Reducing Greenhouse Gas Emissions from Rice in Vietnam: A Quasi-Experimental Evaluation of a Private Sector Prize Competition that Incentivizes Smallholder Technology Adoption

Adi Greif, adi_greif@abtassoc.com

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Abstract: Flooded rice leads to an estimated twelve percent of global methane emissions and half of all crop-related greenhouse gas (GHG) emissions, making rice a major contributor to global warming. Reducing GHG emissions from rice farming requires rice farmers to adopt a complicated set of new technologies and practices. Governments and aid agencies have been at the forefront of programs to teach rice farmers new practices and have seen success at reducing GHG emissions while maintaining yields. However, pricing arrangements have hampered farmer adoption of improved practices across Asia. The AgResults Vietnam Emissions Reduction Project is one component of a larger, $145 million stakeholder initiative managed by the World Bank to test whether it can spur the private sector through pay-for-results prize competition to build new supply chains that utilize agricultural advances. In Vietnam, the project posited that companies in Thai Binh province (2019-2020) would benefit from aggregating rice farmers to use improved technologies and GHG-emissions practices. In return for using subsidized inputs, farmers bought company inputs and/or sold their rice to companies. We conducted two quasi-experimental analyses by matching selected control and treatment communes and taking matched stratified samples of approximately 2,100 farmers in each of the Spring and Summer 2020 rice seasons. Results show that yield increased by 8-12%. Revenue also increased and is statistically significantly higher in treatment compared to matched control communes. Revenues are estimated to increase even after subsidies are removed, but this effect is driven increased yield and sales, rather than increased sales value of the rice. The number of dry days, the primary driver of reduced GHG emissions, is also statistically significantly higher in the treatment in the spring. Dry days did not significantly increase in the summer, when monsoon storms makes drainage difficult. The treatment did not cause reductions in a secondary driver of GHG reductions, the amount of nitrogen applied to the soil. This paper is the first to rigorously evaluate whether we can reduce GHG emissions due to rice farming via an innovative prize mechanism that induces private sector development. It also finds that prize competitions do not only incentivize the private sector but can also catalyze the public sector into solving coordination and information challenges.

Keywords: agriculture, rice farming, GHG emissions, quasi-experimental evaluation, Vietnam, AWD

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Introduction

Rice farming leads to an estimated seven to twelve percent of global methane emissions as well as causing even more potent nitrous oxide emissions, making rice a major contributor to global warming (US-EPA 2006). While reducing GHG emissions from rice is crucial to mitigating the impacts of climate change, it simultaneously requires that smallholder farmers maintain food security. Maintaining, or ideally increasing, yields of smallholder farmers while reducing GHG emissions requires training, information on best practices, and aligned incentives for local governments, agribusinesses, and farmers. The difficulty of solving these challenges has led to the current state of market and administrative failures.

The AgResults Vietnam Emissions Reduction Project pioneered an innovative approach to maintaining food security while reducing environmental pollution. In Vietnam's Thai Binh province, the AgResults Vietnam project ran a pay-for-results prize competition (2019-2020) between four rice companies to see whether companies could measurably reduce the GHG emissions of smallholder farmers while improving yield. To understand the extent to which the pay-for-results prize competition successfully led to smallholder technology adoption and reduced GHG emissions, we used quasi-experimental methods to evaluate data collected from household-level surveys. We conducted two surveys of around 2,100 rice farmers each across Thai Binh province, one in the Spring 2020 rice growing season, and one in the Summer 2020 season.

We find a statistically significant increase in yield and revenue for smallholder farmers. Smallholder farmers adopted new technologies at statistically significant rates, and we estimate that even when subsidies by companies are removed, gains in income will outweigh increased costs of the new technologies. In terms of reducing GHG emissions, we find statistically significant reductions in the use of water, which is the main driver of GHG emissions. Findings are more mixed however, for fertilizer use. The data and these results will be discussed following sections that describe the theoretical framework of the prize competition and the setting.

We also find that despite the private nature of the prize competition, in reality the competition and successful reduction of GHG emissions heavily relied on cooperation with the public sector, and in particular the cooperative leaders. The market incentives in turn provided the cooperative leaders with the knowledge and incentives to change water usage toward an alternate wetting-and-drying system, and aggregated farmers on contiguous plots to take advantage of economies of scale. To our knowledge, this was not only one of the first agricultural prize competitions focused on farmer adoption but also an early one to, despite its focus on the private sector, use private sector incentives to help the public sector overcome various coordination and information challenges.

Background: Prize Competition ‘Pay-for-Results’ Mechanisms

Environmental pollution is a classic example of a negative externality, where consumers, and producers often do not pay the full cost of environmental pollution. GHG emissions from flooded rice farming are particularly potent, as oxygen is blocked from reaching organic matter decaying under the water, allowing bacteria that emits methane to grow. Methane has 84 times the warming potential of carbon dioxide (Kritee and Ahuja 2013). Dry rice plants on the other hand, act as a sort of straw for releasing nitrous oxide from the soil into the atmosphere. Recent research indicates the plant may itself also form nitrous oxide (Timilsina, et al. 2020). Although far less of it is emitted than methane, nitrous oxide has 300 times the warming potential of carbon dioxide (Kritee and Ahuja 2013).

Economists and others have offered multiple solutions from this type of negative externality, ranging from Pigouvian taxes, certification schemes, and emissions regulations to carbon markets. They have also extensively debated the merits of public versus private solutions (Arrow 1970, Beckerman 1972, Pigou 1920). Despite more recent calls for hybrid public-private policy tools for improved ‘environmental governance’ (Lemos and Agrawal 2006) or ‘ecological modernization’ (Sonnenfeld and Mol 2002), there is little consideration of the relationship between public and private incentives in agri-environmental schemes.

In many countries that produce methane and nitrous oxide through flooded rice farming, such as those in Asia, long histories of strong government intervention make completely private initiatives to change agricultural practices impossible. At the same time it can be difficult for governments to have the resources necessary to generate sufficient information on best practices. It can also be difficult for governments to increase farmer adoption of new technologies without imposing high costs (such as taxes on older seed and fertilizer types).

One potentially under-utilized policy tool for overcoming market failures while also providing local governments with the ability to overcome various information and coordination challenges is using pay-for-results (PfR) prize competitions. Prize competitions that use “pay-for-results” (PfR) mechanisms for market development base their prizes on achievement of procuring or selling pre-determined targets - usually the volume or value of a technology or its derivative product. This mechanism differs from grants and contracts, which provide payment for technology development or service delivery.

Pay-for-results prize competitions for enviro-agricultural market development schemes are still relatively new, yet evidence from other sectors indicate their potential. Pay-for-results (PfR) mechanisms have broken down implementation barriers and driven progress on intractable social challenges in diverse sectors (see a review by Meuth Alldredge et al. 2020). Payment for environmental services have successfully increased forest cover (Arriagada et al. 2012, Jayachandran et al. 2017). In the energy sector PfR mechanisms have incentivized the adoption, sale and use of climate-friendly energy technologies and promoted innovation across the energy supply chain (Usmani et al. 2017).

The benefits of PfR prize competitions are normally associated private sector incentives for long-term sustainability. In practice however, the AgResults Initiative projects in other countries such as Kenya and Nigeria, have shown that government cooperation is often required to gain the appropriate permissions to run large-scale prize competitions involving thousands or even tens of thousands of farmers. In those competitions, choice over agricultural technology adoption was highly individual – in one case requiring farmers to choose to buy sealable storage bags, and in the other to treat their crops with Aflasafe (Narayan et al 2020; Ness-Edelstein 2019; Ness Edelstein et al 2020; Narayan et al 2020). There has been much less understanding of prize competitions where cooperation with the public sector goes beyond an enabling environment to active recruitment, training, and direct participation in the new technologies.

The Setting

The AgResults Vietnam GHG Emissions Reduction prize competition pilot ("AgResults Vietnam project") worked in Thai Binh province. The program implementers chose Vietnam due to its positive enabling environment and specific features of Vietnam's institutional environment for rice-growing. The Government of Vietnam (GoV) had explicit goals and targets to reduce GHG Emissions by 2020 and increase public awareness of climate change in the 2012 document, The National Strategy on Environment Protection to 2020, with Visions to 2030. Notable programs encouraged by the GoV to reduce GHG emissions are the "three down three up" initiative to reduce quantities of seeds, fertilizer and pesticide and increase productivity, quality and efficiency; the "1 Must - 5 Reduction" initiative to use certified seeds while reducing use of water, fertilizer, seed, pesticide and post-harvest waste; and the "System of Rice Intensification" technique to save water. Some provinces allocated funding to expand successful pilot programs (Thang and Linh 2014). The document did not mandate methods to implement these initiatives, nor did it have a plan for collaboration with the private sector, providing an opportunity to design useful programming.

