AGRICULTURAL PRODUCTIVITY AND CLIMATE SMART SOLUTIONS IN SOUTHWESTERN BANGLADESH

BY

SELEN ALTIOK

A thesis submitted to the

School of Graduate Studies

Rutgers, The State University of New Jersey

In partial fulfillment of the requirements

For the degree of

Master of Science

Graduate Program in Food and Business Economics

Written under the direction of

Dr. Carl Pray

And approved by

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New Brunswick, New Jersey

January, 2019

ABSTRACT OF THE THESIS

Agricultural Productivity and Climate Smart Solutions in Southwestern Bangladesh

By SELEN ALTIOK

Thesis Director:
Dr. Carl Pray

This study evaluated the impacts of fertilizer deep placement (FDP) technology introduced by the International Fertilizer Development Center (IFDC) in the designated Feed the Future (FTF) districts in Southwestern Bangladesh. The traditional method of applying fertilizer to rice in this area is broadcasting urea on the flooded rice fields just before planting the crop and then broadcasting more urea after the rice is established. The rice plants absorb only about 30% of the nitrogen that is broadcasted and the rest ends up polluting water sources with excess nitrates and emitting nitrous oxide (N_20) through volatilization. The IFDC introduced fertilizer deep placement (FDP) technology to farmers in Bangladesh to improve domestic food security and farmer resiliency among the most vulnerable populations to climate change. According to the IFDC, FDP increases the efficiency of nitrogen applied by placing urea briquettes 7-10 cm into the soil by the roots. The urea briquettes slowly release nitrogen in the soil increasing the plant's absorption of nutrients and decreases nitrates released into the air, irrigated water and runoff. The objective of this research was to examine the effects of adopting FDP technology on farmer yields, fertilizer productivity and revenues and the differences in fertilizer input (kg/ha) between broadcasting and FDP application. This study uses data from a survey of 2,000 farmers from 10 districts in Southwest Bangladesh collected in 2015 and 2016. All farmers surveyed used either deep-placement and/or broadcast prilled urea, thus all farmers used fertilizer during production. The surveyed population is divided into two treatment groups: (1) Fully adopted FDP; and (2) Mixed users using both fertilizer practices. Their yields, revenues, fertilizer productivity and average fertilizer inputs are analyzed through OLS fixed effects regressions. The results show a positive significant relationship between fertilizer deep placement use and yields, total revenues, net-revenues and fertilizer productivity. There is a negative significant relationship between FDP technology and average fertilizer input. The farmers that fully adopted fertilizer deep placement had higher yields, revenues and fertilizer productivity, and less fertilizer input than the mixed and broadcasted users. Additionally, the adoption behavior in the 2015 treatment groups is compared to the behavior in 2016 from the surveyed households. Our study shows that deep-placement technology can be a climate-smart practice in helping farmers mitigate greenhouse gas emissions and slow climate change; however, it continues to face adoption barriers for farmers in Bangladesh.

ACKNOWLEDGEMENTS

I would like to deeply thank my advisors Dr. Carl Pray and Dr. Michael Camasso; both of you guided me tremendously through this research process and helping me push beyond my academic limits. Thank you so much for your support and for sharing your knowledge with me.

Thank you Dr. Paul Gottlieb for joining this committee and for providing your invaluable advice and guidance while I was your Teaching Assistant for two years.

Thank you to my family, Eda and Mom, for always being there with endless support, love and guidance.

Thank you International Fertilizer Development Center (IFDC) for giving me the invaluable opportunity to use the data from Bangladesh.

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Introduction

Bangladesh is a developing country with a transitioning agricultural sector employing more than half of the working population. The country has seen tremendous progress and growth over the last few decades, but currently faces resource, technology and climate constraints for meeting future demands in cereal consumption. The population of Bangladesh is around 161 million people with 66% living in rural areas and 88% relying on agriculture for income (CIAT 2017). The agriculture sector employs around 41% of the labor force and contributes about 15% to the country's Gross Domestic Product (GDP) (BBS 2017), and since the early 2000s, the annual GDP growth has been 6% (FTF 2011). Currently, there are 126 crops grown throughout the country including rice, wheat, maize, pulses and roots, spices, vegetables, fruits, tea, tobacco, and sugar crops (BBS 2017). Rice is the most dominant crop with 80% of cultivated land devoted to rice paddies and Bangladesh is the world's fourth-largest rice producing country behind China, India and Indonesia (IFDC 2013). There have been significant improvements in livelihoods due to increases in farmer incomes; however, 32% live under the national poverty line with 69% making $3.10/day and 19% making $1.90/day (CIAT 2017). Institutional and governmental policies have allowed for significant growth in grain production, such as rice and maize, but the country still relies on imports for other crops and agricultural products (CIAT 2017). The agricultural sector faces challenges that hinder future crop stability such as declining soil fertilities, lack of financial resources, low technology uptake, and coping with climate change.

Bangladesh is considered one of the most vulnerable countries to climate change. It is a low-lying country with a subtropical monsoon climate and is prone to flooding and higher temperatures (Ali 2014). Climate change is affecting rice crop productivity with droughts, floods, declining soil fertility and erratic storms. Rice is the country's main crop for agricultural economic growth and food security; however, paddy farmers face long-term challenges to rice production` that require mitigation and adaptive efforts. Most farmers are small-scale on one hectare or less and confronted with increasing demands for rice from growing populations (Linquist 2012). The increasing demand is putting pressure on irrigated rice fields, soil fertility and ecosystem balances contributing to higher methane (CH_4) emissions and other environmental degradation (Ali 2014). It is a staple crop for more than 150 million people and inhabits over three-fourths of the total cropped area (Nash 2016). It is harvested on more than two-thirds of the total cropped area and provides 70% of the calories consumed (Nash 2016). According to the FAO, Bangladesh's average rice yield is around 2933 kg/ha, which is lower in yield than Vietnam (5631 kg/ha), India (3590 kg/ha), and Thailand (3000 kg/ha) (FAOSTAT 2014). Bangladesh's lower yields are partly from soil fertility depletion and excessive chemical and nitrogen fertilizer applications from intensified rice production systems (Ali 2014). Excessive or inadequate fertilization has a higher global warming potential and decreases the rice paddy's utilization of nutrients (Miah 2016). Agricultural emissions from paddy rice systems, particularly CH_4 and N_20, are four times higher than the emissions from other cereal crops (Miah 2016). The higher rates of fertilizer application and N_20 paddy emissions are highly due to a common farming practice known as broadcasted prilled urea.

In Bangladesh and other rice producing countries, higher fertilization rates from broadcasted prilled urea is shown to not sustain long term yields and productivity. Broadcasted urea has proven to be less efficient in nutrient absorption by the rice crops and increases levels of ammonia volatilization, leaching and surface runoff (Miah et al 2016). Upland crops use between 40-60% of the nitrogen broadcasted and flooded systems use 20-40%, while the rest of fertilizer applied is lost through runoff containing potassium, nitrogen and phosphorous and polluting nearby water sources (Zhu 2001). Specifically, denitrification produces nitrous oxide (N_20), a very potent greenhouse gas in which one pound of N_20 on warming is around 300 times of carbon dioxide (EPA 2017). Nitrous oxide molecules have a lifetime of 114 years in the atmosphere with one of the highest global warming potentials (GWP), which is the gas' absorption capacity and lifetime in the atmosphere (EPA 2017). Nitrous oxide is one of the most dangerous pollutants emitted from rice paddies from inefficient fertilization and soil imbalances in flooded systems, thus solutions involving win-win situations for farmers and the climate are most beneficial long term. Low crop productivity, soil imbalances and environmental degradation are challenges the Feed the Future (FTF) Districts are currently exposed to.

Bangladesh's Agro-Ecological Conditions

Bangladesh has thirty agro-ecological zones (AEZ) determined by diverse agro ecologies, soil compositions, land types and climate conditions (BBS 2018). Peak rainfall season is from June to September and precipitation varies from 1,110 mm in the northwest to 5,690 mm in the northeast (BBS 2018). The Feed the Future Districts in Southern Bangladesh are classified into four different agro-ecological zones: High and Low Ganges River Floodplain, Low Ganges River Floodplain, Ganges Tidal Floodplain and Gopalganj-Khulna Beels (BBS 2018). Highland classified areas are above normal flood levels suitable for dry land crops, or for transplanted rice paddies in impermeable surfaces (BBS 2018). Medium highlands normally flood 90 cm deep while lowland areas can flood between 180 to 300 cm deep. These conditions allow for suitable crops for broadcasted shallow flooding or transplantation of Aus and Aman rice paddies (BBS 2018). The High Ganges River Floodplain soils are mainly calcareous clay compositions, brown or dark grey, on the upper floodplain ridges and in basins (BBS 2018). Organic matter is low in brown ridge soils and higher in the dark grey floodplain soils with low to medium fertility levels (BBS 2018). The Ganges Tidal Floodplain have silty grey clays with less calcereous soils with more acidic topsoils, higher fertility levels and organic matter (BBS 2018). The Gopalganj-Khulna Beels are low-lying basins with dark grey acidic and noncalcareous clays overlying peat or muck at 25-100cm (BBS 2018). Bangladesh's diverse agro-ecological landscape has allowed for various crops to flourish and grow, but is now challenged by unpredictable climate changes.

The three seasons in Bangladesh are Aus, Aman and Boro in which the rice crop is cultivated, transplanted and harvested. During the Aus season, the rice growing conditions are rainfed in upland areas and seeds are broadcasted in March and April (Shelley 2016). The Aman season is also rainfed with seedlings from the Aus season and transplanted between May and August (Shelley 2016). Boro season is predominantly irrigated rice planted between December and February and harvested between April and June (Shelley 2016). Rice harvesting and planting occur mainly in the Boro and Aman seasons, both posing its own environmental challenges for farmers. The Aman season provides enough precipitation for rainfed paddy systems but has an erratic monsoon climate with damaging floods (Nash 2016). The Boro season is a dry winter climate with less precipitation, thus farmers rely on irrigation for higher rice yields and productivity (Nash 2016). Boro rice occupies about 60% of cropped area relying on groundwater irrigation from deep tube well, shallow tube well or low lift pump technologies (Nash 2016). This analysis focuses on the Boro season since farmers use more agricultural inputs such as fertilizers, machineries, labor, and irrigation, which increases the production costs, yields and greenhouse gas (GHG) emissions.

Research Problem and Objective

A crucial input for agricultural growth and crop efficiency is fertilizer. In most rice paddy systems, the traditional method of applying nitrogen fertilizer is through broadcasting prilled urea to the surface of wet soil (Harun 2015). A major problem among Bangladeshi farmers is the excessive and inefficient use of nitrogen fertilizers, which can reduce crop growth while polluting the environment (Miah 2016). Ultimately, the low nutrient absorption rates in rice paddies from broadcasting result in higher amounts of ammonium nitrogen in the flooded waters while methane (CH_4), carbon dioxide (CO_2) and nitrous oxide (N_2O) are emitted to the atmosphere. Climate smart practices in soil and fertilizer management will increase farmer incomes and will greatly improve poverty reduction and self-reliance in rice production.

In Bangladesh, urea fertilizer is monitored and subsidized by the Government of Bangladesh (GOB) to provide accessible, timely and available fertilizer to farmers in each district (Renfro 1992). Subsidized urea was a government incentive for farmers to use fertilizers and to increase fertilization rates for higher crop yields (Renfro 1992); however, over time, fertilizer intensification became an environmentally degradative practice. The International Fertilizer Development Center (IFDC) introduced Fertilizer Deep Placement (FDP) technology to Southwest Bangladesh through the USAID-funded project Accelerating Agricultural Productivity Improvement (AAPI) (Harun 2015). The adoption of climate-smart fertilizer technologies, such as Fertilizer Deep Placement (FDP), can improve mitigation and adaptation efforts in the southwestern regions. FDP relies on briquettes of solidified fertilizers (also known as guti fertilizer), which are compacted urea with some only nitrogen or a mixture of nitrogen, potassium and phosphorous (NPK) (IFDC 2018). They are manually placed 7-10 centimeters below soil surface in a more controlled and precise system than broadcasting. (IFDC 2018). The briquette slowly releases nutrients over the crop's growth cycle and requires only one application, while broadcasted urea could require two to three applications (Miah 2016). Despite the potential economic and environmental benefits, FDP has not been adopted by farmers in many parts of Bangladesh.

The objective of this research was to assess the impacts of adopting FDP technology on farmer yields, total revenue, net economic benefits, fertilizer productivity and fertilizer input applied between the traditional broadcast method and deep-placement technology. The net economic benefits are the increases in revenue when FDP is adopted minus the increases in costs from higher guti fertilizer prices. Fertilizer productivity is defined as the amount of fertilizer applied in kilograms per hectare of yield. Additionally, another research objective is to analyze district-level differences from 2015 to 2016 in adoption behavior to suggest potential barriers farmers face during Boro rice production. Market fertilizer prices for guti urea fertilizer are higher than prilled urea, thus a subsidy may be needed to encourage more adoption of FDP or a decrease in subsidies for prilled urea.

Chemical Fertilizer and Fertilizer Deep Placement (FDP)

Chemical fertilizers were introduced to Bangladesh in the 1950s, and shortly after, the Bangladesh Agricultural Development Corporation was created to promote the use of fertilizers for accelerating agricultural production (Parikh 1990). The intensified use of fertilizers have played a crucial role for increasing crop yields in Bangladesh, particularly with increasing adoption rates of high yielding rice varieties (HYVs). Currently, Bangladesh consumes higher levels of fertilizer input (NPK) at 253 kg/ha compared to South Asia's total average of 160 kg/ha (CIAT, 2017). Bangladesh's fertilizer consumption increased 57%, or about 9.5% annually, from 2009 (189 kgs/ha) to 2015 (297 kgs/ha) (WBG Database 2018). According to Parikh et al., the type of fertilizer used and its intensity are most determined by the rice type used, harvesting area, labor, infrastructure, manures and fertilizer prices. In general, rice production has a high urea demand accounting for 80% of all fertilizer demanded from farmers (Rahman 2015). Demands for urea fertilizer remain high in hopes for increasing yields and maintaining productivity; however, broadcasting prilled urea is not a long-term sustainable solution for increasing crop productivities in rice producing countries.

Fertilizer Deep Placement (FDP), popularly known as "Guti Urea", is considered a climate smart practice because it increases farmer revenues and crop yields by improving soil management and restoring nutrient balances in the rice paddies. It decreases the amount of nitrogen input needed which then decreases the amount of nitrogen lost to erosion and flooding. Improved soil and fertilizer management will increase the nutrients absorbed by the plants, which will help increase plant productivity and emit less pollution. There are two components to FDP application, and the first one is farmers retrieving the fertilizer briquette produced by commercially available fertilizers (IFDC 2017). The second component is the placement of the fertilizer briquettes below the soil surface centered among four rice plants with a spacing of 20 cm x 20cm (Azumah 2017). The briquette machine was designed for easing the production of guti fertilizer and currently, there are 2,500 briquette machines provided by ten main manufacturers (IFDC 2017) employing many Bangladeshi women into the labor force (IFDC 2017). In Table 1 below shows from 1990s to early 2000 the increase in briquette sales, total area coverage of FDP, and increases in paddy production but the variability with briquette machines is a supply-side problem that will be discussed further in detail in later sections.

