Figure 2. Impact of agricultural practices:
Net GHG emissions on an area basis**
(tCO₂e/ha/yr)



* The estimated reduction in direct N₂O emissions per hectare was calculated for constant fertilizer application rates unchanged from the initial management practices within conventional rice systems.

**Figure 3. Impact of agricultural practices:
Net GHG emissions on total area of impact**
(tCO₂e/yr)



* The estimated reduction in direct N₂O emissions per hectare was calculated for constant fertilizer application rates unchanged from the initial management practices within conventional rice systems.

GHG emission intensity

Emission intensity (GHG emissions per unit of output) is a useful indicator of LED in the agricultural sector. Table 1 summarizes emission intensity findings for aman and boro rice varieties without and with agricultural practices supported by AAPI. No data were available on yields of individual crops for vegetables when data were collected, which prevented calculation of emission intensity.

Annual yield. Irrigated (boro) and seasonally flooded (aman) rice had yield improvements of 9% and 14% respectively, due to UDP, AWD and improved soil management.

Emission intensity. Changes in agricultural practices encouraged by AAPI resulted in reductions in crop emission intensity ranging from 10 to 48%.

Table 1. Emission intensity by product

	Project agricultural practices	Total GHG emissions per ha (tCO ₂ e/ha) ⁽¹⁾	Annual yield (t/ha) ⁽²⁾	Emission intensity (tCO ₂ e/t product) ⁽³⁾
Irrigated rice - Boro (AWD & UDP)	No project	13.30	6.20	2.14
	Project	7.49	6.73	1.11
	Difference (%)	-5.81 (-44%)	0.53 (9%)	-1.03 (-48%)
Irrigated rice - Boro (UDP)	No project	13.30	6.20	2.14
	Project	13.03	6.73	1.94
	Difference (%)	-0.27 (-2%)	0.53 (9%)	-0.21 (-10%)
Seasonally flooded rice - Aman (UDP)	No project	11.38	3.66	3.11
	Project	11.20	4.19	2.67
	Difference (%)	-0.17 (-2%)	0.53 (14%)	-0.43 (-14%)

Notes:

1. Total GHG emissions per hectare identifies the emissions per hectare of product harvested.
2. Annual yield identifies the tonnes of product produced per hectare harvested each year.
3. Emission intensity is calculated by dividing the total GHG emissions per hectare by the annual yield.

Low emission program design considerations

This analysis of GHG emissions and carbon sequestration by agricultural practice raises issues that those designing or implementing other programs will need to consider in the context of low emission agriculture and food security for smallholder farmers, including:

- **Reducing barriers to UDP uptake.** Can tools suitable for smallholder production systems be introduced to reduce the labor intensity of manually placing UDP briquettes, thereby increasing farmer adoption and reducing the likelihood of disadoption? How do agricultural policies (such as government subsidies on fertilizer) impact UDP adoption?
- **Assessing AWD feasibility.** What is the geographic suitability of AWD? What are the specific barriers to farmer uptake and adoption at scale? What social and institutional enabling conditions could effectively foster adoption? What public or private investment is necessary to increase widespread AWD adoption? How do irrigation infrastructure, practices and policies impact AWD adoption?
- **Introducing short-duration varieties (SDV).** Since SDV rice reduces flood duration, what role could it play in reducing emissions? Can current rice growing cycles be reduced without compromising yields and the resilience of the cropping system? What are the productivity and resilience co-benefits of SDV rice? Are there other benefits to SDV rice, such as enabling an additional crop cycle due to the earlier harvest of SDV rice?

Methods for estimating emissions

A comprehensive description of the methodology used for the analysis presented in this report can be found in Grewer et al. (2016); a summary of the methodology follows. The selection of projects to be analyzed consisted of two phases. First, the research team reviewed interventions in the FTF initiative and additional USAID activities with high potential for agricultural GHG mitigation to determine which activities were to be analyzed for changes in GHG emissions and carbon sequestration. CCAFS characterized agricultural interventions across a broad range of geographies and approaches. These included some that were focused on specific practices and others designed to increase production by supporting value chains. For some activities, such as technical training, the relationship between the intervention and agricultural GHG impacts relied on multiple intermediate steps. It was beyond the scope of the study to quantify emission reductions for these cases, and the research team therefore excluded them. Next, researchers from CCAFS and USAID selected 30 activities with high potential for agricultural GHG mitigation based on expert judgment of anticipated emissions and strength of the intervention. The analysis focused on practices that have been documented to mitigate climate change (Smith et al. 2007) and a range of value chain interventions that influence productivity.

Researchers from FAO, USAID, and CCAFS analyzed a substantial range of project documentation for the GHG analysis. They conducted face-to-face or telephone interviews with implementing partners and followed up in writing with national project management. Implementing partners provided information, data, and estimates regarding the adoption of improved agricultural practices, annual yields, and postharvest losses. The underlying data for this GHG analysis are based on project monitoring data.

The team estimated GHG emissions and carbon sequestration associated with agricultural and forestry practices by utilizing EX-ACT, an appraisal system developed by the FAO (Bernoux et al. 2010; Bockel et al. 2013; Grewer et al. 2013), and other methodologies. EX-ACT was selected based on its ability to account for a number of GHGs, practices, and environments. Derivation of intensity and practice-based estimates of GHG emissions reflected in this case study required a substantial time investment that was beyond the usual effort and scope of GHG assessments of agricultural investment projects. Additional details on the methodology for deriving intensity and practice-based estimates can be found in Grewer et al. (2016).

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Info note series

USAID project	Country	Agroforestry, perennial crop expansion	Irrigated rice	Land use, inc. reforestation & avoided degradation	Livestock	Soil, fertilizer management
Accelerating Agriculture Productivity Improvement	Bangladesh		X			X
ACCESO	Honduras	X			X	X
Agricultural Development and Value Chain Enhancement Activity II	Ghana		X			X
Better Life Alliance	Zambia	X		X		X
Chanje Lavi Planté	Haiti	X	X	X		X
Pastoralist Resiliency Improvement and Market Expansion	Ethiopia				X	
Peru Cocoa Alliance	Peru	X				X
Resilience & Economic Growth in Arid Lands-Accelerated Growth	Kenya				X	
Rwanda Dairy Competitiveness Project	Rwanda				X	

All info notes are available at: <https://ccafs.cgiar.org/low-emissions-opportunities-usaid-agriculture-and-food-security-initiatives>

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CCAFS and Info Notes

The CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) is a strategic partnership of CGIAR and Future Earth, led by the International Center for Tropical Agriculture (CIAT). CCAFS brings together some of the world's best researchers in agricultural science, development research, climate science and Earth System science, to identify and address the most important interactions, synergies and tradeoffs between climate change, agriculture and food security.

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