Simultaneously, rice cultivation is a crucial pillar of food security in Vietnam and the GoV is interested in initiatives that can improve income from rice farming while maintaining household-level food availability. Rice production from 2008-2018 increased from 38.7 million tons to 44 million tons, providing more sustainable food security than most developing countries in Asia and 55% of total dietary energy for the Vietnamese population. Rice production has successfully provided food security by a central land-use policy that dedicated plots to households. Under Resolution No. 63/NQ-CP on 23 December 2009, 3.8 million hectares were reserved for rice production through 2020 and involves a system for registering land by household name every five or ten years. This system has led to small-scale holdings; more than 85% of households cultivate less than 0.5 hectares as compared to the average small-scale farm size of two hectares defined by the FAO. The fragmented nature of land holdings makes intensification and mechanization challenging (Anh and Nghiep 2020). As a result of the difficulties involved in making a living from rice farming alone on small plots and strict regulations requiring the land to be used only for rice, some smallholder farmers migrate to find work in cities instead (Giesecke et al 2013). To overcome these challenges, the Resolution's objectives include more value chain competitiveness and improved research capacity, in addition to climate change mitigation and poverty reduction targets (Anh and Nghiep 2020).

The GoV thus had an enabling policy environment from the GHG emissions and food security standpoints; meanwhile Thai Binh province served as a useful setting for the pilot program due to the high density of farmers, a high level of institutional organization of the farmers, and the relatively few international actors in the province. Thai Binh Province is in the Red River Delta (RRD) which has a high density of small-holder farmers (SHFs) – approximately 2.5 million farms. It also has the highest concentration of farmer cooperatives in the country, enabling the coordination of farmer groups. The percentage of irrigated land is also high, allowing for water drainage (Devienne 2006). Although other institutions are involved in local agricultural programming, there were no other major international donor programs in the province at the time. The project implementer thus posited that any results of the prize competition would be more easily attributable to the prize competition rather than other simultaneous programs (AgResults 2015).

The Intervention

The AgResults Vietnam project conducted two rounds of prize competitions, one focused on technology development and one on application. The first round, in 2017, provided prizes to companies that developed packages of new technologies and practices that, according to measurements taken on demonstration test plots, reduced GHG emissions without sacrificing yields. The test plots were compared to emissions on demonstration plots that used standard practices in the province. Research measuring GHG emissions from different packages of technologies and practices (and not only modeling them) for rice farming is still a preliminary and growing field (see the metaanalysis of IRRI projects in Vietnam by Vo et al. 2020).

Companies that passed the first round were eligible for the second round of the prize competition, which is the round upon which this evaluation focuses. The second round provided financial awards to companies proportional to the number of farmers that adopted the program, the number of repeat farmers over time, the extent to which farmers reduced GHG emissions, and the extent to which yield increased.

The project hypothesized that the prize competition would induce companies to find ways to overcome market failures by incentivizing and training farmers to change their practices and buying behavior, especially in the categories of water management, fertilizer use, rice varieties, and rice husk and straw residue management.[1] The project left specifics up to the competing companies ("the competitors") but did allow companies to use the prize award money toward subsidies to farmers.

[1] This wording has been simplified for clarity, for original wording see https://agresults.org/projects/vietnam. The project originally also planned to consider organic amendments: type, amount applied, and timing of application, as stated in the AgResults, May 15 2015, Vietnam GHG Emissions Reduction Pilot Business Plan. However, none of the company competitors recommended organic amendments as part of their package of practices.

Four companies signed up to participate in the second round. One aims to produce higher-quality rice marketed for export to Japan, two sell rice seed rather than grain (which also requires high quality production) and the fourth sells high-priced slow-release fertilizer. Each company recruited farmers by first reaching out to cooperative leaders and then selecting interested farmers. One of the seed companies is large and well-established with repeated relationships with existing farmers. The prize competition took place over four crops: Spring 2019, Summer 2019, Spring 2020, and Summer 2020. The external evaluation took place in Spring and Summer 2020.

We as the evaluators expected, based on major contributors to GHG emissions and the logic of the prize competition, to see:

- *H1a: Reduced GHG emissions (as modeled by a specialized firm)*
- *H1b: Reduced water use (measured as self-reported days the field has 0 cms of water)*: Draining fields periodically, using techniques such as "Alternate Wetting and Drying" (AWD) reduces the buildup of methane-producing bacteria in flooded fields. The number of dry days thus serves as a proxy for reduced GHG emissions; it is a crude proxy since the timing and duration of dry days is also crucial to reducing emissions. Farmers must be trained to use appropriate AWD schedules so that rice plants are flooded at the times the plants require a lot of water for growth and stability as well as to ensure nitrous oxide emissions are also minimized.[2] AWD can also help make it more effective to apply pesticides and fertilizer on fields that are not flooded to prevent their dilution.
- *H1b: Cooperation with the public sector to help reduce water use (evaluated through qualitative interviews with cooperative leaders).* Although the prize competition is explained as a means for solving market failures, in this setting it is not possible for competitors to change water schedules to reduce water without the active work of the cooperative leaders in charge of the drains. The cooperative leaders also cannot choose to drain plots individually and rather must change water usage at a higher (usually village) level. Thus we as the evaluators also hypothesized that the competitors would need to find a way to work closely with cooperative leaders to see substantial reductions in GHG emissions through water drainage.
- *H2: Reduced amount of nitrogen applied (measured in kgs per hectare, self-reported):* Reducing kilograms of nitrogen applied as fertilizer will reduce soil nitrogen and thus nitrous oxide emissions. Although some amount of nitrogen is necessary to promote rice growth, over-use of nitrogen in fertilizers can be prevented by:

[2] AWD also has unclear consequences for plant protection against disease and pests. Farmers in qualitative interviews expressed fear that rats would no longer drown and could be a serious concern. However, AWD may be beneficial against other plant diseases.

    - Using 'slow-release' fertilizers. These fertilizers have a coating that wear off in sunlight or water over time, enabling more efficient uptake of nitrogen. These fertilizers are more expensive but require fewer applications
    - Training of farmers to understand necessary amounts of nitrogen along with other elements such as phosphorus and potassium that also promote rice growth
- *H3: Reduced planting density (measured in kgs of seed per hectare, self-reported):* Since nitrous oxide is released through rice stalks, one way to reduce GHG emissions is to instead have fewer rice stalks, but more tillers of rice off of each stalk instead. Doing so can also ensure that yields are maintained or improved while reducing GHG emissions. Planting density can be reduced by:
    - Transplanting fewer seeds, or by thinning out stalks by hand after planting.
    - Using improved rice varieties to increase yield per plant[3]
- *H4: Increased use of bioenzymes (binary variable for use of bioenzyme, self-reported):* Rice husk and straw residue management also impacts GHG emissions. Farmers that plant in both spring and summer crops need to remove residue prior to the next crop season. The timing between spring and summer crops is too short to allow for natural decomposition in time, but with the application of bioenzymes the decomposition allows for two seasons of rice. The bioenzyme alternative is better than burning residue, which gets rid of it quickly but also contributes to air pollution. Another option is to remove the residue off the field, where ideally it can be sold or donated for other uses such as mushroom growing compost or creating straw brooms. Soil carbon is beneficial for plant growth, and can also trap carbon in soil, reducing GHG emissions.[4]
- *H5: Increased yield (self-reported kgs per hectare)*. We anticipate that competitors will only use GHG emissions interventions to the extent that the interventions also help increase yield. Farmers are often risk-averse (for an example of Vietnamese farmer risk aversion due to fertilizer quality control see Khor et al 2018). Without clear evidence that it is worthwhile and not risky to change practices and buying behavior, farmers will be unlikely to buy the products of the companies in the future. The first round of the prize competition demonstrated potential to improve yield through the practices that also reduce GHG emissions, such as reducing planting density, and using improved seed varieties and fertilizers.
- *H6: Increased revenue, with and without subsidies (self-reported Vietnamese dong (VMD)/hectare).* As above, we posit that farmers will only engage in changing practices and buying behavior if they expect overall gain. Competitors also need to ensure that

[3] Another goal of using improved rice varieties in the AgResults Business Plan (2015) is to control growing season length. Varieties that grow more quickly allow farmers to grow two seasons of rice. Using improved seed varieties can also ensure farmers grow higher-value rice or rice suitable for specific conditions such as drought, high altitudes, or saline soils.

[4] That said, the role of organic matter decomposition in potentially releasing GHG emissions is complex and still being researched (Wang et al. 2018).

these gains will be sustained even in the absence of subsidies if they intend to continue beyond the life of the prize competition.