Table 1: Statistics of Earlier FDP Stages in Bangladesh

Year (July-June)	FDP Briquette Sales (tons)	FDP Area Coverage (ha)	Increased Paddy Production (tons)	Briquette Machines Sold
1995-96	0.3	2	2	-
1996-97	98	610	744	2
1997-98	1,639	10,180	12,419	20
1998-99	15,691	108,434	132,290	212
1999-00	83,000	335,158	408,893	303
2000-01	91,840	379,056	462,448	116
Source: Bangladesh Department of Agricultural Extension				

Irrigation and Water Resources

During the Boro season, irrigation is highly prevalent in Southern regions increasing the land's capacity for higher yields. Irrigation technology is one of the most important production inputs for cultivating Boro rice. Since the 1970s, traditional and modern groundwater irrigation technologies tripled the country's rice production (Ahmed 2013). Traditional methods include a water-lifting devise (*done*), swing basket and dug-well and modern technologies are shallow and deep tubewells and low-lift pumps (Ahmed 2013). In the FTF regions, shallow tubewells are the predominant irrigation technologies used by farmers with 60% of irrigation used from groundwater and 18% is from surface water (Ahmed 2013). Irrigation also promotes the adoption of high-yielding and modern rice varieties with irrigation used on about 80% of the total HYV rice area in the FTF regions (Ahmed 2014). According to the International Food Policy Research Institute (IFPRI), irrigation plays three significant roles in agricultural productivity: (1) irrigation increases cropping intensity and eases land constraint during Boro season; (2) irrigation complemented with fertilizers and high-yielding rice varieties produces significant yield increases compared to rain-fed paddies; (3) reducing risks posed by rain-fed rice seasons in aus and aman (Ahmed 2014).

The most agriculturally developed region with the largest area for irrigation is the northwest, while the southwest is less developed with higher risks of flooding (Chowdhury 2010). Shallow tube well irrigation technology is most popular for agricultural use and is causing a widespread decline in the seasonal water table (Chowdhury 2010). According to Chowdhury's study of input efficiency, Bangladeshi farmers are least efficient with irrigation water management compared to land, labor, power tiller and fertilizer use. The irrigation pumps have varying degrees of efficiency and can be very costly for farmers because of the energy expenditure of lowering the groundwater table (Chowdhury 2010).

Fertilizer Market and Subsidies in Bangladesh

Fertilizer has been tremendously important for promoting agricultural development and self-sufficiency in Bangladesh (Huang 2017). The chemical fertilizers used include macronutrients of nitrogen (N from urea), phosphorous and potassium, and the micronutrients include sulfur, zinc and boron (Huang 2017). In the 1950s, fertilizer was initially distributed to farmers without any cost until the formation of the Bangladesh Agricultural Development Corporation (BADC) in the early 1960s (Huang 2017). The BADC sold fertilizer to private dealers and was solely responsible for the procurement, transportation and storage of fertilizer throughout all the sub-districts (Upazilas) (Huang

2017). Fertilizer sold to farmers were uniformly regulated and fixed prices subsidized by the Government of Bangladesh that were imported until 1962 (Huang 2017). Both the public and private sector play important roles in fertilizer supply and marketing to farmers (IFDC 2017). Currently, the government has control and manages the fertilizer industry with national prices fixed at the importer, distributor, wholesale and retail levels and subsidized to farmers to promote fertilizer use (Jahan 2017). The government provides the private sector direct reimbursement of the total fertilizer import costs incurred plus an importer's margin, which encourages the private sector involvement in the fertilizer import industry (Huang 2017). The government's role and regulation decisions take on these forms: (1) the quantity and type of fertilizer than can be imported and procured; (2) fertilizer prices at the import, factory and retail levels; (3) the number of dealers and retailers in the fertilizer industry; (4) geographic locations of dealers (IFDC 2017). The fertilizer industry is very controlled and has little incentive to engage in technology development and farmer education (IFDC 2017). The Government of Bangladesh appointed the Bangladesh Chemical Industries Corporation (BCIC) for all dealers involved with the distribution of urea, and opened 21 fertilizer warehouses in the northwest and southwest of Bangladesh (BBS 2018). There are around 4,700 active BCIC-licensed dealers with up to nine retailers each, creating close to 45,000 retail sale points (BBS 2018). The Government of Bangladesh fertilized subsidies provides stability for rice farmers in timely supplies, and local price stabilities in retail prices with a stable fertilizer crop and price ratio (Huang 2017).

Feed the Future (FTF) Initiative 2011-2015

The Feed the Future (FTF) 2011-2015 Multi-Year Strategies were approved for Bangladesh in 2011 under the U.S. Government's global hunger and food security initiative (FTF 2011). The FTF Bangladesh program focuses on accelerating and diversifying staple crop production for increasing the availability, accessibility and utilization of nutritional foods (FTF 2011). The Government of Bangladesh (GOB) and the FTF Initiative focused development efforts in the Southern regions due to higher susceptibility to climate extremes, salinity and environmental degradation lagging behind the Northern and Central regions in rice productivity (FTF 2011). The FTF Bangladesh program is represented by four main goals: (1) On-farm productivity; (2) Investment in market systems and value chains, (3) Food security policy and planning capacity; and (4) Agricultural innovation capacity enhanced (FTF 2011). The areas chosen for intervention in Mission Dhaka were based on: (1) areas with highest potential for impact and scalability, (2) comparative advantage vis-à-vis other donors, NGOs and the GOB, and (3) geographical limitations or advantages (FTF 2011). Geographic selection was based on regions with perceived growth potential and the areas with the highest malnutrition and poverty levels (FTF 2011). Mission Dhaka's beneficiaries are small-holder farmers of small to medium sized land who can diversify production and agricultural-based enterprises (FTF 2011). The GOB is determined to increase agricultural productivity through introducing new rice resistant varieties and other crops, suitable crops for multi-cropping systems, protecting soil balances and fertility and promoting sustainable practices through the Mission Dhaka initiative (FTF 2011).

The Accelerating Agriculture Productivity Improvement (AAPI) (FY2010-2015) project specifically was designed in 2010 under a cooperative agreement with the International Fertilizer Development Center (IFDC) as an implementing partner (FTF 2011). The IFDC conducted FDP research in Bangladesh in the 1980s and trialed with farmers between 1999 and 2000 (Mulligan 2016). In 2007, the technology reached farm level and by 2013, over 2 million farmers were using or had used fertilizer deep placement (Mulligan 2016). The expected results of the AAPI project are for 3.5 million farmers to adopt the fertilizer deep placement (FDP) technology, for collaborations with private fertilizer sectors, increase awareness of FDP among farmers and micro-enterprises and for overall improvements in fertilizer utilization, yields and productivity (FTF 2011).

The goal of the Accelerating Agriculture Productivity Improvement (AAPI) was to improve food security throughout Bangladesh by diffusing and developing lasting sustainable technologies that are accessible and available for smallholder farmers. According to the International Fertilizer Development Center's (IFDC) 2017 annual report, the fertilizer deep placement (FDP) technology adoption has increased yields by 18% and incomes by $220 per hectare in Bangladesh (IFDC 2017). FDP technology also benefits agribusiness dealers and the Government of Bangladesh through enhancing profits and savings (IFDC 2017). The hired laborers for briquette making machines earned an average gross profit of $5,000 during the 2015 Boro rice season with net returns to dealers averaging $1 per 50-kg bag (IFDC 2013). The average gross profit of $3,000-5,000 in Bangladesh can help families afford nutritious food and better education for children (IFDC 2017). In 2013, the Walmart Foundation Activity started with goals of deep-placement training for 40,000 women in vegetable production with an estimated of 160,000 women farmers adopting FDP technology (IFDC 2017). The adoption of FDP has also saved the Government of Bangladesh around $98 million in fertilizer subsidies in the past 5 years since the start of the Accelerating Agriculture Productivity Improvement (AAPI) project in Bangladesh (IFDC 2017). The IFDC began a project in Myanmar in 2014 called the Fertilizer Sector Improvement (FSI+) collaborating with Syngenta, private fertilizer sector, agro-input dealers, local agribusinesses, NGOs and smallholder farmers (IFDC 2017). The FSI+ project is expected to diffuse FDP technology to 52,000 farmers with 35 small businesses sharing the cost of machinery briquettes (IFDC 2017).

Previous Case Studies on Fertilize Deep Placement (FDP)

Hasan et al studied the adoption of climate smart practices in southern district of Patuakhali in Bangladesh (Hasan 2018). There were 118 randomly selected farmers and 17 climate-smart practices identified, one of which is fertilizer deep placement (Hasan 2018). Patuakhali is a coastal district similar to a number of districts in our study, and agriculture is becoming more difficult in these regions due to increases in soil salinity and infertility from fluctuating tidal cyclones and monsoons (Hasan 2018). Hasan et al studied the relationship between adopting climate-smart practices and household food security. The independent variables included in the study were personal education, occupation, family size, farm size, pond size, cattle ownership, annual household income, market difficulty access to farm information and perception of climate change (Hasan 2018). The Department of Agricultural Extension (DAE) disseminated the 17 climate-smart practices to farmers through its established Climate Field School (CFS) program and these practices were deemed essential for increasing adaptive capacity towards climate change (Hasan 2018). Of the farmers sampled, a total of 49 farmers adopted before 2013 and 81 farmers in 2016 with a maximum of 4 continuous years of use (Hasan 2018). Hasan's results show that despite the difficulty adopting fertilizer deep placement, the adoption rate was higher for deep-placement technology than other climate-smart practices because of the need, suitability, and enabling environment provided by the IFDC's trainings and extension programs (Hasan 2018).

Paddy farmers in Ghana are predominantly operating under diminishing marginal returns to scale with opportunities for improvement in production efficiencies and crop productivity (Azumah 2017). Almost 80% of the rice produced in Ghana is from smallholder farmers with 90% of farm sizes less than 2 hectares (Azumah 2017). Similar to Bangladesh in previous years, Ghana has experienced increases in rice yields from fertilizer subsidy programs, irrigation technology adoption and policy improvement. However, the country is also experiencing soil infertility, crop efficiencies and high environmental degradation (Azumah 2017). Azumah's study examined the effects of FDP technology adoption on the technical efficiency among 200 randomly selected farmers in irrigated rice systems (Azumah 2017). The farmers were grouped into those who adopted (138 farmers) and did not adopt (62 farmers) with an average farmer cultivating on 2.7 acres (Azumah 2017). Their Maximum Likelihood (ML) and Ordinary Least Squares (OLS) results show that deep-placement of briquetted urea has a positive and significant affect on rice output and technical efficiency (Azumah 2017). The AIC technical efficiency model shows that a 100% increase in urea briquette usage leads to a 16.5% increase in rice output and NPK fertilizer is 16.8% (Azumah 2017). The study recommends for FDP to be incorporated into Ghana's national agricultural policies and extenstion services to increase accessibility in training for farmers for further adoption (Azumah 2017).

In Indonesia, farmers have been using deep placement technology since the early 1990s through government dissemination to West Java, Yogyakarta and East Java provinces (Pasandaran 1999). It has shown to increase average rice yields by 400 (kg/ha), decrease urea consumption by 60 kilograms per ha and have a 25% saving in nitrogen fertilizer rates (Pasandaran 1999). Farmers recognize the benefits of adopting FDP technology but have problems with its labor-intensive nature and with storage, distribution and its proper usage (Pasandaran 1999). Some of the disadvantages seen in Indonesia were the manual, time-consuming and intensive labor required for placing urea briquettes into the soil (Pasandaran 1999). There were deep-placement machines made by the Center for Agricultural Machinery Development (CAMD) following specific criterias in mitigating the barriers of labor and time; however, they were also viewed as unpopular or inaccessible (Pasandaran 1999). Farmers noted a few requirements in adopting FDP technology as accessability, inexpensiveness, simple, light and locally made (Pasandaran 1999). The farmers in Java region noted the advantages of FDP as: (1) reduced fertilizer rates; (2) higher productivity per hectare; (3) higher profits per hectare; (4) and less pollution (Pasandaran 1999). On the contrary, farmers noted the limitations as: (1) more labor required; (2) less practical to use than broadcasting prilled urea; and (3) higher costs (Pasandaran 1999). The study recommended a stronger linkage between distributors of urea and the producers of the briquettes for more timely deliveries to farmers at the beginning of the season (Pasandaran 1999). Another recommendation was for better information diessemination and organized campaigns at the farm-level on FDP technology, along with credit and pricy policy provisions for purchasing urea tablets at one time (Pasandaran 1999).

Previous developments in mechanizing deep placement were attempted for reducing the labor required in placing the briquettes below the soil's surface (Bautista 2001). Earlier station experiments and trials developed protoype applicators but had their own issues in performance, design and other mechanical issues in water-fed conditions (Bautista 2001). Additionally, the improper use of mechanical deep-placement could negatively impact yields through the briquette placement in the soil and the timing of the application (Bautista 2001). In the FTF districts in Bangladesh, a manually operated injection device was developed by the Wageningen Agricultural University and Homeco BV manufacturer (Baustista 2001). When the handle of the applicator is pushed down, the fertilizer in the injection pipe is forced into the soil which saves the manual labor of implanting directly, but still is considered more labor than broadcasting (Bautista 2001). Farmers in the FTF districts have very low use rates of the deep-placement applicator and have difficulty accessing the applicator in their districts.

In 2013, the International Food Policy Research Institute (IFPRI) conducted the Agricultural Technology Adoption Survey of 2,400 rice farmers in 20 FTF zones in Bangladesh (Ahmed 2014). In this study, the surveyed households had a similarly high percentage of awareness of Guti Urea (94%) to our studied population with about 10.8% of rice farmers using FDP (Ahmed 2014). Also similar to our surveyed population, the high percentages of FDP knowledge sourced from fellow farmers (77%) (Ahmed 2014). The FDP farmers used 42.7% less urea during boro rice cultivation and they had 13.1% higher paddy yields than the farmers who broadcasted prilled urea (Ahmed 2014). A few concerns non-adopted farmers reported were: (1) requires many laborers to apply guti urea; (2) guti urea is not always available; (3) application requires line sowing (more precise system);

(4) physically inconvenient; and (5) applicator is not always available (Ahmed 2014). The study noted that around 36% of the surveyed FDP farmers had dis-adopted within the first year of use possibly indicating that the technology's benefits are not outweighing the costs or cultural changes (Ahmed 2014). IFPRI's four-year observation period (2010-2013) concluded that the survival rate of adoption, which is the total amount of uninterrupted time farmers use the technology, is low for FDP technology (Ahmed 2014).

Previous case studies of fertilizer deep placement (FDP) technology have shown to benefit farmers, crop yields and soil imbalances in other rice producing countries. However, despite the economic benefits, farmers view deep-placement technology as having high opportunity and labor costs from the intensive manual requirements. Adoption rates of FDP technology increase when farmers are given resources, financial tools and training programs that clearly demonstrate the benefits of adoption to farmers compared to broadcasted urea. Farmers in Bangladesh will continue benefitting from adopting FDP technology if the main technology obstacles are lessened.