Methods

We used a quasi-experimental matching design to assess the impact of the AgResults Vietnam project on the smallholder outcomes. First we selected treatment and control communes based on balanced baseline characteristics.[5] Within the treatment communes, we randomly selected farmers that participated in the treatment. We matched comparison farmers to the treatment farmers by selecting a stratified sample that mimicked the competitor selection process, in addition to weighting farmers based on individual characteristics.[6] For three of the four competitors, we chose comparison farmers from control communes. For one of the competitors however, we selected comparison farmers in communes assigned to treatment that did not take up the treatment. These were the only other farmers that worked with that particular company and were suitable comparisons. The challenge of a design relying on ex-post identification of the treatment and comparison group is selection bias. There may be underlying reasons why some eligible communes were targeted by AgResults, and those reasons might explain observed differences between the treatment and comparison group even in the absence of AgResults.

Although it is impossible to eliminate the threat of unobserved selection bias, we mitigate selection bias at the farmer and commune level through an explicit understanding of how competitors selected cooperatives with which to work. Competitor selection occurred at the cooperative level and was exogenous to individual farmer characteristics. Typically, competitors asked cooperative leaders to identify a favorable village or neighborhood with contiguous rice plots. They asked cooperative leaders to coordinate with the owners of the contiguous plots to create a site of at least 1500 square meters. Depending on the competitor, the site also had to meet additional specifications such as having a high elevation/flat terrain or otherwise very good water drainage control, being situated near a main access road, and/or including farmers already known to the competitor. Based on our interviews with competitors, we understood that competitors considered large contiguous areas crucial to the project for ease of draining and for economies of scale, since the competitors might provide inputs, training, monitoring, and might also buy rice directly from the farmer area at the end of the season[7].

The farmers in the selected areas tended to be whomever happened to, pre-program, own sufficiently suitable land next to other similarly suitable farmers. Based on our cooperative leader interviews, there was little farmer-level selection. Farmers almost never refused to participate, although some later dropped out (often an entire area might drop together). This may be because farmers in cooperatives often follow the cooperative leaders' schedule regardless – announcements for times to fertilizer are broadcasted on speakers throughout villages – and the

[5] Commune is usually synonymous with cooperative, except for a few cases with two cooperatives in one commune

[6] The evaluation started out with a randomized control trial (RCT) that leveraged the villages and cooperatives set aside as control that were ineligible for the prize. 205 communes were assigned to treatment and 50 assigned to control. However, we could not convince competitors to randomly select cooperative leaders or farmers within treatment villages.

[7] Competitor interviews, full citation forthcoming.

farmers found the promise of economic gain credible.[8] We might expect competitors to select commercially oriented farmers with larger plots, but we did not find evidence of this sort of selection. Some farmers prior to the program had only grown food for home consumption. farmers were also not selected based on large plot size. Exhibit 1.

shows the distribution of AgResults farmers' plot sizes and compares it with the distribution of all farmer rice plot sizes in Thai Binh. The AgResults farmers have similar, and perhaps even slightly smaller rice plots compared to Thai Binh rice farmers in general.

Exhibit 1. Distribution of farmers' plot area designated for rice (square meters)		
	Thai Binh rice farmers, Spring 2018	Recruited AgResults Crop 3 farmers, Spring 2020
1st percentile	25	120
5th percentile	360	250
10th percentile	500	321
25th percentile	864	500
50th percentile (median)	1416	900
75th percentile	2112	1370
90th percentile	2804	1951
95th percentile	3281	2500
99th percentile	4489	3960
Sample size	481,761	10,369
Source: AgResults evaluation baseline data, and Verifier scouting data at the start of Spring 2019.		

Using the information from interviews with competitors and cooperative leaders, and also using the information about participating farmers' plot sizes, we stratified the recruitment of comparison farmers by competitor-selection-type. **Error! Reference source not found.** illustrates the stratification we will conduct *within each control cooperative* to select comparison farmers that "match" the type of farmers that might be recruited if the cooperative had been assigned to the treatment group. Competitors are assigned codes (I4, I5, I18, I23) to preserve confidentiality.

Exhibit 2. Sample selection protocol for comparison farmers in control communes				
	Percent of AgResults Spring 2019 Farmers	Number of farmers to sample in each control cooperative (total 23)	Area/neighborhood selection criteria (All: neighborhood is flat/high elevation, or otherwise easy for discharge of water)	Number of farmers, by rice plot size (all farmers required to have minimum 300 m^2 under rice)
I4	26%	6	Fields are near the road[9]	4 farmers with > 900 m^2 2 farmers with < 900 m^2

[8] Our in-country consultant met with hundreds of farmers and found no evidence of coercion. Farmers were open about what parts of the program they appreciated and found helpful, and what parts they found onerous.

[9] This criteria did not end up being restrictive.

I5	42%	10	Farmer has worked with the company previously	5 farmer with > 900 m^2 5 farmers with < 900 m^2
I18	19%	4	Area has lots of rice farmers.	1 farmer with > 900 m^2 3 farmers with < 900 m^2
I23	14%	3	Can use a transplanter[10]	0.5 farmer with > 900 m^2 2.5 farmers with < 900 m^2

In coordination with the cooperative leaders in control communes, we selected 12, 20, 8, and 6 farmers who meet the criteria listed in **Error! Reference source not found.**for each of the four competitors respectively, based on a 2018 list of farmers. We then randomly ordered each set and recruited farmers in order of the randomly sorted list until we achieved a sufficient number of responses.

We used observable characteristics to mitigate commune-level bias. The selected treatment communes have, on average, larger areas under rice production (in spring and summer) and slightly higher yields. We found that, taken together, these characteristics distinguish the selected treatment communes from the non-selected communes and their differences are statistically significant (the global F test yields a p-value of 0.032). We excluded a few control communes with the lowest areas under rice production at baseline, and a few selected treatment communes with the highest areas under rice production to make them more similar.[11]

Competitor I5 provides reassuring evidence against commune-level bias for the "comparison" communes taken from the communes assigned to treatment. This competitor only worked with farmers with whom they had previously worked; these were only in the communes assigned to treatment. Company technicians assure us that no underlying differences relevant to the outcomes in communes caused them to reach out to some communes assigned to treatment rather than others. Rather, they had reached out to all communes with which they worked that planted the seed varieties allowed by the project. As for the rest of the communes, some of them are currently in the process of switching seed varieties so as to continue the program. Others ended up working with one of the other competitors, showcased their suitability for program inclusion.

This design has the "cost" of having a sample that is representative of roughly 85% of the treatment area instead of 100%. To mitigate concern that the treatment sample may not be fully representative of the competitors' engagement with AgResults farmers, we stratified the treatment and comparison sample by competitor such that the number of communes served by each competitor in the sample will be in the same proportions as the number of communes served by each competitor in the full population of communes served by the AgResults project.

Model and Weights

[10] The competitor relaxed this requirement after the program started, since it is also possible to transplant by hand or thin sown rice.

[11] To mitigate bias due to cooperative leader characteristics, we asked control farmers whether their cooperative leaders encourage innovation in rice farming (around 70-75% said yes). A forthcoming robustness check will restrict the sample to only the 'innovative' rice cooperatives.

We use linear or logit regression models to estimate the average impact of AgResults on farmers' outcomes (see equation 1). Household survey responses are clustered in villages, and we do not view these responses as independent across farmers because AgResults was implemented at the village/site level instead of the household level. Thus, the primary sampling unit is a village and statistical precision is more a function of the number of villages in the treatment and comparison groups than of the number of households in the treatment and comparison groups.[12]

$$y_{ij} = \alpha + D_j\delta + X_i\beta + Z_j\gamma + \varepsilon_{ij} \qquad \text{[Equation 1]}$$

The regression allows us to answer research questions about the effect of AgResults on farmers competitors said they worked with or reached out to – as measured by coefficient δ on D. In the regression equation above, y_{ij} is the outcome for respondent i in village j; D_j, the treatment indicator, is equal to one if the individual's village j is a treated village, and 0 if it is a comparison village; the coefficient, δ, represents the average treatment effect; X_i includes the household level covariates for person i and Z_j represents the village level covariates such as temperature or soil composition for village j; and the individual idiosyncratic error term ε_{ij} is cluster robust at the village level. The covariates in our impact regressions controlled for cooperative-level, farmer-level, and when appropriate plot-level characteristics that could influence the outcome (see the Data section for more details_.

We also used analysis weights in the income survey to achieve two goals: (1) make the treatment group farmers representative of all farmers participating in AgResults, and (2) improve the comparability of the comparison group to the treatment group on baseline characteristics.

$$wgh_{combined} = wgh_{stratification} * wgh_{balance}$$

The stratification weight ($wgh_{stratification}$) makes the treatment group representative of all farmers participating in AgResults. The sample of treatment group respondents is stratified by competitor, with sample counts displayed in Exhibit 3. The stratification weight for each sampled AgResults farmer is equal to the number of verified farmers who worked with that farmer's competitor divided by the number of interviewed farmers who worked with that farmer's competitor. The stratification weight for each sampled non-AgResults farmer is equal to the number of all verified AgResults farmers divided by the number of all interviewed non-AgResults farmers.

Exhibit 3 showcases the number of AgResults farmers compared to the sample size. One result of this weighting is that it is possible for outcomes across all seasons to not be between results for the spring and summer seasons.

Exhibit 3. Number of sampled and all AgResults farmers

	Spring 2020		Summer 2020		Combined both seasons	
	N	Percent of all AgResults farmers	N	Percent of all AgResults farmers	N	Percent of all AgResults farmers
	All AgResults Farmers, accounting for repeat farmers					

[12] This design precludes selection of comparison group farmers who live in the same village as one or more treatment group farmers—a circumstance that might result in agricultural practices induced by the AgResults intervention spilling over into the comparison group.

I4	1814	22%	5562	29%	6530	31%
I5	3895	47%	5052	27%	5218	25%
I18	1334	15%	5878	13%	6417	29%
I23	1202	16%	2386	31%	2429	14%
Non-AgResults	Not applicable					
	Total interviewed farmers					
I4	300	32%	331	34%	631	35%
I5	272	29%	215	22%	387	21%
I18	200	21%	271	28%	471	26%
I23	173	18%	163	17%	336	18%
Non-AgResults	1236	131%	1090	111%	2326	127%
	Combined weighted count, accounting for repeat farmers					
I4	1814	22%	5586	30%	6613	32%
I5	3895	47%	5052	27%	5226	25%
I18	1334	16%	5878	31%	2533	31%
I23	1202	15%	2386	13%	6418	12%
Non-AgResults	8244	100%	18902	100%	20670	101%

To improve the balance on observable characteristics, we use propensity scores. Prior to balancing, we compared the treatment and comparison groups on all characteristics listed in Exhibit 2. Of these, the difference between groups exceeded 0.25 standard deviations of that measure: whether any of the seed types used in the AgResults technologies was one of that cooperative's top three most common seed types grown in 2018 (prior to AgResults) and whether the irrigation system was complete as of 2018. When we applied the propensity score balancing method to only those variables, additional imbalanced arose: whether the commune's irrigation system was managed solely by the cooperative leader, average rice yield, and average value of the cooperative's rice crop. Thus, our propensity score model estimates the propensity to be the treatment group based on these five characteristics. Using propensity scores p, we assign a balancing weight ($wgh_{balance}$) equal to p/(1-p) for comparison farmers and 1 for treatment farmers. We multiply this weight times the stratification weight to get the final analysis weight for the farmer. See Appendix B for weighted balance tables.

Complementing the impact evaluation, the evaluation also obtained qualitative data from competitor interviews, cooperative leaders, and an extensive diary of farmer practices.

Data

For both the treatment and comparison groups, we recruited farmers to respond to a questions in a detailed agricultural survey. To select respondents, we used two-stage sampling, first by village and then smallholder. All farmers who gave consent to be interviewed, and understood that participation was completely voluntary, responded to questions about household demographics, agricultural income, and detailed plot-level information about rice cultivation, input use, harvest, sales, and gendered labor and decisionmaking. We were fortunate that COVID-19 did not impact survey recruitment due to the immediate and intensive quarantine efforts in Vietnam. The survey included 2174 farmers in the summer (1090 treatment, 1084 comparison) over 88 cooperatives and more than 180 villages; in the spring it included 2,201 farmers (945 treatment, 1223 comparison) over 80 cooperatives and 165 villages.

The covariates in our impact regressions control for cooperative-level and farmer-level characteristics. We selected the following baseline cooperative-level covariates because they related to the selection criteria used by competitors or they provide baseline estimates of important outcomes (yield):

- Whether the irrigation was solely managed by the cooperative leader in 2018
- Average rice yield in 2018
- Percent of rice farmers who were members in the cooperative in 2018
- Percent of farmers with at least 1500 square meters for cultivating rice in 2018
- Percent of the cooperative area used for rice cultivation in 2018
- Average area of total rice cultivation per farmer in the cooperative (ha)
- Whether the cooperative owned a riding transplanter in 2018

We also included variables on which comparison groups were imbalanced (difference measured in standard effect size > 0.25) prior to the use of analysis weights:

- Whether one of the top three most common seeds grown in the cooperative in 2018 (pre-AgResults) was an AgResults seed
- Whether the cooperative had a completed irrigation system in 2018
- Average value of rice crop per farmer in 2018

We also included the following cooperative-level covariates that explain carbon content of the soil, weather, and travel time to an urban center:

- Average precipitation Jan-May, imputed
- Minimum temperature, Jan-May, imputed
- soil organic carbon stock at 5-15 cm (tons/ha; 250m resolution, imputed)
- sum of evapotranspiration from Jan-May 2019, mms, imputed
- average travel time from commune to city with 50-100,000 people (imputed)
- District fixed effects (there are 7 districts in Thai Binh)

We also included the following farmer-level covariates which we do not believe to be endogenous, or impacted by AgResults:

- Age
- Sex
- Completed secondary school
- Area used to grow rice
- Total area of rice paddies owned
- Farmer-reported drainage quality (is standing water left after draining-yes/no)
- Whether the plot had loamy soil (as compared to clay, sandy, acid sulphate)
- Whether rice is a main source of income
- Whether the household head completed a secondary education
- Number of assets owned (electric fan, TV, fridge, air conditioner, cell phone, motorbike, car, pesticide sprayer, water pump)
- Income diversity: Number of plant types grown (cereals apart from rice; vegetables; fruit; legumes; tobacco; medicine)

- Income diversity: Number of animal types owned (chicken, ducks, goose, other birds, rabbit, edible fish, cats, dogs, pigs, buffalo/cow/ox/cattle)

For outcome variable measurements:

- Days dry is calculated by the number of days the plot is at 0 cms of water[13].
- Income is calculated as the amount of rice sold multiplied by the price of rice, where all rice sales are scaled to dry rice prices.
- Nitrogen applied is calculated by knowing the amount of fertilizer applied and the percent nitrogen content of the fertilizer type.
- Planting density can be measured in seeds per area, or, for those who transplant, in seeds per hill along with hills per area. We report seeds per sao because this measure is comparable across all farmers.[14]
- Revenue is calculated as the income minus the largest costs of rice farming (land preparation costs, machine and labor costs, harvest machine costs, and pesticide application labor costs) as well as the following costs seen as likely to change due to AgResults – fertilizer, seeds, bioenzymes and lime[15].
- "Sustainable" revenue is the income minus the costs, removing competitor markups/markdowns as well as the largest/most prevalent subsidies (seeds, fertilizer, and bioenzymes). Alternative prices are taken from control farmer averages.

We imputed missing values and extreme outliers (usually two percent of the data at maximum).
GHG emissions estimates: This paper reports emissions estimates generated by a specialized third party firm hired by the implementer called Applied Geosolutions. It used a DeNitrification-DeComposition Model (DNDC) that used inputs (such as drain times and planting dates) provided by cooperative leaders as well as selected site checks of farmer planting and fertilizer practices. The firm gave competitors compliance scores, which the firm incorporated into its modeled emissions. The comparison emissions come from 22 test plots that use the same seed varieties but counterfactual practices. These practices are based on baseline average practices according to a survey Applied Geosolutions oversaw of 720 household survey across Thai Binh,

[13] Some seed varieties grow faster than others. Results are similar when run as a percentage of the growing season, as estimated by the seed variety. Farmers had difficulty recalling exact growing season lengths and there were many seed types used, so we chose a simpler measure.

[14] There was a chance this measure would over-estimate planting density in the treatment, since competitors encouraged farmers to thin saplings after planting. However, farmers in the income survey rarely reported thinning so we did not anticipate this issue being a substantive concern.

[15] Large costs are imputed based on a separate diary study we conducted of 500 farmers each season. We randomly two farmers per cooperative from lists provided by cooperative leaders of farmers who sell rice, live in the province, and have high enough literacy and numeracy to fill out the diary The diary study allowed for much more detailed cost breakdowns and was more accurate since farmers filled it out throughout the season. We excluded rat killing costs, plot rental costs, irrigation fees, pesticides and other costs such cooperative fees, root stimulant, and measures to control disease. These costs were difficult for farmers to remember reliably, especially when costs were a mix of cooperative and individual fees. Data from the farmer diaries also showed these costs as too small to impact results. Cash awards promised to farmers by the competitors are also excluded since they have not yet been distributed.

randomized by production area and soil type.[16] Differences in emissions are largely driven by different water drainage schedules.