Hypotheses

$H1_{a:}$ Farmers who adopted fertilizer deep placement (FDP) will experience higher yields per hectare of rice produced.

$H1_b$: Farmers who adopted FDP will experience higher revenues per hectare of rice produced.

$H2_a$: Farmers who exclusively use FDP will have higher yields than farmers who use both methods of fertilizers, or who do not use FDP.

$H2_{b:}$ Farmers who exclusively use FDP will have higher revenues than farmers who use both methods of fertilizers, or who do not use FDP.

H3: Farmers who adopt FDP will reduce nitrogen fertilizer use per hectare of rice and increase fertilizer productivity.

The research objective is to find out whether the expected economic benefits from using FDP are as large as studies on experiment stations and on small samples led the IFDC and USAID to expect. I assessed the economic impact of the adoption of FDP technology on crop yields, input costs, fertilizer productivity and farmer revenues on 2000 randomly selected farmers from the FTF zones in southwestern Bangladesh. My second objective is to assess whether there are some policy measures that could increase the value of applying FDP. I would look at the possibility of government programs to lower the cost of FDP and make it more accessible to farmers.

My analyses focused only on the Boro season because rice paddies have greater water control more irrigation and less floods. This in turn allows for better household level comparisons of the impact of the introduced fertilizer technology. If FDP technology can boost farm productivity to higher possibility frontiers (PPFs) with lower input levels of urea fertilizer, then local-scale resiliency, productivity and efficiency can be achieved for Bangladeshi farmers.

Methodology

The 2015 Boro household survey were given to a sample household population from the FTF districts through a multi-stage cluster sampling and systematic random sampling (Harun 2015). During the first stage, 50% of districts (10 districts) were randomly selected from the total 20 Feed the Future designated districts, then in the second stage, 29 upazilas were randomly selected from 56 upazilas from the 10 districts (Harun 2015). In the final sampling stage, 125 villages were randomly selected from 4,504 villages of the

29 upazilas selected in stage two from the 10 districts from stage one (Harun 2015). The 2,000 sampled households were selected as survey respondents using a systematic sampling procedure from the 125 villages with a ratio of 16 respondents per village from 29 upazilas and 10 districts. The three-stage systematic sampling from the original 20 FTF districts is shown in Table 2 below.

Table 2: AAPI Multi- Stage Sampling in Bangladesh

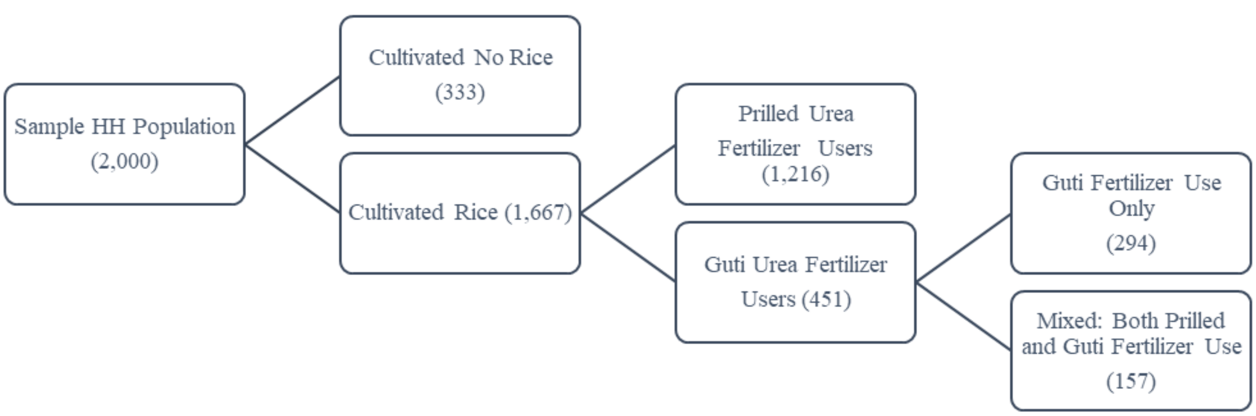
Districts (20)		Survey Districts (10)	No. of upazilas in survey districts		No. of survey upazilas	No. of Villages in survey upazilas		No. of survey Villages	No. of survey Households
Bagerhat Chuadanga		Bagerhat	6		3	373		10	160
Jessore Jhenaidah		Jessore	8		4	708		20	320
Khulna Magura		Jhenaidah	6		3	477		13	208
Narail Meherpur		Khulna	5		3	303		8	128
Satkhira Barguna	Stage-1	Magura	4	Stage-2	2	272	Stage-3	7	112
Barisal Bhola		Meherpur	3		2	130		4	64
Patuakhali Jhalokati		Barguna	4		2	210		6	96
Pirojpur Faridpur		Barisal	8		4	564		16	256
Gopalganj Madaripur		Faridpur	8		4	866		24	384
Rajbari, Shariatpur		Madaripur	4		2	601		17	272
Total			**56**		**29**	**4,504**		**125**	**2,000**

Source: IFDC- AAPI Household Survey on Rice Production during 2015 Boro Season

Study Area and the Questionnaire

The main objective of the household survey was to assess the number of households using and the total area under FDP technology for crop cultivation in the AAPI designated areas (Harun 2015). The 2015 IFDC household surveys were conducted in Southwestern Bangladesh from June to August in 125 villages, 92 unions, 29 upazilas and 10 districts. The coastal districts surveyed are Bagerhat, Khulna, Barguna and Barisal, and the non-coastal regions are Jessore, Jhenaidah, Magura, Meherpur, Faridpur and Madaripur. The sample household population consists of 2,000 farmers mainly cultivating rice with other crops such as vegetables, fruits and maize. About 96% of the survey respondents are male averaging 47.4 years old, 4.5 years of education, household size of 5 members with 1.5 family members are involved in agricultural labor. The average farm type falls between marginal (0.05-0.49 acres) to small (0.50-2.49 acres) sized land averaging 8.2 plots for cultivation, and 2.5 plots cultivated with an average of 90.71 decimals (0.36 hectares) of cultivated crop area. As shown in Figure 1 below, the 2,000 farmers are initially broken into farmers that cultivated rice (1,667) and farmers that did not cultivate rice (333). Of the 1,667 farmers, 453 farmers used guti fertilizer on some or all rice plots and 1,216 farmers broadcasted prilled urea with no adoption of the guti technology. The 453 farmers that used the guti fertilizer are further divided into two groups of full and partial adopters. The full adopters of guti fertilizer were 294 farmers using the FDP method on all cultivated paddy plots. The partial adopters, or the experimenters, were 157 farmers using both FDP and broadcasting methods on cultivated plots.

Figure 1: Breakdown of 2015 Household Sample of FDP Adopters and Non-Adopters

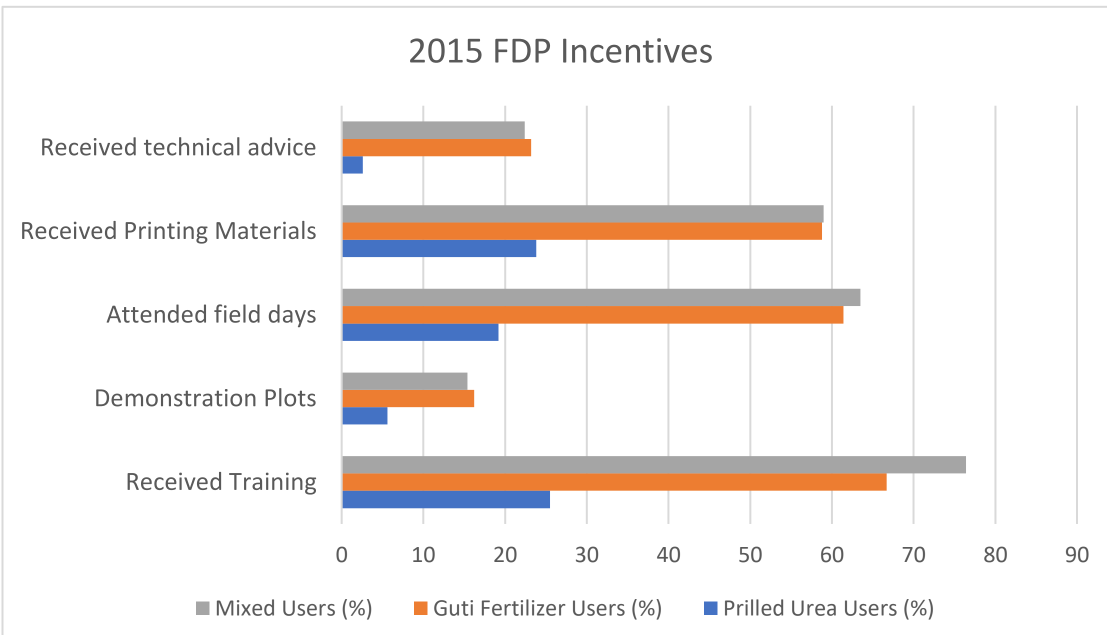


Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

Out of the 2,000 households surveyed, around 995 households (50%) reported that they previously used FDP technology in rice and other non-rice crops over a course of 15 years. Around 97% of the farmers that broadcasted prilled urea in 2015 had previously heard of deep-placement technology. Farmers were asked which year they first used guti fertilizer in crop production, and the earliest recorded date was 1999, but around 100 respondents answered 2010. There were 600 respondents that recorded first-time use in 2012 to 2014. Additionally, a majority of the farmers that used the technology before used it during Boro rice cultivation. Around 21% of them said they used deep-placement for the first time in Aman or Aus seasons. In Figure 3 below, the adoption incentive summaries of the AAPI project are shown for the different groups.

The farmers that fully or partially adopted FDP, 70% of them noted that they received training on the use of guti fertilizer from the AAPI project from IFDC. Around 74% of the farmers that did not adopt said they received no training from the AAPI project. Around 14% of the farmers that used guti fertilizer said they established demonstration plots of FDP with the support from the AAPI project, and only around 1% of the broadcasted farmers had demonstration plots. About 62% of FDP users attended field days organized by the IFDC- AAPI project, while 14% of prilled urea users attended. There were similar percentages of farmers receiving printed materials on guti fertilizer and deep-placement method. In Figure 2 below, the adoption incentive summaries of the AAPI project are shown for the different groups. The majority of farmers that did not adopt FDP technology noted that the main adoption barriers are: (1) the lack of knowledge of guti fertilizer; (2) FDP is not easily available or accessable; (3) it is not habituated for rice transplantation; (4) higher labor intensity than urea broadcast; (5) the applicator or fertilizer machinery is not available in the community. The barriers that received the highest amount of respondents were the lack of availability of the guti fertilizer, the high labor intensity involved with the application and the guti urea's applicator is not available for easing labor for deep-placement. A majority of the farmers that did use FDP answered that the new technology increased their rice yields, less urea fertilizer was needed and fertilizer costs were less; however, less stated that for the new technology was efficient and habituated during transplantation and rice production.

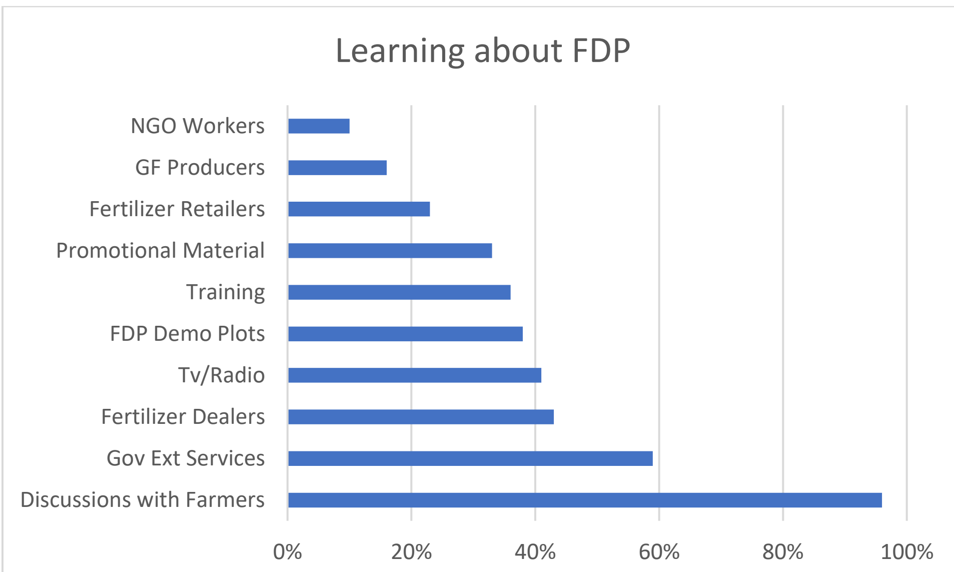
Figure 2: FDP Incentives from the IFDC-AAPI Project



Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

Among the sources of learning about deep-placement technology, Figure 3 below shows the distribution of educational sources on fertilizer deep placement accessable to farmers. Most farmers (96%) learned from farmers' meetings and dicussions with other farmers, around 59% learned from government extension services and 43% from fertilizer dealers. According to these results as well as the 2013 IFPRI study, the main outlet for farmers to learn and gain awareness of FDP technology is through interactions with local farmers and neighbors already using the technology. Around 40% of all the farmers noted that training and demonstration plots were how they learned about the technology, but around 25% or less of broadcasters received training and atended demonstration plots. In Figure 3, it shows the major sources of knowledge for FDP technology in the community. Farmers gain the most knowledge about farming practices and technologies through observing and interacting with other farmers in the community.

Figure 3: FDP Learning and Knowledge Sources at the Local Level



Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

Characteristics for Agricultural Inputs, Prices and Costs

The household survey includes modules on fertilizer, chemical, and agricultural technology use questioned in a dichotomous format as: (1= they used the input, 0= did not use the input). Both broadcasted and FDP users use other forms of fertilizer during production. Around 60% of prilled urea (PU) users use organic fertilizer (60%) while 70%

from guti fertilizer users. Almost all households supplement nitrogen fertilizer with TSPDAP, MOP and gypsum chemical fertilizers while zinc sulphate is not as common. Borax is also not as common to use but is applied more with guti fertilizer users (46%). In terms of machinery use and ownership, there were only 45 households that responded yes for the usage of the guti fertilizer applicator and 14 households for applicator ownership. The low use rate of the FDP applicator could be due to a supply side issue farmers face at the district level since its unavailability is one of the noted barriers to the technology. Other technologies farmer rely on during the Boro season are irrigation technologies mentioned earlier: shallow tubewells, deep tubewells and low lift pumps. Shallow tubewells have higher use and ownership rates than deep tubewells and low lift pumps. Out of the 1,276 households that use shallow tubewells, 484 have ownership and 792 rent. Guti urea users (both fully and mixed adopters) have higher ownership rates of shallow tube wells of around 45% compared to 35% of prilled urea users. We would expect that the farmers who adopt FDP in the Boro season will also rely more on irrigation technologies. All households use chemical sprayer technologies around similar rates between 90-95%, but with ownership rates slightly more for guti and mixed groups at 45-50% compared to 40% for PU users.