Results

To highlight the results in this section: the number of dry days increases from a mean of 13.5 to 18.6 (p<.01) in the spring season but the changes runs in the opposite direction during the monsoon season in the summer (p<.01) and is overall not statistically significant on average across both seasons. Modeled GHG emissions show reductions. There is no evidence of change in the amount of nitrogen used. Bioenzyme use drastically increased in the treatment, in both seasons and both on straw and stubble. (p<.01). Yield also increased by about 10%, or 0.4-0.7 metric tons per hectare (p<0.01).

Income and cash value also increased (p<0.01/p<.05 depending on the season). (Results without intervention forthcoming). Where results by season are not shown, they are similar to the results across both seasons.

Exhibit 4
Hypothesis 1a: Number of Days the Plot is Dry

	Ag-Results average	Comparison average	Difference	Standard Error	P value	Impact as %	Ag-Results N	Comparison N
Avg both seasons	10.5	11.1	-0.6	0.889	0.49	-5.4	6021	6939
Spring	18.6	13.5	5.1 ***	0.999	0.000	37.8	2835	3669
Summer	4.1	5.6	-1.5 ***	0.561	0.007	-26.8	3186	3270

*p<0.1, **p<.05, ***p<.01

Hypothesis 1b

All but a few of the treatment cooperative leaders - forty-seven total - responded to a survey about the challenges and benefits of the AgResults program. Of these, 31 (or 65%) mentioned difficulties mobilizing or aggregating farmers, and 31 also mentioned difficulties with draining water (or having flat enough fields for drainage). Illustrative quotes (translated) from a cooperative leader demonstrates their difficulties:

> *"Some households who have just joined for the first time are not yet adapted to regulating water for their newly fertilized dry fields, so they protested harshly. There are difficulties regulating water when we meet rainy weather. The land is not uniform, so it is also difficult to drain."*

[16] For reports explaining the GHG emissions estimate procedures see: Dr William Salas, Verifier Lead. Remote Sensing and Modeling to Verify Improved Rice Farming to Scale in Vietnam IRC2018 Singapore – 14.30- 16.00 Monday October 15th; Agresults Learning Brief #2. January 2018. Results and Observations from the Vietnam Challenge Project's First Cropping Season. Agresults Learning Brief #1. September 2017.

[Summer cooperative leader survey question responses 2020]

"Implementation in large fields is difficult, due to the difficulty of accumulating a large area of fields, for example 20 ha divided by several hundred households; Implementing water regulation (doing a whole field is easy but only 15- 20 ha is difficult)"
[Summer cooperative leader survey question responses 2020]

"[Main difficulties are] Mobilizing farmers to zoning (because many large-area families gathered in an area do not want to participate), mobilizing transplanting of a rice variety (Because many large-area families gathered in an area do not all want to transplant the same rice varieties), encouraging farmers to change their production habits (from single production to mass production)."
[Summer cooperative leader survey question responses 2020]

The challenges faced by cooperative leaders shows that this project was not a private sector initiative alone; the cooperative leaders were crucial to aggregating and coordinating farmers, along with training farmers to understand that reduced water usage would not reduce yield.

Hypothesis 1c
According to the third party verifier, on average all competitors reduced GHG emissions, although Competitor I4 had a substantially higher reduction at 21% compared to the others at 3-6%. The average amount reduced across the seasons is also higher for Competitor I4, at 1.24 tons per hectare on average compared to .24-.6 for the others. No estimates of certainty were provided. These outcomes also may underestimate the true emissions reduction due to the roughly estimated penalties for non-compliance (More estimates are forthcoming).

Exhibit 5: GHG Reductions with Penalties

GHG Reductions					
	Spring '19	**Sum '19**	**Spr '19**	**Sum '19**	**Overall**
Total GHG Reductions (metric tons, across all competitors)	**250**	**1000**	**180**	**900**	**2330**
Tons per hectare (avg)					
I4	1.84	1.92	0.2	1	1.24
I5	0.35	1.32	0.19	0.55	0.60
I18	0.77	0.82	-0.14	-0.53	0.23
I23	-0.03	1.11	0.23	-0.36	0.24
Avg Total	**0.61**	**1.41**	**0.18**	**0.34**	**0.64**
% CO2 Reduction					

I4	36.86	26.98	5.91	12.65	21
I5	5.13	10.89	3.86	5.10	6
I18	9.87	5.32	-3.06	-4.62	2
I23	-0.53	8.29	5.45	-2.81	3
Avg % Total	**10.39**	**12.46**	**3.95**	**3.35**	**8**
Source: AgResults Steering Committee Slides 2019					

Estimates of reductions are much higher without penalties for non-compliance.

Exhibit 6: Reduction without penalties:

Competitor	season	Area	GHG Reductions
		(ha)	(tons CO2eq/ha)
i18	'19 spring	45	1.37
i18	'19 summer	44	2.98
i18	'20 spring	79	0
i18	'20 summer	658	0.69
i23	'19 spring	176	0.33
i23	'19 summer	115	2.41
i23	'20 spring	121	0.49
i23	'20 summer	216	1.11
i4	'19 spring	107	2.11
i4	'19 summer	189	3.28
i4	'20 spring	306	0.2
i4	'20 summer	890	2.95
i5	'19 spring	93	0.97
i5	'19 summer	435	2.48
i5	'20 spring	478	0.28
i5	'20 summer	588	1.74

Exhibit 7

Hypothesis 2: Nitrogen amount (kgs per sao)

	Ag-Results average	Comparison average	Difference	Standard Error	P value	Impact as %	Ag-Results N	Comparison N
Avg both seasons	2.9	3	-0.1	0.139	0.551	-3.3	6021	6939
Spring	2.7	2.9	-0.2	0.163	0.222	-6.9	2835	3669
Summer	3	2.9	0.1	0.118	0.576	3.4	3186	3270
*p<0.1, **p<.05, ***p<.01								

Exhibit 8

Hypothesis 3: Planting Density in kgs/sao

	AgResults average	Comparison average	Difference	Standard Error	P value	Impact as %	AgResults N	Comparison N
Avg both seasons	1.3	1.4	-0.1 ***	0.046	0.009	-7.1	6021	6939
Spring	1.2	1.4	-0.2 ***	0.045	0	-14.3	2835	3669
Summer	1.3	1.5	-0.2 ***	0.051	0.004	-13.3	3186	3270

*p<0.1, **p<.05, ***p<.01

Exhibit 9 [more results forthcoming, they are similar to these results]
Hypothesis 4: Bioenzyme used or not (yes/no), on average across both seasons

	AgResults average	Comparison average	Diff-erence	Standard Error	P value	Impac t as %	Ag-Results N	Comp-arison N
Used bio-enzyme on straw Spr20	24.2	5.9	18.3 ***	2.689	0	310.2	2007	2313
Used bio-enzyme on stubble Spr20	32.7	10.5	22.2 ***	3.692	0	211.4	2007	2313
Used lime on straw Spr20	8.4	9.1	-0.7	1.99	0.712	-7.7	2007	2313
Used lime on stubble Spr20	12	15	-3	2.471	0.227	-20	2007	2313

*p<0.1, **p<.05, ***p<.01

Exhibit 10
Hypothesis 5: Yield (metric tons per hectare)

	Ag Results average	Comparison average	Difference	Standard Error	P value	Impact as %	Ag-Results N	Comparison N
Avg both seasons	5.3	4.9	0.4 ***	0.071	0	8.2	6021	6939
Spring	5.6	5	0.6 ***	0.112	0	12	2835	3669
Summer	5.1	4.7	0.4 ***	0.08	0	8.5	3186	3270

*p<0.1, **p<.05, ***p<.01

The income increase of 162,400 VND per sao translates to roughly $7.08 per sao, or .036 hectares. This translates to $194 per hectare.[17]

Exhibit 11 [further tables including counterfactual without AgResults intervention forthcoming]
Hypothesis 6: Revenue or Income in '000 VND per sao, across both seasons

Rice income (cash) net of costs (1000s VND/sao)					
Average, spring and summer crop	65	-97.4	162.4 ***	47.2	0.001

[17] Revenue and cost calculations subject to slight changes forthcoming.

Rice income (cash) net of costs (1000s VND/sao)					
Spring 2020	259.9	20	239.9 ***	56.2	0.000
Summer 2020	16.5	-244	260.5 ***	43.9	0.000
Harvest value net of costs (1000s VND/sao)					
Average, spring and summer crop	867.3	794.4	72.9 **	35.8	0.043
Spring 2020	944.6	820.8	123.8 ***	39.3	0.002
Summer 2020	891.6	769.2	122.4 **	51.8	0.019

*p<0.1, **p<.05, ***p<.01

Discussion

To go through the hypotheses in order: For H1 on the number of dry days, we had many reports from cooperative leaders that monsoon storms made drains impossible in the summer. The mean dry days in the summer is much lower, around 4 instead of 13-18 as a result. The poor drainage in the summer meant that the overall reduced dry days was not significant. However, the spring results are strong and aligned with the reduced GHG emissions findings. Applied Geosolutions found that GHG emissions were substantially reduced. The largest reduction was from competitor I4. More analysis as to why that may have been the case is forthcoming. Preliminarily, the result does not seem correlated with the number of days dry. It may be related to the specific timing of drainage. The sooner drainage occurs, the less time methane has to build up. This competitors' schedule has two relatively early drains and is the only competitor to drain around 30 days after planting. Planting density was also substantively lower for this competitor, which likely contributed to reduced GHG emissions.

For H2 and H3: The amount of nitrogen did not reduce as expected by our hypotheses. Looking descriptively at secondary outcomes, the amount of fertilizer applied also did not reduce by a statistically significant amount. That said, there is descriptive evidence that the number of times farmers applied fertilizer increased slightly (p<.01). If farmers applied fertilizer over more times without increasing overall fertilizer use, then nitrogen use may have been more efficiently taken up by plants by being spread out over more time. This practice change may have contributed to higher yield for some competitors. [18] Planting density results are straightforward and having fewer but healthier plants may also contribute to improved yield.

Exhibit 12
Descriptive:
[fertilizer quantity applied table forthcoming]

Number of fertilizer applications					
Average, spring and summer crop	2.8	2.6	0.2 ***	0.064	0
Spring 2020	2.6	2.5	0.1	0.08	0.243
Summer 2020	2.8	2.5	0.3 ***	0.07	0

*p<0.1, **p<.05, ***p<.01

In terms of Hypothesis 4: The AgResults program successfully led to the adoption of bioenzyme use where it previously was not used. Since lime usage did not reduce, bioenzyme was not merely a new substitute for lime. The incorporation of rice straw and stubble back into the soil may be a contributor toward higher yields for some competitors. However, according to preliminary conversations with Applied Geosolutions, bioenzymes impacted the GHG emissions model less than expected, so the emissions benefits from this practice change is unclear.

Hypothesis 5: As discussed above, yield significantly increased as a result of competitor technology packages. We do not have a large enough sample to identify what components of the 11 or so different technology packages competitors used drives the increases precisely. It does not seem to be due to fertilizer usage, since quantities applied did not statistically significantly change. It is also unlikely to be a result of the number of times fertilizer was applied (at least, not in isolation). Two competitors with improved yields had opposite fertilizer practices: one applied 2 times and the other 4. The competitors also differ as to whether they require bioenzymes. It is possible that one practice or bundle of practices improved yields for one competitor while a different practice or bundle of practices improved yield for another. Evidence that specific practices matter comes from variation in results using the same seed variety. BC15 is a fairly common seed variety that had high yields under competitors I4 and I5 but not under competitor I18 (See Appendix A).

Lower planting density seems to be consistent with higher yield. Yield also did increase more for the newer and rarer seed types: DS1 and DS3 (used by competitor I4) and LTH31 used by competitor i18) (See Appendix A). Anecdotally, some farmers also reported that intermittent

[18] These results depend on the competitor. Farmers on average apply fertilizer two-three times, and one competitor only required two applications. On the other hand, one competitor required four.

spacing techniques strengthened saplings and increased yield, but overall only 7-10% of farmers report using this technique, and treatment is not greater than the control.

Exhibit 13
Hypothesis 6 revenue: Descriptive

Rice sale price (1000s VND/MT)					
Average, spring and summer crop	7.8	7.9	-0.1	0.113	0.222
Spring 2020	7.7	8	-0.3 ***	0.108	0.008
Summer 2020	8.2	8.1	0.1	0.174	0.679

*p<0.1, **p<.05, ***p<.01

[Costs in the absence of the intervention but assuming farmers buy the same inputs forthcoming]

Total costs, with AgResults interventions (1000s VND/sao)					
Average, spring and summer crop	582.2	577.3	4.9	11.8	0.681
Spring 2020	585.5	573	12.5	15.9	0.434
Summer 2020	580.2	578.1	2.1	12.9	0.871

*p<0.1, **p<.05, ***p<.01

Overall, the program provided clear benefits for yields while reducing planting density. A majority of treatment farmers in the income study report seeing a benefit from the new practices, such as needing to pay for less seed, reduced pesticide use and increased herbicide use. Less than five percent describe any aspect of the program as challenging.

Conclusion and Policy Recommendations

There is strong evidence that the prize competition reduced GHG emissions while increasing yield. Since 65-75% of CO_2 emissions reductions are due to reduced water use (Steering Committee discussion with Applied Geosolutions, 2019) which is in the control of local cooperative leaders and cannot be done for individual farmers, reducing GHG emissions required the private sector to cooperate with the public sector. Results also rely on infrastructure capable of draining fields, which was possible in Vietnam for the spring season but not during summer monsoon storms. That specifics of water irrigation systems matter is a finding echoed by others who have also done projects in Asia promoting AWD (Richards and Sander 2014).

The project reached around 25-28,000 unique farmers[19] and there is also strong evidence that the program changed farmer practices, including fertilizer type and number of application times (although not overall quantity); seed type and planting density; and bioenzyme use. It also standardized practices. Competitors appreciated the resulting economies of scale,[20] as did cooperative leaders. As one cooperative leader summarizes:

The rice is blossoming at the same time; high uniformity leads to easy harvesting by machine. The purchase of products for farmers is convenient. [This competitor bought wet rice from the field, saving farmers the effort of drying it]

[Summer cooperative leader survey question responses 2020]

Or:

The cooperative operates smoothly because farmers transplant in large fields…this reduced the the cost of reaper and reduced the rice dropped in the field. The cost of transplanting is lower (reduced rice seed, less workdays due to sparse transplanting), the amount of fertilizer absorbed in the soil is not lost. It is reducing pests and diseases, reducing pesticide costs, aphids, drying, rolling leaves. There is higher productivity.

[Summer cooperative leader survey question responses 2020]

That said, the specific incentives provided by different competitors were crucial to whether farmers were willing to stay in the program. One competitor, a large-scale seed company that only worked with repeat farmers over many seasons, was willing to pay a markup in price in return for a stable supply of rice seed and cooperative leaders reported high farmer satisfaction at having a stable market along with one willing to pay above-market prices. On the other hand, another competitor focuses on building a relatively new product: high-value rice for export to Japan. The competitor did not buy with above-market prices. It also required transplanting a stickier rice variety seed, which anecdotally farmers found labor intensive. As cooperative leaders noted for why farmers dropped out:

Taking care of the rice fields according to the project's instructions is laborious, but the selling price is lower than the market price

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[19] It is difficult to measure unique smallholder farmers precisely since some competitors attempted to game the system by dividing one landowner's plots among children. Also, many farmers did not work their own land and instead allowed other villagers to work their land while they earned money in nearby cities. Those other villagers thus sometimes showed up in AgResults twice: with their own plot, and with the plot of their neighbors'.

[20] Citations of interviews forthcoming.

There may also be tradeoffs between labor intensity and GHG emissions reductions based on changing fertilizer practices. Cooperative leaders, and anecdotal interviews with farmers, revealed a lot of pushback by farmers on fertilizer schedules that require many application rounds. Farmers found the travel time to apply fertilizer across many fields onerous. Some competitors also recommended extra doses of highly concentrated nitrogen in the form of urea for fields that were underperforming. Labor intensity and the need for stable and successful production may be why we do not see reductions in nitrogen or in fertilizer usage.

Almost all of the cooperative leaders expressed that they appreciated the knowledge gained from the program. In contexts such as this one where the competitors applied new packages of technologies, one lesson might be to be careful of what knowledge to promulgate based on the certainty of the results. Farmers successfully adopted practices related to planting density, seed varieties, and water usage that preliminarily seem related to reduced GHG emissions. However, they also adopted bioenzymes, an expensive item where the relationship to reduced emissions is less clear.