As Table 3 shows, the average fertilizer prices (Tk/Kgs) for prilled, guti and guti NPK differ slightly across the 10 surveyed districts with highest prices in Taka for guti fertilizer for deep-placement application. The average prilled urea prices for the 10 districts range from 16.42 in Fandpur to 18.10 in Barisal and a total average of 17.32 for all districts. The average guti price ranges from 19.52 in Fandpur to 21.24 in Khulna averaging 20.75 for all districts. The specialized form of guti fertilizer known as ‘NPK’ is not as commonly used among farmers; however, for those who recorded the price, the average for all districts is 23.16 (Tk/Kgs).

Table 3: Average Fertilizer Prices (Tk/Kgs) in Surveyed Districts

Surveyed Districts and # of HHs	Average Prilled Urea Price	Average Guti Price	Average Guti NPK Price
Madaripur (n=272)	17.64	21.20	-
Fandpur (n=384)	16.42	19.52	22
Magura (n=112)	17.22	20.94	-
Jhenaidah (n=208)	17.12	20.55	23.5
Meherpur (n=64)	17.13	20.82	23.5
Bagerhat (n=160)	17.08	20.87	23.33
Barguna (n=96)	17.77	21.10	23.5
Barisal (n=256)	18.10	21.09	-
Jessore (n=320)	17.34	20.18	23.15
Khulna (n=128)	17.42	21.24	-

Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

Analytical Framework: The Production Function Model

The linear production function is expressed in a functional form as (Petrin 2004):

$$Q= f(X_1, X_2, X_3, \ldots, X_n), \quad (1)$$

where Q is the output explained by X1, X2, X3,…,Xn, which are the inputs to production such as labor, capital, land, and other resources (Norton 2010). A production function describes the relationship between the level of production with one input while other factors are held fixed, which can also be called the input-response relationship (Norton

2010). In this approach, we are identifying the farmers who have higher average yields, revenues, economic benefits and fertilizer productivity and lower fertilizer inputs with the same set of inputs to production. For the given fertilizer technology, there are different output levels obtained from the various combinations of inputs at the farmer level (Norton 2010). We can determine if the outputs to production are from using fertilizer deep placement (FDP) or from other agricultural or demographic inputs. The production function frontier for the i^{th} farmer can be written as (Petrin 2004):

$$Y_i = f(x_i) + \varepsilon_i \tag{2}$$

where Y_i is the output in terms of yield (kg/dc), total revenue (tk/dc), net-revenue, fertilizer productivity (kg/dc) and average fertilizer input (kg/dc). X_i is the vector of production and technology inputs, and e_i is assumed to be independently and identically distributed N(0, σ^2).

The Empirical Model

OLS regression analyses were used for equations three to five below with fixed effects for the third model in Equation 5. The tests compared yields, total revenues, net revenues, fertilizer productivity and average fertilizer inputs for farmers using broadcast urea, fertilizer deep placement (FDP) and a mixed application of both. The five dependent variables are continuous variables measured over the household cultivated area in decimals. Decimals were converted to hecatres for analyses and interpretation (1 hectare = 247 decimals). Yield is expressed in kilograms per decimal of area cultivated and total revenue is expressed in Taka Dollars per decimal of cultivated area. ‘Net’ revenue in this analysis includes fertilizer costs for each household whether they used guti or prilled urea; therefore, net revenue shows the net economic benefit of FDP adoption. Average fertilizer productivity is the amount of fertilizer in kilograms applied for every hectare of rice in yields. Average fertilizer input is the amount of fertilizer applied in kilograms for the cultivated area at the household level. For all models, it is assumed that the dependent variables are linear functions of the explanatory variables in the prodution function.

The 1,665 farmers that cultivated rice are analyzed separately in three groups with two being treatment groups (note: 2 farmers were dropped from broadcast group due to outlier effects on the analysis). The first group are the 1,214 farmers that did not adopt the deep-placement technology and continued the traditional broadcast method. The first treatment group are the 254 farmers that fully adopted FDP and the second treatment group are the 157 farmers that partially adopted FDP, or experimented while using prilled urea. The partial adoptors are households that used both the broadcasting and deep-placement fertilizer methods on their cultivated rice plots. The farmers in dummy variable D_1 take on the value of 1 if they fully adopted FDP and 0 if they did not adopt. The farmers in dummy variable D_2 take on the value of 1 if they partially adopted FDP and 0 if they did not adopt. The reference category for both dummy variables are the farmers that did not cultivate deep-placement technology and only broadcasted prilled urea. The 451 farmers that used FDP technology are separated into two dummy variables due to district-level differences between the households that either fully or partially adopted FDP, thus the two groups were analyzed separately. Model 1 in Equation 3 below, the dependent variable Y_i represents the five dependent variables , (i= yield, total revenue, net revenue, fertilizer productivity and fertilizer input) and D_j are the two treatment groups.

$$Y_i = \beta_0 + \beta_1 D_j \tag{3}$$

Model 2 in Equation 4 is a linear function of the dependent variables and the agricultural production inputs. The independent variables are all cateogical variables expressed as 1 if farmers used it during rice production and 0 if they did not. Additionally, the specific agricultural production inputs were selected due to their possible effects as incentives or barriers to the adoption of fertilizer deep placement. The first variable listed is the type of rice variety used with 1 as the local variety and 0 as modern or hybrid varieties. In terms of other fertilizers or chemicals used, borax and zinc sulphur were included whether farmers used it or not during production. Machinery inputs included are tractor, power tiller and shallow tube well with all expressed as 1 if the farmers used it or 0 if not. The adoption incentive variables are whether the farmers attended training or demonstration plots led by the AAPI project (Yes=1, No=0).

$$Y_i = \beta_0 + \beta_1 D_j + \beta 2LocalVar + \beta 3BoraxUse + \beta 4ZincSulphUse + \beta 5TracU + \beta 6PowerTillerUse + \beta 7ShallowtubewUse + \beta 8\ Training + \beta 9Demoplot \quad (4)$$

Model 3 in Equation 5 is a fixed effect OLS model including 8 of the 10 districts surveyed to account for some of the variability among the three groups of farmers (non-adopters, fully adopters, and mixed adopters) at the district level. Each district is labeled one through ten according to the survey respectively as: Madaripur, Faridpur, Magura, Jhenaidah, Meherpur, Bagerhat, Barguna, Barisal, Jessore and Khulna. Barguna district was excluded from the regression since the surveyed farmers did not cultivate rice, and Meherpur is used as the reference group in the fixed effect model. Additionally, socioeconomic variables gender, age, education, farmsize and total household labor were added to the model. Gender is a dummy variable with 1 as male and 0 as female and farmsize has 6 categories ranging from landless (0.0-0.04 acres) to large size (>7.50 acres). Age, education and total household labor are continous variables with age and education exressed in years. The labor variable is the total number of household members involved in agricultural activities over the amount of cultivated land for each household.

$$Yi= \beta 0 + \beta 1Di + \beta 2Gender + \beta 3Age + \beta 4Educ + \beta 5Farmsize + \beta 6TotHHlabor + \beta 7LocalVar + \beta 8BoraxUse + \beta 9zincsulphUse + \beta 10TracU+ \beta 11PowerTillerUse + \beta 12ShallTubewUse + \beta 13Training+ \beta 14Demoplot +\sum_{\substack{k=1-10 \\ k\neq 5,7}}^{8} \beta_J \, District \tag{5}$$

1st OLS Regression Model

The regression results for Model 1 are shown in tables 6 through 15 for the 5 dependent variables and the treatment groups. The five dependent variables tested have significant relationships with D1 and D2 with other explanatory variables not included. In terms of averages as noted in Table 4 below, broadcasted farmers have lower average yields, revenues and fertilizer productivities than the farmers who used FDP technology. In hectares, the broadcasted farmers have an average yield of 6,032 kilograms of rice per hectare with average fertilizer input of 311.4 kilograms per hectare. Farmers who adopted have average yields of 6,563 kilograms per hectare and 170.50 kilograms of guti urea were used for deep-placement. As expected, the farmers who use both fertilizer applications (mixed users) fall between the broadcasted and fully adopted users. The mixed users have yields around 6,230 kilograms per hectare cultivated and average fertilizer input of 257 kilograms. Average total revenues and net revenues as seen in Table 4 below higher for guti urea users with the ‘net’ revenues of FDP use higher for both D1 and D2. Despite the higher market prices of guti fertilizer briquettes, guti urea users use less fertilizer, which lowers the costs of fertilizer per hectare. The average fertilizer costs were calculated in Table 5 from the total amount of fertilizer used at the average district-level market price. The total fertilizer cost for broadcasted farmers is \$64 per hectare compared to \$42 and

$55 for full and partial adopters respectively. In general, Model 1 regression analyses show there is a positive significant relationship between D1 and D2 with yield, total revenues, net revenues and fertilizer productivity, while having a negative significant relationship with fertilizer applied. We can come to this conclusion with the first simple regression model with no covariates included. These are the results we expected among the three groups of farmers.

Table 4: Summary of Dependent Variables at the Household Level

Dependent Variables	Prilled Urea Broadcasters	FDP Adopters	Mixed Adopters
Yield (kg/ha)	6,032	6,563	6,230
Total Revenue ($/ha)	$1,149	$1,255	$1,182
'Net' Revenue ($/ha)	$1,077	$1,210	$1,125

Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

Table 5: Fertilizer Input and Production Costs at the Household Level

Summary of Cost and Fertilizer Variables among Prilled, Guti and Mixed Groups			
	Prilled Urea Users (1,216)	Guti Urea Users (294)	Mixed Users (157)
Fertilizer input (kg/ha)	311.4	170.50	257
Cost of Fertilizer ($/ha)	64.25	41.78	54.51
Average Fertilizer Productivity (kg/decimal)	21.20	39.39	26.50

Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

Table 6: OLS Regressions Model 1- Yield and Fully Adopted FDP

Model 1 OLS Regression Results Dependent Variable: Yield (Kg/dc) Independent Variable: Fully Adopted FDP	
Constant	24.41 *** (0.09)
D1 (1= Fully adopters, 0=Non-Adopters)	2.15*** (.21)
N	1,508
R^2	0.07
F Statistic (df = 1; 1506)	107.94

Note:
D1 are farmers who fully adopted FDP and only used guti fertilizer during rice production. The reference group are the farmers that only used broadcasted prilled urea.
** $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$*
Figures in parentheses are standard errors.

Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

Table 7: OLS Regression Model 1 – Yield and Partially Adopted FDP

Model 1 OLS Regression Results Dependent Variable: Yield (Kg/dc) Independent Variable: Partially Adopted FDP	
Constant	24.41 *** (0.09)
D2 (1= Mixed Users, 0= Non-Adopters)	0.84 *** (0.27)
N	1,371
R^2	0.007
F Statistic (df = 1; 1369)	9.74

Note:
D2 are farmers who partially adopted FDP and used both prilled urea and guti urea fertilizer during rice production. The reference group are the farmers that only used broadcasted prilled urea.
** $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$*
Figures in parentheses are standard errors.

Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

Table 8: Regressions Model 1- Total Revenue and Fully Adopted FDP

Model 1 OLS Regression Results Dependent Variable: Total Revenue (Tk/dc) Independent Variable: Fully Adopted FDP	
Constant	387.52 *** (1.89)
D1 (1= Fully adopters, 0= Non-adopters)	37.24 *** (4.29)
N	1,508
R^2	0.05
F Statistic (df= 1;1508)	75.18

Note:
D1 are farmers who fully adopted FDP and only used guti fertilizer during rice production. The reference group are the farmers that only used broadcasted prilled urea.

** p < 0.1; ** p < 0.05; *** p < 0.01*
Figures in parentheses are standard errors.

Table 9 Regression Model 1- Total Revenue and Partially Adopted FDP

Model 1 OLS Regression Results Dependent Variable: Total Revenue (Tk/dc) Independent Variable: Partially Adopted FDP	
Constant	387.52 *** (1.89)
D2 (1= Mixed Users, 0= Non-adopters)	12.60** (5.61)
N	1,371
R^2	0.003
F Statistic (df= 1;1369)	5.04

Note:
D2 are farmers who partially adopted FDP and used both prilled urea and guti urea fertilizer during rice production. The reference group are the farmers that only used broadcasted prilled urea.

** p < 0.1; ** p < 0.05; *** p < 0.01*
Figures in parentheses are standard errors.

Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

Table 10: OLS Regressions Model 1- Net Revenue and Fully Adopted FDP

Model 1 OLS Regression Results Dependent Variable: Net Revenue (Kg/dc) Independent Variable: Fully Adopted FDP	
Constant	365.99 *** (1.87)
D1 (1= Fully adopters, 0=Non-Adopters)	44.75 *** (4.25)
N	1,507
R^2	0.07
F Statistic (df = 1; 1507)	110.99

Note:
D1 are farmers who fully adopted FDP and only used guti fertilizer during rice production. The reference group are the farmers that only used broadcasted prilled urea.
** p < 0.1; ** p < 0.05; *** p < 0.01*
Figures in parentheses are standard errors.

Table 11: OLS Regression Model 1 – Net Revenue and Partially Adopted FDP

Model 1 OLS Regression Results Dependent Variable: Net Revenue (Kg/dc) Independent Variable: Partially Adopted FDP	
Constant	365.99*** (1.87)
D2 (1= Mixed Users, 0= Non-Adopters)	15.68 *** (5.53)
N	1,371
R^2	0.006
F Statistic (df = 1; 1369)	8.05

Note:
D2 are farmers who partially adopted FDP and used both prilled urea and guti urea fertilizer during rice production. The reference group are the farmers that only used broadcasted prilled urea.
** p < 0.1; ** p < 0.05; *** p < 0.01*
Figures in parentheses are standard errors.

Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

Table 12: Regression Model 1: Average Fertilizer Input and Fully Adopted FDP

Model 1 OLS Regression Results
Dependent Variable: Average Fertilizer Input (Kg/dc)
Independent Variable: Fully Adopted FDP

Constant	1.26 ***
	(0.009)
D1	-0.57**
(1= Fully adopters, 0= Non-adopters)	(0.02)
N	1,508
R^2	0.36
F Statistic (df= 1;1506)	849.10***

Note:
D1 are farmers who fully adopted FDP and only used guti fertilizer during rice production. The reference group are the farmers that only used broadcasted prilled urea.

** p < 0.1; ** p < 0.05; *** p < 0.01*
Figures in parentheses are standard errors.

Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

Table 13 OLS Regressions Model 1- Average Fertilizer Input and Partially Adopted FDP

Model 1 OLS Regression Results
Dependent Variable: Average Fertilizer Input (Kg/dc)
Independent Variable: Partially Adopted FDP

Constant	1.26 ***
	(.009)
D2	-0.26***
(1= Mixed Users, 0= Non-adopters)	(0.03)
N	1,371
R^2	0.06
F Statistic (df= 1;1369)	89.12***

Note:
D2 are farmers who partially adopted FDP and used both prilled urea and guti urea fertilizer during rice production. The reference group are the farmers that only used broadcasted prilled urea.