The new technologies used in this program can also be compared to alternative emerging technologies and policy solutions as they emerge.[21] This program laudably focused on generating GHG emissions estimates which allow it to be compared to other programs. The project approved a budget of 8.03 million, although that has not all been spent to date. Much of it goes toward the prize. We preliminarily calculate an estimated CO_2 emissions equivalent reduction of 2508.86 metric tons, or around $3,189 per metric ton of emissions reduced (assuming the entire budget is spent). (This calculation will be refined shortly.) However, it is likely to be substantially cheaper moving forward for companies to continue using the technology packages developed and cooperatives may maintain other benefits from having aggregated farmers more efficiently.

Most programs do not consider comparable costs of program development but rough preliminary estimates show that this program may be reasonably comparable if not better than alternatives. For example, ground cover rice production systems (GCRPSs) save water by covering the ground with a thin film. This technique is currently used in over 4 million hectares in China. A recent development is to make biodegradable films rather than polyethylene mulch film to reduce pollution. One study shows that such a biodegradable film can reduce irrigation water demand by 52–84%, while increasing the average rice yield by 8.5%. Benefits reach up to $39.8 per hectare per year (Yao 2017); our rough estimate of $194 per hectare for farmers and yield increases of around 10% compare favorably, although the costs are not directly comparable since their estimate includes labor costs as well as financial benefits to the environment.

[21] Carbon markets would not likely have been suitable for the program at this preliminary stage, but there may be potential for the now-mobilized farmers to become involved in carbon market initiatives. Biogas company involvement is another growing opportunity for capturing GHG emissions from rice.

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Appendix A: Descriptives, unweighted, by competitor-seed technology package

AgResults competitor-seed descriptives [forthcoming: same table but for comparison groups and the addition of fertilizer quantity applied]

Outcome		i4-DS1	i4-DS3	i4-BC15	i5-BC15	i5-BT7	i18-LTH31	i18-BT7	i18-BC15	i23-T10	i23-BT7	i23-DT8	i23_BC15
Number of survey respondents	**Spr**	180	49	125	416	0	144	187	8	85	90	26	15
	Sum	293	3	98	408	20	0	0	681	23	38	17	218
Yield (metric tons/hectare)	**Spr**	6.4	5.2	6.0	6.5	.	5.7	4.8	5.0	4.7	4.2	4.7	5.4
	Sum	5.6	5.6	5.3	5.3	4.5	.	.	5.4	4.3	4.4	4.7	4.8
Rice value net costs (‘000 VND)	**Spr**	775	485	923	1317	.	827	754	701	848	692	816	848
	Sum	677	488	651	1152	1080	.	.	776	969	1103	1000	791
Costs (‘000 VND) per sao	**Spr**	635	641	676	654	.	673	570	613	643	601	605	659
	Sum	661	812	645	617	483	.	.	593	544	560	522	631
Estimated unsubsidized costs per sao (‘000 VND)	**Spr**	655	671	702	720	.	738	603	692	755	681	785	738
	Sum	703	844	690	686	584	.	.	634	660	660	616	704
Sells rice (% yes)	**Spr**	95	80	75	89	.	45	46	75	39	28	62	47
	Sum	97	100	39	80	90	.	.	44	4	21	41	34
Planting density (kgs/sao)	**Spr**	1.50	1.76	1.15	1.05	.	1.36	1.30	1.33	1.13	1.39	1.19	1.13

Planting density (kgs/sao)	**Sum**	1.48	1.50	1.35	1.03	1.36	.	.	1.39	1.30	1.26	1.41	1.30
Rice sale price, with AgResults interventions	**Spr**	6.05	6.05	7.22	8.27	.	7.29	7.61	7.23	8.55	8.44	8.44	7.90
Rice sale price, with AgResults interventions	**Sum**	6.56	6.50	6.72	9.08	9.97	.	.	6.99	9.72	10.10	8.66	8.00
Rice sale price, without AgResults interventions	**Spr**	5.88	6.05	7.35	7.35	.	7.29	8.24	7.35	9.10	8.24	7.81	7.35
Rice sale price, without AgResults interventions	**Sum**	6.54	6.50	7.79	7.82	9.13	.	.	7.82	9.72	9.13	8.66	7.83
Nitrogen applied (kg/sao)	**Spr**	2.91	3.05	3.19	3.66	.	3.87	3.78	6.65	3.86	3.29	3.17	3.22
Nitrogen applied (kg/sao)	**Sum**	3.30	2.72	2.87	3.80	3.65	.	.	3.70	3.46	3.35	3.10	3.50
Days dry	**Spr**	20.86	20.31	16.28	19.39	.	21.67	16.63	5.00	17.72	21.32	26.54	14.27
Days dry	**Sum**	6.76	0.00	4.16	2.92	9.95	.	.	2.75	5.43	5.84	4.59	1.90

Comparison descriptives by Seeds used in the treatment

	season	Comp-DS1	Comp-BC15	Comp-BT7	Comp-T10	Comp-DT8
Number of survey respondents	**Spring**	3.00	281.00	569.00	330.00	125.00
Rice sale price, with AgResults interventions	**Spring**	5.88	7.34	8.24	9.10	7.81
Planting density (kgs/sao)	**Spring**	1.50	1.52	1.39	1.39	1.38
Days dry	**Spring**	13.00	11.97	20.70	18.24	15.06
Yield (metric tons/hectare)	**Spring**	246.67	234.37	199.90	188.64	213.26
cashpersao_plot	**Spring**	1434.37	1415.66	1333.52	1375.00	1350.68
cashpersaoNoAgR_plot	**Spring**	1434.37	1415.66	1333.52	1375.00	1350.68
Nitrogen applied (kg/sao)	**Spring**	6.84	3.54	4.07	3.44	3.66
incomeinhandpersao_plot	**Spring**	965.00	576.78	326.78	310.96	336.89
revenueincomeAgRpersao_plot	**Spring**	343.19	-56.91	-279.10	-292.91	-285.83
revenueincomeNoAgRpersao_plot	**Spring**	343.19	-57.89	-281.77	-294.14	-286.06

Rice value net costs (‘000 VND)	**Spring**	812.56	781.97	727.64	771.12	727.96
Estimated unsubsidized costs per sao (‘000 VND)	**Spring**	812.56	781.97	727.64	771.12	727.96
Costs (‘000 VND) per sao	**Spring**	621.81	633.69	605.88	603.87	622.72
Estimated unsubsidized costs per sao (‘000 VND)	**Spring**	621.81	633.69	605.88	603.87	622.72
Rice sale price, without AgResults interventions	**Spring**	5.88	7.34	8.24	9.10	7.81
Sells rice (% yes)	**Spring**	0.67	0.50	0.38	0.35	0.38
Number of survey respondents	**Summer**	40.00	1450.00	154.00	71.00	89.00
Days dry	**Summer**	6.30	4.95	7.05	9.77	3.72
Yield (metric tons/hectare)	**Summer**	196.27	203.59	193.18	190.99	183.94
Rice sale price, with AgResults interventions	**Summer**	6.54	7.84	9.13	9.42	8.17
Planting density (kgs/sao)	**Summer**	1.73	1.58	1.31	1.37	1.38
Nitrogen applied (kg/sao)	**Summer**	5.14	3.29	4.10	4.11	3.75
incomeinhand_plot	**Summer**	3023.71	1031.60	894.13	853.47	619.73
cashpersao_plot	**Summer**	1279.50	1329.98	1511.48	1511.70	1348.52
cashpersaoNoAgR_plot	**Summer**	1279.50	1329.98	1511.48	1511.70	1348.52
incomeinhandpersao_plot	**Summer**	888.78	235.27	176.23	229.60	206.63
revenueincomeAgRpersao_plot	**Summer**	221.82	-383.79	-403.10	-386.36	-408.92
revenueincomeNoAgRpersao_plot	**Summer**	225.77	-381.66	-403.44	-388.63	-409.45
Rice value net costs (‘000 VND)	**Summer**	612.54	710.92	932.15	895.74	732.98
revenuevalueNoAgRpersao_plot	**Summer**	612.54	710.92	932.15	895.74	732.98
Costs (‘000 VND) per sao	**Summer**	666.96	619.06	579.34	615.96	615.55
Estimated unsubsidized costs per sao (‘000 VND)	**Summer**	666.96	619.06	579.34	615.96	615.55
Rice sale price, without AgResults interventions	**Summer**	6.54	7.84	9.13	9.42	8.17
Sells rice (% yes)	**Summer**	0.88	0.27	0.21	0.25	0.20

Appendix B: Balance Tables, Weighted

Spring balance table [overall table forthcoming]

Variable Label	Treatment Mean	Comparison Mean	Difference (Absolute)	Difference (% of C)	Difference (Effect Size)	Treatment N	Comparison N
HH head completed primary school	97.5	95.7	1.8	1.9	0.1	945	1236
HH head completed secondary	89.3	86.9	2.4	2.8	0.07	945	1236
Respondent completed primary	97.8	96.1	1.7	1.8	0.1	945	1236
Respondent completed secondary	89.5	88.2	1.3	1.5	0.04	945	1236
Rice is more than half of income	47.4	42.3	5.1	12.1	0.1	945	1236
Rent in at least one plot	54.5	53.7	0.8	1.5	0.02	945	1236
Respondent age	56.4	56.3	0.1	0	0.01	945	1236
HH head age	58.4	58.2	0.3	0	0.03	945	1236
Number of assets owned	2.9	2.9	0	0	0	945	1236
Total types of Cash Crops Grown (%)	0.8	1	-0.2	-0.2	-0.18	945	1236
Total types of animals owned (%)	3.3	3.8	-0.5 ***	-0.1	-0.28	945	1236
Plots include those with sandy soil (%)	26.9	30.6	-3.7	-12.1	-0.08	945	945
Plots include those with clay (%)	18.6	14.2	4.4	31	0.12	945	945
Plots include those with loam (%)	88.2	85.2	3	3.5	0.09	945	945
Total land owned, m2	0.1	0.1	0.0 **	0	0	945	1236
Total paddy owned, m2	0.1	0.1	0.0 **	0	0	945	1236
Total land rented in, m2	0	0	0	.	0	945	1236
Total land owned, sao	39.2	27.9	11.3 **	0.4	0.21	945	1236
Total paddy owned, sao	36.3	25.5	10.8 **	0.4	0.21	945	1236
Total land rented in, sao	15.8	14	1.8	0.1	0.05	945	1236
Total land worked, rice in m2	0.1	0.1	0	0	0	945	1236
Total land worked, rice in sao	51.8	40.3	11.5	0.3	0.16	945	1236
Percent of commune area used for rice cultivation, Spring 2018 (%)	54.2	54.4	-0.2	-0.4	-0.02	945	1236
Percent of commune area used for rice cultivation, Summer 2018 (%)	54.6	54.5	0.1	0.2	0.01	945	1236

At least one of top 3 common seed varieties at baseline is an approved AgResults (%)	87.8	90.5	-2.7	-3.0	-0.06	945	1236
Percent of population that are listed members of cooperative (%)	38.2	36.9	1.3	3.3	0.05	945	1236
Percent of cooperative members who have farmers larger than 1500 square meters (%)	55.1	57.3	-2.2	-3.7	-0.15	945	1236
Cooperative has at least 1 riding transplanter (%)	13.7	3.9	9.8	98.0	0.31	945	1236
Cooperative has at least 1 walking transplanter (%)	33.6	48.7	-15.1	-50.3	-0.31	945	1236
Cooperative experienced rice blast (%)	96.7	96.7	0	0.0	0	945	1236
Cooperative experienced sheath blight (%)	62.6	56.2	6.4	10.7	0.13	945	1236
Cooperative experienced southern rice black-streaked dwarf virus (%)	19.8	16.8	3	15.0	0.08	945	1236
Cooperative experienced brown back rice plant hopper (%)	5.9	27.4	-21.5 *	-215.0	-0.73	945	1236
Cooperative experienced rice leaf folder (%)	16.9	16.2	0.7	3.5	0.02	945	1236
Cooperative experienced bacterial leaf blight disease (%)	16.6	11	5.6	28.0	0.17	945	1236
Water managed solely by leader (%)	21.2	20.6	0.6	3.0	0.01	945	1236
At least 85% of drainage requirements met (%)	72.6	70	2.6	3.7	0.06	945	1236
Irrigation system in place (yes=1; Not yet=0) (%)	62.5	58.7	3.8	6.3	0.08	945	1236
Year irrigation system built (%)	1990	1988	2	0	0.13	945	1236
Days rice fields flooded (%)	96.2	97.7	-1.4	0	-0.09	945	1236
Average yield (MT/hectare) (%)	7.1	7.1	0	0	0	945	1236
Average value of production per farmer per cooperative (VND/MT) (%)	9.10E+06	9.50E+06	337877.8	0	-0.21	945	1236
Average farmer rice cultivation area per cooperative (ha) (%)	0.2	0.2	0	0	0	945	1236

Summer balance table

Variable Label	Treatment Mean	Comparison Mean	Difference (Absolute)	Difference (% of C)	Difference (Effect Size)	Treatment N	Comparison N
HH head completed primary school	98.1	96.3	1.8	1.9	0.11	1084	1090
HH head completed secondary	90.3	87.7	2.6	3	0.08	1084	1090
Respondent completed primary	98.1	95.8	2.3 *	2.4	0.13	1084	1090
Respondent completed secondary	91.2	86.8	4.4 **	5.1	0.14	1084	1090
Rice is more than half of income	33.2	24.2	9.0 ***	37.2	0.2	1084	1090
Rent in at least one plot	60.8	48.8	12.0 ***	24.6	0.24	1084	1090
Respondent age	56	56.8	-0.8	0	-0.09	1084	1090
HH head age	57.9	58.3	-0.4	0	-0.04	1084	1090
Number of assets owned	3.1	3	0.1	0	0.1	1084	1090
Total types of Cash Crops Grown (%)	0.9	1	-0.1	-0.1	-0.08	1084	1090
Total types of animals owned (%)	3.6	3.8	-0.2	-0.1	-0.11	1084	1090
Plots include those with sandy soil (%)	32.2	38.2	-6	-15.7	-0.13	1084	1084
Plots include those with clay (%)	17.1	18.7	-1.6	-8.6	-0.04	1084	1084
Plots include those with loam (%)	88.5	81.3	7.2 **	8.9	0.2	1084	1084
Total land owned, m2	0.1	0.1	0	0	0	1084	1090
Total paddy owned, m2	0.1	0.1	0	0	0	1084	1090
Total land rented in, m2	0	0	0	.	0	1084	1090
Total land owned, sao	29.5	24.5	5	0.2	0.11	1084	1090
Total paddy owned, sao	25.9	21.9	3.9	0.2	0.09	1084	1090
Total land rented in, sao	14.8	12.5	2.3	0.2	0.07	1084	1090
Total land worked, rice in m2	0.1	0.1	0	0	0	1084	1090
Total land worked, rice in sao	41	34.7	6.3	0.2	0.1	1084	1090
Percent of commune area used for rice cultivation, Spring 2018 (%)	52.5	54.9	-2.4	-4.8	-0.2	1084	1090
Percent of commune area used for rice cultivation, Summer 2018 (%)	52.8	55.1	-2.3	-4.6	-0.19	1084	1090
At least one of top 3 common seed varieties at baseline is an approved AgResults (%)	81.7	82.7	-1	-1.3	-0.02	1084	1090
Percent of population that are listed members of cooperative (%)	44.7	40.6	4.1	10.2	0.15	1084	1090

Percent of cooperative members who have farmers larger than 1500 square meters (%)	52	52.4	-0.4	-0.8	-0.03	1084	1090
Cooperative has at least 1 riding transplanter (%)	14.6	10	4.6	46.0	0.14	1084	1090
Cooperative has at least 1 walking transplanter (%)	45.6	36.3	9.3	18.6	0.19	1084	1090
Cooperative experienced rice blast (%)	95.2	95	0.2	0.2	0.01	1084	1090
Cooperative experienced sheath blight (%)	61.5	45.8	15.7	26.2	0.31	1084	1090
Cooperative experienced southern rice black-streaked dwarf virus (%)	17.6	5.9	11.7 **	58.5	0.33	1084	1090
Cooperative experienced brown back rice plant hopper (%)	7.2	21.1	-13.9	-139.0	-0.46	1084	1090
Cooperative experienced rice leaf folder (%)	10.5	24.3	-13.8	-138.0	-0.37	1084	1090
Cooperative experienced bacterial leaf blight disease (%)	14.3	11.3	3	30.0	0.1	1084	1090
Water managed solely by leader (%)	22.3	30	-7.7	-38.5	-0.17	1084	1090
At least 85% of drainage requirements met (%)	65.6	74.7	-9.1	-13.0	-0.21	1084	1090
Irrigation system in place (yes=1; Not yet=0) (%)	57	46.2	10.8	18.0	0.22	1084	1090
Year irrigation system built (%)	1991.6	1991.3	0.2	0	0.01	1084	1090
Days rice fields flooded (%)	96.5	96.9	-0.4	0	-0.03	1084	1090
Average yield (MT/hectare) (%)	7.1	7	0.1	0	0.23	1084	1090
Average value of production per farmer per cooperative (VND/MT) (%)	9.00E+06	8.60E+06	337877.8	0	0.16	1084	1090
Average farmer rice cultivation area per cooperative (ha) (%)	0.2	0.2	0	0	0	1084	1090