** p < 0.1; ** p < 0.05; *** p < 0.01*
Figures in parentheses are standard errors.

Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

Table 14: OLS Regressions Model 1- Average Fertilizer Productivity and Fully Adopted FDP

Model 1 OLS Regression Results Dependent Variable: Average Fertilizer Productivity (Kg/dc) Independent Variable: Fully Adopted FDP	
Constant	21.20 *** (0.28)
D1 (1= Fully adopters, 0= Non-adopters)	18.19** (0.62)
N	1,508
R^2	0.36
F Statistic (df= 1;1506)	860.16

Note:
D1 are farmers who fully adopted FDP and only used guti fertilizer during rice production. The reference group are the farmers that only used broadcasted prilled urea.

** p < 0.1; ** p < 0.05; *** p < 0.01*
Figures in parentheses are standard errors.

Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

Table 15: OLS Regressions Model 1- Average Fertilizer Productivity and Fully Adopted FDP

Model 1 OLS Regression Results Dependent Variable: Average Fertilizer Productivity (Kg/dc) Independent Variable: Partially Adopted FDP	
Constant	21.20*** (.28)
D2 (1= Mixed Users, 0= Non-adopters)	5.30 *** (0.82)
N	1,371
R^2	0.36
F Statistic (df= 1;1369)	41.85***

Note:
D2 are farmers who partially adopted FDP and used both prilled urea and guti urea fertilizer during rice production. The reference group are the farmers that only used broadcasted prilled urea.

** p < 0.1; ** p < 0.05; *** p < 0.01*
Figures in parentheses are standard errors.

Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

2nd OLS Regression Model

In the 2nd regression models below in tables 16-24, the results show a strong and consistent fertilizer effect of adopting FDP technology on the dependent variables when covariates are added. A farmer that did not use deep-placement technology and broadcasted urea fertilizer had an average yield of 5,482 (kgs/ha) of rice while a fully adopted farmer had 6,000 (kgs/ha) of rice holding all other variables constant. The farmers who partially adopted FDP also had slightly higher yields of 5,791 (kgs/ha). wIn the regression model with yield as the dependent variable and treatment group D1, the agricultural inputs significantly ($p<0.01$) impacting yield are the , tractor and shallow tube well technologies. They are all categorized as either used or not used during crop production with no use as the reference category (1= Used, 0= Not Used). Tractor use has a negative signficiant relationship with yield, thus the farmers who used a tractor have a decrease in average yields by 171 kilograms per hectare. The relationship between tractor and yields is unclear with the information given, but the technology's inefficient or excessive use could impact yield. Additionally, shallow tubewell irrigation technology increases yields by 350.88 kilograms per hectare. The positive signficiant relationship between shallow tubewell irrigation and yield is expected since many Boro farmers use irrigation technology for rice production efficiency. Additionally, total revenues and net revenues are higher for both D1 and D2 than for broadcasted farmers which is expected from higher yields. The technologies that remain significant are power tiller and shallow tubewell use, which show a positive effect on total revenue for both models of D1 and D2. The farmers that use local rice variety seeds have a positive relationship with yield ($p < 0.05$). Many of the farmers couple the use of local variety seeds with HYV or modern seeds, thus there is not much to say about this relationship. The net revenue models show that the farmers who fully and partially adopted the technology have higher net economic benefits from using guti fertilizer than the farmers who used prilled urea.

The average fertilizer productivity models have similar relationships between the dummy variables and production inputs. The use of local variety seeds and powertiller use have negative relationships with fertilizer productivity. The negative relationship between powertiller and fertilizer productivity is also unclear, but it could be possible that powertiller use has a relationship with higher fertilizer applied, which would decrease fertilizer productivity. It is expected that D1 and D2 both have signficant and positive impacts on fertilizer productivity since FDP technology is increasing yields and decreasing fertilizer input per hectare. The average fertilizer input models show that D1 and D2 have negative significant relationships with the fertilizer applied (kg/dc) compared to broadcasted farmers. When farmers use FDP technology, our results show that despite adding other commonly used production inputs, the technology itself increases yields, revenues, net economic benefits and fertilizer productivity while decreasing fertilizer applied per hectare of rice.

Table 16: Regression Model 2- Yield, Fully Adopted FDP and Agricultural Inputs

Model 2 OLS Regression Results Dependent Variable: Yield (Kg/dc) Observations = 1,508	
Constant	22.18 *** (0.50)
D1 (1= Fully adoptors, 0= Non-adopters)	2.12*** (0.22)
LocalVariety (1= LV, 0= Otherise)	-0.69 (0.21)
BoraxU (Yes=1, No=0)	0.01 (0.03)
ZincSU (Yes=1, No=0)	-0.01 (0.02)
TracU (Yes=1, No=0)	-0.60*** (0.22)
PTU (Yes=1, No=0)	1.51 (0.50)
STWU (Yes=1, No=0)	1.42 *** (0.18)
Training (Yes=1, No=0)	-.0.02 (0.19)
DemoPlot (Yes=1, No=0)	-0.46 (0.43)
R^2	0.14
F Statistic (df = 9; 1498)	26.77
Note: $* p < 0.1; ** p < 0.05; *** p < 0.01$ *Figures in parentheses are standard errors.*	

Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

Table 17: Regression Model 2- Yield, Partially Adopted FDP and Agricultural Inputs

Model 2 OLS Regression Results Dependent Variable: Yield (Kg/dc) Observations = 1, 373	
Constant	22.41***
	(0.47)
D2 (1= Mixed adoptors, 0= Non-adopters)	1.02***
	(0.28)
LocalVariety (1=LV, 0=Otherwise)	-0.74***
	(0.21)
BoraxU (Yes=1, No=0)	0.01
	(0.03)
ZincSU (Yes=1, No=0)	-0.01
	(0.02)
TracU (Yes=1, No=0)	-0.67***
	(0.23)
PTU (Yes=1, No=0)	1.38***
	(0.47)
STWU (Yes=1, No=0)	1.32 ***
	(0.19)
Training (Yes=1, No=0)	-0.05
	(0.20)
DemoPlot (Yes=1, No=0)	-0.24
	(0.51)
R^2	0.08
F Statistic (df = 9; 1361)	13.94
Note: ** p < 0.1; ** p < 0.05; *** p < 0.01* *Figures in parentheses are standard errors.*	

Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

Table 18: Model 2 Regression Results- Total Revenue, Fully Adopted FDP, Agricultural Inputs

Model 2 OLS Regression Results Dependent Variable: Total Revenue (Tk/dc) Observations = 1, 510	
Constant	302.27*** (10.00)
D1 (1= Fully adoptors, 0= Non-adopters)	36.24*** (4.35)
LocalVariety (1=LV, 0=Otherwise)	9.53** (4.14)
BoraxU (Yes=1, No=0)	0.92 (0.61)
ZincSU (Yes=1, No=0)	-0.50 (0.44)
TracU (Yes=1, No=0)	-7.30* (4.41)
PTU (Yes=1, No=0)	53.84*** (9.93)
STWU (Yes=1, No=0)	45.67 *** (3.59)
Training (Yes=1, No=0)	0.35 (3.69)
DemoPlot (Yes=1, No=0)	-1.56 (8.51)
R^2	0.18
F Statistic (df = 9; 1498)	37.49
Note: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$ *Figures in parentheses are standard errors.*	

Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

Table 19 Model 2 Results- Total Revenue, Partially Adopted FDP, Agricultural Inputs

Model 2 OLS Regression Results Dependent Variable: Total Revenue (Tk/dc) Observations = 1, 371	
Constant	306.64 *** (9.49)
D2 (1= Mixed adoptors, 0= Non-adopters)	16.60*** (5.66)
LocalVariety (1= LV, 0= Otherwise)	7.95** (4.28)
BoraxU (Yes=1, No=0)	0.89 (0.62)
ZincSU (Yes=1, No=0)	-0.57 (0.45)
TracU (Yes=1, No=0)	-7.51 (4.63)
PTU (Yes=1, No=0)	50.81*** (9.36)
STWU (Yes=1, No=0)	43.64 *** (3.76)
Training (Yes=1, No=0)	1.74 (3.95)
DemoPlot (Yes=1, No=0)	4.12 (10.28)
R^2	0.15
F Statistic (df = 9; 1361)	25.75
Note: ** p < 0.1; ** p < 0.05; *** p < 0.01* *Figures in parentheses are standard errors.*	

Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

Table 20 Model 2 Results- Net Revenue, Fully Adopted FDP and Agricultural Inputs

Model 2 OLS Regression Results Dependent Variable: Net Revenue (Tk/dc) Observations = 1, 507	
Constant	286.69*** (9.10)
D1 (1= Fully adoptors, 0= Non-adopters)	43.93*** (4.31)
LocalVariety (1=LV, 0=Otherwise)	9.02** (4.10)
BoraxU (Yes=1, No=0)	0.97 (0.61)
ZincSU (Yes=1, No=0)	-0.49 (0.44)
TracU (Yes=1, No=0)	-6.72 (4.43)
PTU (Yes=1, No=0)	47.44*** (9.82)
STWU (Yes=1, No=0)	45.89 *** (3.55)
Training (Yes=1, No=0)	0.58 (3.65)
DemoPlot (Yes=1, No=0)	-2.30 (8.42)
R^2	0.20
F Statistic (df = 9; 1497)	41.41
Note: ** p < 0.1; ** p < 0.05; *** p < 0.01* *Figures in parentheses are standard errors.*	

Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

Table 21 Model 2 Results- Net Revenue, Fully Adopted FDP and Agricultural Inputs

Model 2 OLS Regression Results Dependent Variable: Net Revenue (Tk/dc) Observations = 1, 371	
Constant	290.54 *** (9.35)
D2 (1= Mixed adoptors, 0= Non-adopters)	19.39*** (5.59)
LocalVariety (1=LV, 0= Otherwise)	7.31* (4.22)
BoraxU (Yes=1, No=0)	0.94 (0.61)
ZincSU (Yes=1, No=0)	-0.57 (0.44)
TracU (Yes=1, No=0)	-7.04 (4.64)
PTU (Yes=1, No=0)	45.00*** (9.23)
STWU (Yes=1, No=0)	43.90 *** (3.71)
Training (Yes=1, No=0)	1.77 (3.90)
DemoPlot (Yes=1, No=0)	5.17 (10.13)
R^2	0.15
F Statistic (df = 9; 1361)	25.68
Note: ** p < 0.1; ** p < 0.05; *** p < 0.01* *Figures in parentheses are standard errors.*	

Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

Table 21 Model 2 Results- Fertilizer Productivity, Fully Adopted FDP and Agricultural Inputs

Model 2 OLS Regression Results Dependent Variable: Average Fertilizer Productivity(Kg/dc) Observations = 1,508	
Constant	26.54*** (1.54)
D1 (1= Full Adopters, 0= Non-adopters)	18.42*** (0.67)
LocalVariety (1=LV, 0=Otherwise)	-1.62 ** (0.64)
BoraxU (Yes=1, No=0)	0.04 (0.09)
ZincSU (Yes=1, No=0)	-0.03 (0.07)
TracU (Yes=1, No=0)	0.75 (0.69)
PTU (Yes=1, No=0)	-6.32*** (1.53)
STWU (Yes=1, No=0)	1.27 ** (0.55)
Training (Yes=1, No=0)	0.32 (0.57)
DemoPlot (Yes=1, No=0)	-2.31 * (1.31)
R^2	0.38
F Statistic (df = 9; 1498)	101.2
Note: ** p < 0.1; ** p < 0.05; *** p < 0.01* *Figures in parentheses are standard errors.*	

Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

Table 22 Model 2 Results- Fertilizer Productivity, Fully Adopted FDP and Agricultural Inputs

Model 2 OLS Regression Results Dependent Variable: Average Fertilizer Productivity (Kg/dc) Observations = 1,371	
Constant	26.88*** (1.48)
D2 (1= Partial Adopters, 0= Non-adopters)	5.05*** (0.88)
LocalVariety (1=LV, 0=Otherwise)	-2.03 *** (0.67)
BoraxU (Yes=1, No=0)	0.04 (0.10)
ZincSU (Yes=1, No=0)	-0.04 (0.07)
TracU (Yes=1, No=0)	0.26 (0.73)
PTU (Yes=1, No=0)	-6.30*** (1.46)
STWU (Yes=1, No=0)	1.07 * (0.59)
Training (Yes=1, No=0)	-0.07 (0.62)
DemoPlot (Yes=1, No=0)	-1.19 * (1.60)
R^2	0.38
F Statistic (df = 9; 1361)	8.43
Note: ** p < 0.1; ** p < 0.05; *** p < 0.01* *Figures in parentheses are standard errors.*	

Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

Table 23 Model 2 Results- Fertilizer Input, Fully Adopted FDP and Agricultural Inputs

Model 2 OLS Regression Results Dependent Variable: Average Fertilizer Input (Kg/dc) Observations = 1,508	
Constant	0.89*** (0.05)
D1 (1= Full Adopters, 0= Non-adopters)	-0.58*** (0.02)
LocalVariety (1=LV, 0=Otherwise)	0.03 (0.02)
BoraxU (Yes=1, No=0)	-0.00 (0.02)
ZincSU (Yes=1, No=0)	-0.00 (0.00)
TracU (Yes=1, No=0)	-0.02 (0.21)
PTU (Yes=1, No=0)	0.38*** (0.05)
STWU (Yes=1, No=0)	0.02 (0.02)
Training (Yes=1, No=0)	-0.02 (0.04)
DemoPlot (Yes=1, No=0)	0.02 (0.04)
R^2	0.39
F Statistic (df = 9; 1498)	108.90
Note: * p < 0.1; ** p < 0.05; *** p < 0.01 *Figures in parentheses are standard errors.*	

Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

Table 24 Model 2 Results- Fertilizer Input, Fully Adopted FDP and Agricultural Inputs

Model 2 OLS Regression Results Dependent Variable: Average Fertilizer Input (Kg/dc) Observations = 1,371	
Constant	0.91***
	(0.05)
D2 (1= Mixed Adopters, 0= Non-adopters)	-0.24***
	(0.03)
LocalVariety (1=LV, 0= Otherwise)	0.04
	(0.02)
BoraxU (Yes=1, No=0)	-0.002
	(0.02)
ZincSU (Yes=1, No=0)	-0.00
	(0.00)
TracU (Yes=1, No=0)	-0.02
	(0.02)
PTU (Yes=1, No=0)	0.35***
	(0.05)
STWU (Yes=1, No=0)	0.01
	(0.02)
Training (Yes=1, No=0)	-0.003
	(0.02)
DemoPlot (Yes=1, No=0)	-0.07
	(0.05)
R^2	0.11
F Statistic (df = 9; 1361)	18.89
Note: ** p < 0.1; ** p < 0.05; *** p < 0.01* *Figures in parentheses are standard errors.*	

Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

3rd OLS Fixed Effects Regression Model

In Model 3, socio-demographic variables were added and 8 districts for fixed effects of variability unaccounted for outside of the independent variables. These results are listed in Tables 25 through 34. The fertilizer effect of deep-placement technology still held when other covariates and districts were added to the model. D1 and D2 still have positive and significant impacts on yields, total revenues, net revenues and fertilizer productivity as expected. Within the socio-demographic variables, age has a significant and negative relationships with yield, total revenue and net revenue for both D1 and D2 ($p<0.05$). In general, this relationship with age and yield could be expected among smallholder farmers with high labor requirements for rice paddies. The other socio-demographic variables added such as gender, education, farmsize and household labor do not have any significant impacts on any of the dependnet variables tested. The agricultural production variables that held in many of fixed effect models were local seed variety used and tractor and shallow tubewell use. The negative relationship with local seed variety is unclear with the information given. As mentioned earlier, tractor use has a consistent negative relationship with the dependent variables which could possibly show overuse or inefficient use of the technology. Shallow tubewell use has a signficant and positive relationship ($p<0.01$) with yield, total revenues and net revenues, and a slightly significant relationship ($p<0.10$) with fertilizer productivity. A relationship is expected since many farmers rely on this irrigation technology for rice paddy production. Power tiller technology has a positively significant relationship with fertilizer applied ($p<0.01$), and a negative relationship with fertilizer productivity ($p<0.01$). This relationship could be that farmers using higher inputs of fertilizers would also be relying on power tillers for rice cultivation. Additionally, the districts added in each model for the fixed-effects have significant relationships with the Meherpur district. Meherpur was chosen as the base category because it had the least percentage of farmers using FDP technology during the 2015 Boro season. As the results show, there is great variability among the districts in terms of yields, revenues, fertilizer applied and productivity, which will be discussed briefly in the next section. However, district-level differences in Bangladesh are very complex ranging from differences in soil quality, environmental conditions and fertilizer markets, thus further district-level research is necessary.

Table 25: Model 3 Fixed Effects Regression Results- Yield

Model 3 OLS Fixed Effect Regression Results Dependent Variable: Yield(Kg/dc) Observations = 1,506	
Constant	24.51*** (0.83)
D1 (1= Fully adopters, 0= Non-adopters)	2.32 *** (0.22)
Age (in years)	-0.01 ** (0.006)
Gender (Male=1, Female=0)	0.44 (0.37)
Educ (in years)	0.005 (0.02)
Farmsize (1-4)	-0.004 (0.11)
TotHHL	0.07 (0.10)
Local Variety (1=LV, 0=Otherwise)	-1.15 *** (0.22)
BoraxU (Yes=1, No=0)	0.008 (0.03)
ZincSU (Yes=1, No=0)	-0.004 (0.02)
TracU (Yes=1, No=0)	-0.91 *** (0.23)
PTU (Yes=1, No=0)	0.54 (0.53)

STWU (Yes=1, No=0)	0.81***
	(0.22)
Training (Yes=1, No=0)	-0.09
	(0.18)
DemoPlot (Yes=1, No=0)	-0.39
	(0.42)
Distict1 (Dis 1=1, Dis5=0)	-0.84*
	(0.44)
Distict2 (Dis 2=1, Dis5=0)	-0.90**
	(0.43)
Distict3 (Dis 3=1, Dis5=0)	-0.88 *
	(0.50)
Distict4 (Dis 4=1, Dis5=0)	0.69
	(0.44)
Distict6 (Dis 6=1, Dis5=0)	-1.84***
	(0.51)
Distict8 (Dis 8=1, Dis5=0)	-1.66 ***
	(0.50)
Distict9 (Dis 9=1, Dis5=0)	0.22
	(0.43)
Distict10 (Dis 10=1, Dis5=0)	-1.63 ***
	(0.51)
R^2	0.18
F Statistic (df = 22; 1483)	16.33
Note:	
** p < 0.1; ** p < 0.05; *** p < 0.01*	
Figures in parentheses are standard errors.	

Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

Table 13.2: Model 3 Fixed Effects Regression Results- Yield

Model 3 OLS Fixed Effect Regression Results Dependent Variable: Yield(Kg/dc) Observations = 1,369	
Constant	24.65 ***
	(0.82)
D2 (1= Mixed adopters, 0= Non-adopters)	1.17 ***
	(0.27)
Age (in years)	-0.02 **
	(0.006)
Gender (Male=1, Female=0)	0.64 *
	(0.38)
Educ (in years)	0.00
	(0.02)
Farmsize (1-4)	0.04
	(0.11)

TotHHL	0.12
	(0.10)
LocalVariety (1=LV, 0=Otherwise)	-0.40
	(0.27)
BoraxU (Yes=1, No=0)	0.00
	(0.03)
ZincSU (Yes=1, No=0)	-0.00
	(0.02)
TracU (Yes=1, No=0)	-1.03***
	(0.24)
PTU (Yes=1, No=0)	0.34
	(0.50)
STWU (Yes=1, No=0)	0.56 ***
	(0.22)
Training (Yes=1, No=0)	-0.21
	(0.19)
DemoPlot (Yes=1, No=0)	-0.07
	(0.50)
Distict1 (Dis 1=1, Dis5=0)	-0.92 **
	(0.44)
Distict2 (Dis 2=1, Dis5=0)	-0.96**
	(0.43)
Distict3 (Dis 3=1, Dis5=0)	-0.88 *
	(0.50)
Distict4 (Dis 4=1, Dis5=0)	0.81
	(0.44)
Distict6 (Dis 6=1, Dis5=0)	-2.08 ***
	(0.52)
Distict8 (Dis 8=1, Dis5=0)	-2.07 ***
	(0.51)
Distict9 (Dis 9=1, Dis5=0)	0.28
	(0.42)
Distict10 (Dis 10=1, Dis5=0)	-2.00 ***
	(0.50)
R^2	0.17
F Statistic (df = 22; 1346)	12.19
Note:	
* *p* < 0.1; ** *p* < 0.05; *** *p* < 0.01	
Figures in parentheses are standard errors.	

Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

Table 27: Model 3 Fixed Effects Regression Results- Total Revenue

Model 3 OLS Fixed Effect Regression Results Dependent Variable: Total Revenue (Tk/dc) Observations = 1,506	
Constant	386.26 *** (14.82)
D1 (1= Full Adopters, 0= Non-adopters)	41.22*** (3.84)
Age (in years)	-0.25 ** (0.11)
Gender (Male=1, Female=0)	2.11 (6.58)
Educ (in years)	0.54 (0.38)
Farmsize (1-4)	-0.27 (2.02)
TotHHL	2.28 (1.79)
LocalVariety (1=LV,0= Otherwise)	-3.37 ** (3.93)
BoraxU (Yes=1, No=0)	0.32 (0.53)
ZincSU (Yes=1, No=0)	-0.20 (0.39)
TracU (Yes=1, No=0)	-10.15** (4.07)
PTU (Yes=1, No=0)	13.88 (9.41)
STWU (Yes=1, No=0)	12.63 *** (3.90)
Training (Yes=1, No=0)	-1.39 (3.22)
DemoPlot (Yes=1, No=0)	1.57 (7.44)
Distict1 (Dis 1=1, Dis5=0)	-18.13 ** (7.79)
Distict2 (Dis 2=1, Dis5=0)	1.62 (7.57)
Distict3 (Dis 3=1, Dis5=0)	-14.24 (8.88)
Distict4 (Dis 4=1, Dis5=0)	23.59*** (7.79)
Distict6 (Dis 6=1, Dis5=0)	-78.12 *** (9.00)
Distict8 (Dis 8=1, Dis5=0)	-69.65 ***

	(8.96)
Distict9 (Dis 9=1, Dis5=0)	16.52 **
	(7.55)
Distict10 (Dis 10=1, Dis5=0)	-71.54 ***
	(8.98)
R^2	0.39
F Statistic (df = 22; 1483)	43.38
Note:	
** p < 0.1; ** p < 0.05; *** p < 0.01*	
Figures in parentheses are standard errors.	

Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

Table 28: Model 3 Fixed Effects Regression Results- Total Revenue

Model 3 OLS Fixed Effect Regression Results Dependent Variable: Total Revenue (Tk/dc) Observations = 1,369	
Constant	393.72***
	(14.32)
D2 (1= Mixed Adopters, 0= Non-adopters)	22.96 ***
	(4.77)
Age (in years)	-0.26 **
	(0.11)
Gender (Male=1, Female=0)	2.16
	(6.47)
Educ (in years)	0.32
	(0.39)
Farmsize (1-4)	0.94
	(2.00)
TotHHL	3.06 *
	(1.81)
LocalVariety (1=LV, 0=Otherwise)	-4.98
	(3.89)
BoraxU (Yes=1, No=0)	0.35
	(0.52)
ZincSU (Yes=1, No=0)	-0.22
	(0.37)
TracU (Yes=1, No=0)	-11.55***
	(4.12)
PTU (Yes=1, No=0)	7.63
	(8.80)
STWU (Yes=1, No=0)	8.03**
	(3.97)

Training (Yes=1, No=0)	-2.71
	(3.33)
DemoPlot (Yes=1, No=0)	11.52
	(8.62)
Distict1 (Dis 1=1, Dis5=0)	-18.97 **
	(7.65)
Distict2 (Dis 2=1, Dis5=0)	3.46
	(7.54)
Distict3 (Dis 3=1, Dis5=0)	-16.54 *
	(8.74)
Distict4 (Dis 4=1, Dis5=0)	27.26***
	(7.70)
Distict6 (Dis 6=1, Dis5=0)	-86.39 ***
	(9.10)
Distict8 (Dis 8=1, Dis5=0)	-76.66 ***
	(8.89)
Distict9 (Dis 9=1, Dis5=0)	17.89 **
	(7.42)
Distict10 (Dis 10=1, Dis5=0)	-79.88 ***
	(8.86)
R^2	0.41
F Statistic (df = 22; 1346)	42.68
Note:	
** p < 0.1; ** p < 0.05; *** p < 0.01*	
Figures in parentheses are standard errors.	

Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

Table 29: Model 3 Fixed Effects Regression Results- Net Revenue

Model 3 OLS Fixed Effect Regression Results Dependent Variable: Net Revenue (Tk/dc) Observations = 1,505	
Constant	366.94 ***
	(14.68)
D1 (1= Full Adopters, 0= Non-adopters)	48.32***
	(3.84)
Age (in years)	-0.26 **
	(0.11)
Gender (Male=1, Female=0)	1.84
	(6.52)
Educ (in years)	0.56
	(0.38)
Farmsize (1-4)	-0.12
	(2.00)
TotHHL	2.35
	(1.77)

LocalVariety (1=LV,0= Otherwise)	-3.21 **
	(3.90)
BoraxU (Yes=1, No=0)	0.34
	(0.53)
ZincSU (Yes=1, No=0)	-0.19
	(0.38)
TracU (Yes=1, No=0)	-9.46 **
	(4.03)
PTU (Yes=1, No=0)	9.91
	(9.32)
STWU (Yes=1, No=0)	12.81***
	(3.88)
Training (Yes=1, No=0)	-1.22
	(3.20)
DemoPlot (Yes=1, No=0)	0.31
	(7.37)
Distict1 (Dis 1=1, Dis5=0)	-19.22**
	(7.72)
Distict2 (Dis 2=1, Dis5=0)	5.31
	(7.50)
Distict3 (Dis 3=1, Dis5=0)	-13.27
	(8.80)
Distict4 (Dis 4=1, Dis5=0)	23.42***
	(7.71)
Distict6 (Dis 6=1, Dis5=0)	-74.02 ***
	(8.92)
Distict8 (Dis 8=1, Dis5=0)	-68.42 ***
	(8.88)
Distict9 (Dis 9=1, Dis5=0)	17.91 **
	(7.48)
Distict10 (Dis 10=1, Dis5=0)	-68.32 ***
	(8.98)
R^2	0.40
F Statistic (df = 22; 1482)	43.38
Note:	
** p < 0.1; ** p < 0.05; *** p < 0.01*	
Figures in parentheses are standard errors.	

Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

Table 30: Model 3 Fixed Effects Regression Results- Net Revenue

Model 3 OLS Fixed Effect Regression Results Dependent Variable: Net Revenue (Tk/dc) Observations = 1,369	
Constant	373.25***
	(14.16)
D2 (1= Mixed Adopters, 0= Non-adopters)	25.37***
	(4.72)
Age (in years)	-0.27 **
	(0.11)
Gender (Male=1, Female=0)	1.71
	(6.40)
Educ (in years)	0.32
	(0.38)
Farmsize (1-4)	1.02
	(2.00)
TotHHL	3.14 *
	(1.78)
LocalVariety (1=LV, 0=Otherwise)	-4.99
	(3.85)
BoraxU (Yes=1, No=0)	0.36
	(0.51)
ZincSU (Yes=1, No=0)	-0.22
	(0.37)
TracU (Yes=1, No=0)	-11.22***
	(4.07)
PTU (Yes=1, No=0)	5.07
	(8.70)
STWU (Yes=1, No=0)	8.48**
	(3.93)
Training (Yes=1, No=0)	-2.64
	(3.30)
DemoPlot (Yes=1, No=0)	11.78
	(8.52)
Distict1 (Dis 1=1, Dis5=0)	-20.38 ***
	(7.57)
Distict2 (Dis 2=1, Dis5=0)	7.39
	(7.45)
Distict3 (Dis 3=1, Dis5=0)	-15.33 *
	(8.64)
Distict4 (Dis 4=1, Dis5=0)	26.97***
	(7.61)
Distict6 (Dis 6=1, Dis5=0)	-80.67***
	(8.99)
Distict8 (Dis 8=1, Dis5=0)	-75.01 ***

	(8.79)
Distict9 (Dis 9=1, Dis5=0)	19.35***
	(7.33)
Distict10 (Dis 10=1, Dis5=0)	-76.33 ***
	(8.76)
R^2	0.41
F Statistic (df = 22; 1346)	42.10
Note:	
** p < 0.1; ** p < 0.05; *** p < 0.01*	
Figures in parentheses are standard errors.	

Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

Table 31: Fixed Effects Regression Results- Fertilizer Input

Model 3 OLS Fixed Effect Regression Results Dependent Variable: Average Fertilizer Input (Kg/dc) Observations = 1,506	
Constant	1.11***
	(0.08)
D1 (1= Full Adopters, 0= Non-adopters)	-0.54 ***
	(0.02)
Age (in years)	0.00
	(0.00)
Gender (Male=1, Female=0)	0.02
	(0.04)
Educ (in years)	-0.00
	(0.00)
Farmsize (1-4)	-0.004
	(0.01)
TotHHL	-0.004
	(0.009)
LocalVariety (1=LV, 0= Otherwise)	-0.009
	(0.02)
BoraxU (Yes=1, No=0)	-0.002
	(0.02)
ZincSU (Yes=1, No=0)	-0.00
	(0.002)
TracU (Yes=1, No=0)	-0.02
	(0.02)
PTU (Yes=1, No=0)	0.22 ***
	(0.05)
STWU (Yes=1, No=0)	0.004
	(0.02)

Training (Yes=1, No=0)	-0.02
	(0.02)
DemoPlot (Yes=1, No=0)	0.05
	(0.04)
Distict1 (Dis 1=1, Dis5=0)	0.03
	(0.04)
Distict2 (Dis 2=1, Dis5=0)	-0.16 ***
	(0.04)
Distict3 (Dis 3=1, Dis5=0)	-0.07
	(0.05)
Distict4 (Dis 4=1, Dis5=0)	0.02
	(0.04)
Distict6 (Dis 6=1, Dis5=0)	-0.27 ***
	(0.05)
Distict8 (Dis 8=1, Dis5=0)	-0.08 *
	(0.05)
Distict9 (Dis 9=1, Dis5=0)	-0.08 **
	(0.04)
Distict10 (Dis 10=1, Dis5=0)	-0.21***
	(0.05)
R^2	0.45
F Statistic (df = 22; 1483)	54.78
Note:	
** p < 0.1; ** p < 0.05; *** p < 0.01*	
Figures in parentheses are standard errors.	

Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

Table 32: Fixed Effects Regression Results- Fertilizer Input

Model 3 OLS Fixed Effect Regression Results Dependent Variable: Average Fertilizer Input (Kg/dc) Observations = 1,369	
Constant	1.18***
	(0.08)
D2 (1= Mixed Adopters, 0= Non-adopters)	-0.21***
	(0.03)
Age (in years)	0.00
	(0.00)
Gender (Male=1, Female=0)	0.02
	(0.04)
Educ (in years)	-0.00
	(0.00)
Farmsize (1-4)	-0.00
	(0.01)

TotHHL	-0.00
	(0.01)
LocalVariety (1=LV, 0=Otherwise)	-0.00
	(0.02)
BoraxU (Yes=1, No=0)	-0.002
	(0.002)
ZincSU (Yes=1, No=0)	-0.00
	(0.002)
TracU (Yes=1, No=0)	-0.006
	(0.02)
PTU (Yes=1, No=0)	0.15***
	(0.05)
STWU (Yes=1, No=0)	-0.009
	(0.02)
Training (Yes=1, No=0)	-0.006
	(0.02)
DemoPlot (Yes=1, No=0)	-0.03
	(0.05)
Distict1 (Dis 1=1, Dis5=0)	0.04
	(0.04)
Distict2 (Dis 2=1, Dis5=0)	-0.17 ***
	(0.04)
Distict3 (Dis 3=1, Dis5=0)	-0.08
	(0.05)
Distict4 (Dis 4=1, Dis5=0)	0.03
	(0.04)
Distict6 (Dis 6=1, Dis5=0)	-0.36 ***
	(0.05)
Distict8 (Dis 8=1, Dis5=0)	-0.10 *
	(0.05)
Distict9 (Dis 9=1, Dis5=0)	-0.08 **
	(0.04)
Distict10 (Dis 10=1, Dis5=0)	-0.23***
	(0.05)
R^2	0.21
F Statistic (df = 22; 1346)	16.53
Note:	
** p < 0.1; ** p < 0.05; *** p < 0.01*	
Figures in parentheses are standard errors.	

Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

Table 33: Fixed Effects Regression Results- Fertilizer Productivity

Model 3 OLS Fixed Effect Regression Results Dependent Variable: Average Fertilizer Productivity (Kg/dc) Observations = 1,506	
Constant	23.20 (2.59)
D1 (1= Full Adopters, 0= Non-adopters)	17.98 *** (0.67)
Age (in years)	-0.02 (0.02)
Gender (Male=1, Female=0)	0.55 (1.15)
Educ (in years)	0.04 (0.07)
Farmsize (1-4)	0.06 (0.35)
TotHHL	-0.07 (0.31)
LocalVariety (1=LV, 0= Otherwise)	-1.30 * (0.69)
BoraxU (Yes=1, No=0)	0.02 (0.09)
ZincSU (Yes=1, No=0)	-0.02 (0.07)
TracU (Yes=1, No=0)	-0.03 (0.71)
PTU (Yes=1, No=0)	-3.94** (1.65)
STWU (Yes=1, No=0)	1.23 * (0.69)
Training (Yes=1, No=0)	0.57 (0.02)
DemoPlot (Yes=1, No=0)	-2.81 (1.30)
Distict1 (Dis 1=1, Dis5=0)	-1.49 (1.37)
Distict2 (Dis 2=1, Dis5=0)	2.17 (1.32)
Distict3 (Dis 3=1, Dis5=0)	0.73 (1.55)
Distict4 (Dis 4=1, Dis5=0)	-0.20 (1.36)
Distict6 (Dis 6=1, Dis5=0)	4.67*** (1.58)
Distict8 (Dis 8=1, Dis5=0)	0.56

	(1.57)
Distict9 (Dis 9=1, Dis5=0)	3.64 ***
	(1.32)
Distict10 (Dis 10=1, Dis5=0)	2.99*
	(1.57)
R^2	0.40
F Statistic (df = 22; 1483)	45.69
Note:	
** p < 0.1; ** p < 0.05; *** p < 0.01*	
Figures in parentheses are standard errors.	

Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

Table 34:: Fixed Effects Regression Results- Fertilizer Productivity

Model 3 OLS Fixed Effect Regression Results Dependent Variable: Average Fertilizer Productivity (Kg/dc) Observations = 1,369	
Constant	22.03
	(2.61)
D2 (1= Partial Adopters, 0= Non-adopters)	4.60 ***
	(0.87)
Age (in years)	-0.03
	(0.02)
Gender (Male=1, Female=0)	0.54
	(1.18)
Educ (in years)	0.02
	(0.07)
Farmsize (1-4)	0.17
	(0.36)
TotHHL	0.05
	(0.33)
LocalVariety (1=LV, 0= Otherwise)	-1.80 **
	(0.71)
BoraxU (Yes=1, No=0)	0.02
	(0.09)
ZincSU (Yes=1, No=0)	-0.03
	(0.07)
TracU (Yes=1, No=0)	-0.84
	(0.75)
PTU (Yes=1, No=0)	-2.53**
	(1.60)
STWU (Yes=1, No=0)	1.27 *
	(0.72)
Training (Yes=1, No=0)	-0.19
	(0.61)
DemoPlot (Yes=1, No=0)	0.61

	(1.57)
Distict1 (Dis 1=1, Dis5=0)	-1.91
	(1.39)
Distict2 (Dis 2=1, Dis5=0)	2.15
	(1.37)
Distict3 (Dis 3=1, Dis5=0)	0.76
	(1.59)
Distict4 (Dis 4=1, Dis5=0)	-0.17
	(1.40)
Distict6 (Dis 6=1, Dis5=0)	7.04***
	(1.66)
Distict8 (Dis 8=1, Dis5=0)	0.44*
	(1.62)
Distict9 (Dis 9=1, Dis5=0)	3.62**
	(1.35)
Distict10 (Dis 10=1, Dis5=0)	2.54
	(1.61)
R^2	0.40
F Statistic (df = 22; 1483)	45.69
Note:	
** $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$*	
Figures in parentheses are standard errors.	

Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

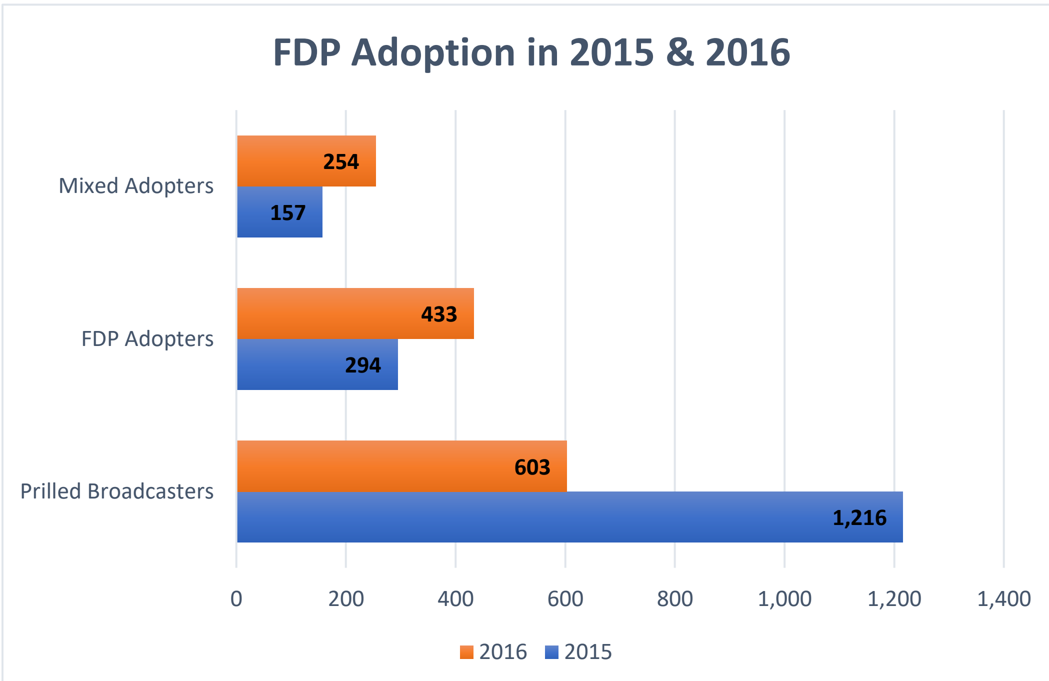
District Level Fixed Effects Analyses

In the ten districts surveyed in Southern Bangladesh, there are considerable district-level differences shown in the fixed-effect models for yield, total revenue, net revenue, fertilizer productivity and average fertilizer input. Some of the district differences are at the agro-ecological levels such as average temperatures, rainfall, nearby rivers, soil qualities, land fertility and ecological zones (BBS 2013). For instance, the ten districts are classified under four agro-ecological zones known as the Ganges Tidal Floodplain (Bagerhat, Barguna, Barisal), High Ganges River Floodplain (Jessore, Magura, Jhenaidah, Meherput), Low Ganges River Floodplain (Faridpur) and Gopalgank-Khulna Bils (Madaripur, Khulna) (Huq 2012). They are also classified under three different soil tracts of coastal saline tract, gangetic alluvium and brahmaputra alluvium (BBS 2013). Differences in soil fertility and quality can impact the yields for farmers as well as the type of agricultural inputs they use. In our sampled population, the average rice cultivated area varies from 0.71 acres in Meherpur to 1.14 acres in Bagerhat while the average fertilizer input (kg/ha) ranges from 212 in Bagerhat to 323 in Madaripur and Meherpur. The average paddy prices also range in price from 14.1 Taka per kilogram of rice in Bagerhat to 16.8 Taka in Jhenaidah. Among the 10 districts, net revenues varied from $915 per hectare to $1,213 and fertilizer cost ranged from $44 to $68 per hectare of rice. Average fertilizer productivity was lowest in Madripur at 5,067 kilograms of rice for every kilogram of fertilizer applied per hectare. The highest fertilizer productivity is in Bagerhat averaging 7,415 kilograms of rice per hectare of fertilizer applied. Meherpur, District #5, has the one of the lowest fertilizer productivities with the least amount of FDP adoption, higher fertilizer costs and yet has higher net revenues than other districts. Some of these differences can be captured by the fixed-effect model; however, the agro-ecological and environmental variabilities are more difficult to analyze. We are also limited on information for other production inputs and costs faced by farmers, thus the net revenues only include the fertilizer costs for guti and prilled urea in kilograms. The net revenue district are significantly different from one another.

FDP Adoption and Barriers from 2015 to 2016

In 2016, the AAPI household surveyed the same 2,000 households from 2015 and there are notable differences among the households that adopted FDP technology and did not adopt. Of the 2,000 households, there were 1,667 farmers that cultivated rice in 2015 whereas only 1,270 households cultivated rice in 2016. Around 77% of the 397 that did not cultivate rice again in 2016 were exclusively broadcasting in 2015. It is uncertain why these farmers did not cultivate rice again, but a potential reason could be from undesirable environmental conditions. There is much variability in adoption rates of FDP from 2015 to 2016 as seen in Figure 4 below. In 2016, around 47% of the farmers still had not adopted FDP technology from the previous year.

Figure 4: FDP Adoption in 2015 and 2016



Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

Around 34% of farmers in 2016 exclusively used FDP, whereas about 20% experimented with both fertilizers. The number of farmers that experimented with FDP in 2016 is higher than the total number of mixed users in 2015. This could mean farmers are gaining higher awareness or interest in the technology from one season to another. The adoption behavior rates in 2016 for FDP technology were much higher in the broadcasted and users. There were 284 broadcasted households who adopted FDP technology in 2016, and 186 broadcasted households who used a mixed method approach in 2016. There were 98 households that continued their use of FDP from one year to another. There were also farmers that dis-adopted or discontinued their use of deep-placement technology. In 2015, there were 83 households who used FDP technology but dis-adopted and returned to broadcasting in 2016. There were 44 farmers who fully adopted FDP in 2015 and partially dis-adopted with mixing prilled urea and guti urea in 2016. Of the 135 households who had a mixed application approach in 2015, 71 had discontinued FDP, 39 completely adopted FDP and 25 remained mixed in the following year. From each district, the overall percentage of broadcasted method dropped while the percentage of FDP application increased.

These results can show an increasing interest and knowledgeability of deep-placement technology among these farmers surveyed. However, it is evident from one year to another that high numbers of farmers are still not adopting FDP while other farmers are discontinuing their use. The low adoption rates could be from the technology barriers farmers noted such as the high labor requirement and lacking access to the FDP applicator. Two of the main barriers to adoption, the inavailability of the guti briquettes and the applicator, are major supply-side barriers of the technology. Moreover, farmers note in the 2016 survey that at crucial times during production, the materials and technology are not always available or accessible. From our data, we cannot make any conclusions about the survival rate of the technology over time due to the limited data on these districts.

Conclusion and Remarks

Fertilizer deep placement (FDP) technology is a climate-smart practice that is proven to increase farm-level productivities and decrease greenhouse gas emissions; however, adoption behavior and technology uptake can be improved in the FTF districts. . Our analyses and other case studies show that farmers who use fertilizer deep placement technology are economically benefiting through higher yields, revenues and net economic benefits and improving fertilizer use and productivity. The research aim for this study was the analyze the impact of FDP technology on yields, total revenues, net revenues, average fertilizer productivity and fertilizer applied per hectare of cultivated rice. The 2,000 surveyed households were analyzed during the heavily irrigated Boro rice season and the farmers were divided into those who fully adopted, partially adopted or did not adopt. The results show that the farmers who fully adopted (D1) or experimented with guti urea (D2) had positively significant relationships in the OLS regression models with yield, total revenues, net revenues and agricultural productivity. There was a negatively significant relationship between D1 and D2 with the average fertilizer applied on the rice paddies. In Model 2, the significant results held as agricultural inputs and adoption incentive variables were added. In the fixed-effect regressions for Model 3, socio-demographic variables and district-effect variables were added to accommodate for variability in the districts. The significant relationships still held for the fixed-effect models. The relationships between farmers who partially and fully adopted FDP technology with yields, revenues and fertilizer use are as expected from the IFDC's technology.

Deep-placement technology is proven to increase crop yields by enhancing nutrient absorption and improving soil conditions. FDP technology also decreases the amount of fertilizer applied per hectare of cultivated rice, thus it decreases the amount of emissions and pollutants produced from irrigated and rain-fed rice paddies. In our study, the farmers who adopt the new technology do have higher economic benefits; however, there seem to be adoption barriers inhibiting the long-term use of deep-placement technology. The adoption barriers that farmers are most concerned with are the labor and time requirements, the accessibility of the guti applicator and the briquette fertilizers and the fertilizer market prices. From 2015 to 2016, there are noticeable differences between district-level adoption rates with farmers that fully adopted or experimented with FDP technology. The overall percentage of broadcasters from all districts had dropped within the one year while the percentage of farmers who fully or partially used deep-placement technology increased. The noticeable changes in adoption behavior from one year to another could be from differences in environmental or agro-ecological factors, accessibility and availability of guti-fertilizer, fertilizer market price differences, labor requirements, and educational sources for FDP technology. It seems from our analyses and previous studies that farmers in Bangladesh have a growing knowledge and awareness of fertilizer deep placement technology since adoption rates have generally increased within a year of production. It also appears that farmers are willing to try the new technology since many broadcasted farmers in 2015 became experimenters or fully adopted users in 2016. The districts have variability in soil characteristics and fertility, environmental and ecological factors and accessibility to markets and production inputs. For further analysis and research, these district-level differences not accommodated for in our fixed-effect models are significant for fully understanding the adoption behavior among the farmers surveyed.

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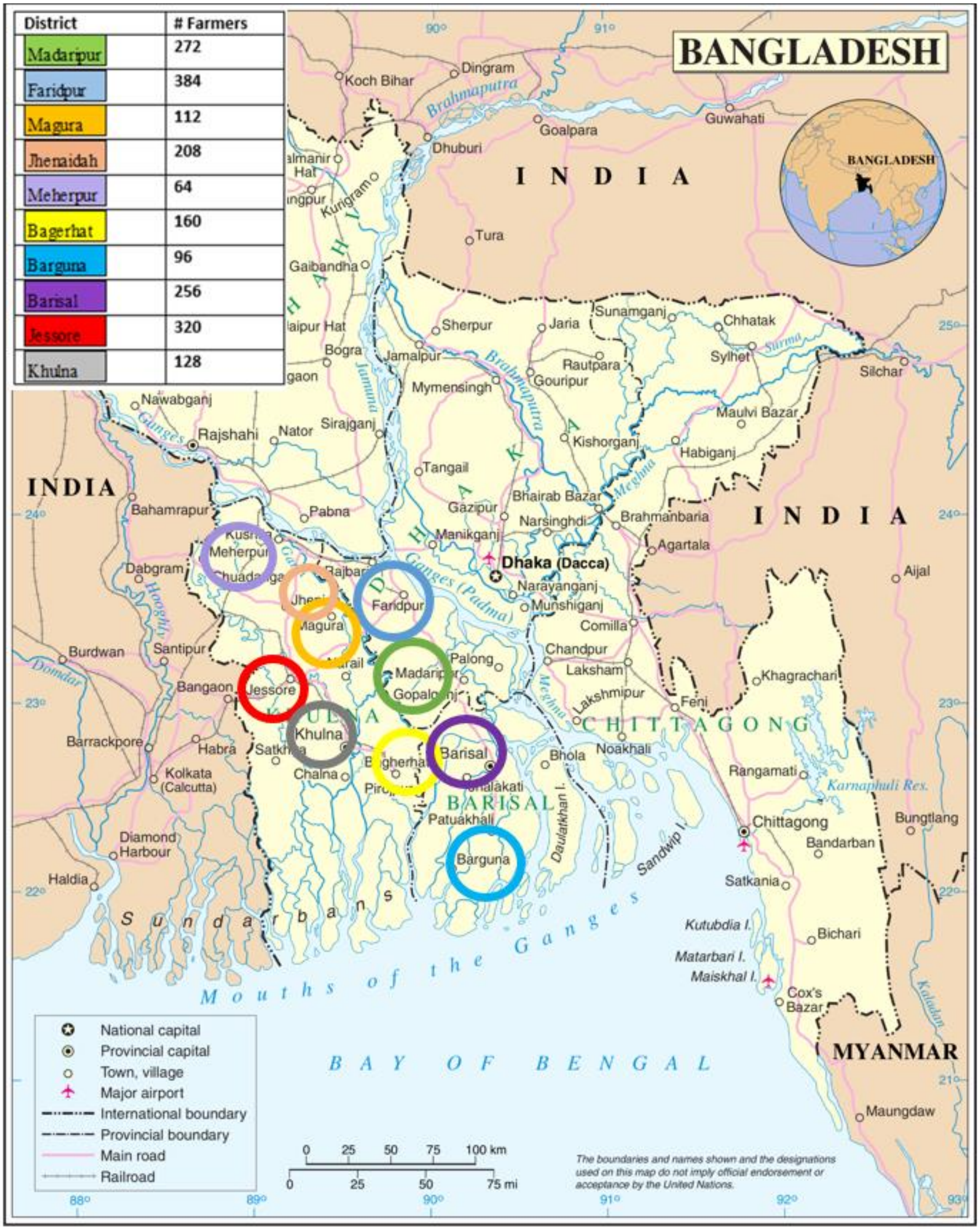
Figure 5: Map of Bangladesh and the 10 Surveyed Districts



Map source:http://ontheworldmap.com/bangladesh/large-detailed-map-of-bangladesh-with-cities.html

Table 35: Summary Statistics of Household Sample Population

Descriptive Variables	Sample Pop (n=2,000)	Cultivated Rice (n=1,667)	Prilled Urea Users (n=1,216)	Guti Urea Users (n=294)	Both PU and GU (n=157)
Gender (M=1, F=0)	x̄: 0.96 s: 0.20	x̄: 0.95 s: 0.21	x̄: 0.95 s: 0.22	x̄: 0.97 s: 0.18	x̄: 0.96 s: 0.21
Age (in years)	x̄: 47.42 s: 13.33	x̄: 47.18 s: 13.25	x̄: 47.45 s: 13.39	x̄: 47.05 s: 12.98	x̄: 45.28 s: 12.62
Education (in years)	x̄: 4.52 s: 4.13	x̄: 4.5 s: 4.17	x̄: 4.36 s: 4.13	x̄: 4.93 s: 4.18	x̄: 4.82 s: 4.41
FarmType (1-5)	x̄: 2.82 s: 0.75	x̄: 2.82 s: 0.76	x̄: 2.81 s: 0.76	x̄: 2.79 s: 0.74	x̄: 2.93 s: 0.80
Total HH members	x̄: 5.33 s: 2.17	x̄: 5.30 s: 2.19	x̄: 5.26 s: 2.09	x̄: 5.31 s: 2.20	x̄: 5.53 s: 2.79
TotalHHLabor	x̄: 1.51 s: 0.78	x̄: 1.52 s: 0.79	x̄: 1.49 s: 0.79	x̄: 1.55 s: 0.79	x̄: 1.64 s: 0.81
TotPlots	x̄: 8.15 s: 4.37	x̄: 8 s: 4.32	x̄: 7.86 s: 4.37	x̄: 7.81 s: 3.80	x̄: 9.40 s: 4.57
TotPlotArea (in decimals)	x̄: 212.40 s: 221.17	x̄: 208.94 s: 186.37	x̄: 206.19 s: 191.1	x̄: 196.92 s: 123.92	x̄: 252.13 s: 234.9
PlotsCult	x̄: 2.53 s: 2.37	x̄: 3.03 s: 2.28	x̄: 2.89 s: 2.21	x̄: 2.87 s: 2.20	x̄: 4.39 s: 2.45
CultPlotArea (in decimals)	x̄: 90.71 s: 80.98	x̄: 90.71 s: 80.98	x̄: 88.45 s: 81.07	x̄: 82.82 s: 61.36	x̄: 122.53 s: 102.66

Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

Table 36: Summary Statitics of Fertilizer Input Variables among Rice and non-Rice Cultivators

FertilizerVariables (Y=1, N=0)	Prilled Urea Users (n=1,216)	Guti Urea Users (n=294)	Both PU and GU (n=157)	Cultivated No Rice (n=333)
OrganicFert	x̄: 0.60 s: 0.49	x̄: 0.70 s: 0.46	x̄: 0.70 s: 0.46	x̄: 0.60 s: 0.49
TSPDAP	x̄: 0.99 s: 0.03	x̄: 1.00 s: 0	x̄: 1.00 s: 0	x̄: 0.99 s: 0.05
MOP	x̄: 0.99 s: 0.05	x̄: 1.00 s: 0	x̄: 0.99 s: 0.08	x̄: 0.99 s: 0.08
Gypsum	x̄: 0.91 s: 0.28	x̄: 0.95 s: 0.21	x̄: 0.95 s: 0.21	x̄: 0.81 s: 0.40
ZincSulph	x̄: 0.84 s: 0.37	x̄: 0.90 s: 0.30	x̄: 0.90 s: 0.30	x̄: 0.65 s: 0.48
Borax	x̄: 0.31 s: 0.46	x̄: 0.46 s: 0.50	x̄: 0.31 s: 0.46	x̄: 0.14 s: 0.35

Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

Table 37: Summary Statistics of Machinery Usage at the Household Level

Machinery Usage (Y=1, N=0)	Prilled Urea Users (n=1,216)	Guti Urea Users (n=294)	Both PU and GU (n=157)	Cultivated No Rice (n=333)
TractorU	x̄: 0.17 s: 0.38	x̄: 0.15 s: 0.35	x̄: 0.15 s: 0.36	x̄: 0.25 s: 0.43
PTU	x̄: 0.97 s: 0.18	x̄: 0.99 s: 0.10	x̄: 0.94 s: 0.24	x̄: 0.98 s: 0.12
STWU	x̄: 0.72 s: 0.45	x̄: 0.72 s: 0.45	x̄: 0.64 s: 0.48	x̄: 0.28 s: 0.45
GUappU	x̄: 0.007 s: 0.08	x̄: 0.06 s: 0.23	x̄: 0.11 s: 0.32	x̄: 0.006 s: 0.08
SpU	x̄: 0.94 s: 0.23	x̄: 0.90 s: 0.30	x̄: 0.95 s: 0.22	x̄: 0.97 s: 0.17

Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

Table 38: Summary Statistics of Machinery Ownership at the Household Level

Machinery Own (Y=1, N=0)	Prilled Urea Users (n=1,216)	Guti Urea Users (n=294)	Both PU and GU (n=157)	Cultivated No Rice (n=333)
PTO	x̄: 0.05 s: 0.23 missing: 42	x̄: 0.08 s: 0.27	x̄: 0.06 s: 0.23 missing: 10	x̄: 0.05 s: 0.23
STWO	x̄: 0.35 s: 0.48 missing:343	x̄: 0.44 s: 0.50 missing obs:83	x̄: 0.46 s: 0.50 missing obs: 58	x̄: 0.40 s: 0.49 missing obs: 240
SPO	x̄: 0.40 s: 0.50 missing obs: 68	x̄: 0.45 s: 0.50 missing obs: 16	x̄: 0.50 s: 0.50 missing: 8	x̄: 0.32 s: 0.47 missing: 10

Note: Data from IFDC- AAPI Household Survey 2015 Boro Season

Table 39: Summary of FDP Adoption Incentive Variables

AdoptionVariables	Question#	Description	Value	Summary Statistics ($\bar{x}$, s, n)	Min	Max
HGU	D21	Have you heard about guti fertilizer?	Yes=1, No=0	0.98, 0.14, 1667 Missing values: 333	0	1
GTechUseBF	D32	If the farmers used GU or GNPK on rice or non rice crops before cultivating in Boro 2015.	0= Not used before 2015, 1= used before 2015	0.48, 0.49, 2000	0	1
Training	E1	Did you receive any training on the use of guti fertilizer from AAPI?	Yes=1, No=0	0.36, 0.48, 1961 Missing values:39	0	1
DemoPlot	E3	Did you establish any demo plots on guti fertilizer with the support from AAPI?	Yes=1, No=0	0.10, 0.30, 955 Missing values: 1,045	0	1
FieldDay	E5	Did you attend any field day on guti fertilizer organized by AAPI?	Yes=1, No=0	0.31, 0.46, 1956 Missing values: 44	0	1

Pamph	E7	Did you receive any printing materials on guti fertilizer?	Yes=1, No=0	0.30, 0.46, 1956 Missing values:44	0	1
TechAdvice	E9	Did you receive any technical advice from guti fertilizer producers on GU use?	Yes=1, No=0	0.07, 0.26, 1951 Missing values: 49	0	1
RYI	F21	Rice yield increased due to use of guti fertilizer	Yes=1, No=0	0.98, 0.14, 959 Missing values: 1041	0	1
LessFinput	F22	Less urea fertilizer is needed than prilled urea for rice cultivation	Yes=1, No=0	0.99, 0.8, 959 Missing values: 1041	0	1
LowUsecost	F23	Low fertilizer use cost due to use of guti fertilizer in rice cultivation	Yes=1, No=0	0.98, 0.13, 959 Missing values: 1041	0	1

Table 40: Codebook

Socioeconomic Variables	Question#	Description	Value	Summary Statistics: ($\bar{x}$, s, n)	Min	Max
Sample Size: HHID	A1	Unique ID given to each HH	Randomized number	n: 2,000	10014	1250128
Gender	A10	Gender of respondent	Male=1, Female=0	0.96, 0.20, 2000	0	1
Age	A11	Age of respondent	Numerical	47.42, 13.33, 2000	18	90
Education	A12	Educational status in years	Numerical	4.52 , 4.13, 2000	0	17
Cultivate	C5	Cultivated rice during Boro 2015	Yes=1, No=0	0.83, 0.37, 2000	0	1

			Focal Variables			
Yield	D113 D114	Yield of rice per HH	Numerical Value (kg/decimal)	24.86 , 3.3, 1,667	7	55.76
Revenue	D113 D114 D115	The total revenue per decimal area of cultivated plots at HH level	Numerical Value	395.32 , 67.43, 1,667	91	892.12
AvgFertInp	D16-D18	Total average fertilizer input per area for each HH	Numerical (Kg/dc)	1.13, 0.37, 1,665	0.13	4.08
D1	D16 D17	Fully adopters: # farmers adopted FDP on all plots cultivated.	1= Fully adopted FDP 0= Did not adopt FDP	0.15, 0.35, 294	0	1
D2	D16 D17	Mixed adopters: # farmers used FDP and prilled broadcast on plots cultivated.	1= Partially adopted FDP 0= Did not adopt FDP	0.08, 0.27, 157	0	1

			Input variables			
TotPlots	C1	The total number of plots for each HH.	Numerical (decimal)	8.15, 4.37, 2000	2	39
TotPlotArea	C3	The area of total plots at the HH level.	Numerical (decimal)	212.40, 221.17, 2000	10	5864
PlotsCult	C5:	Did the farmer cultivate rice plots in Boro?	1=Yes, 0 =No	2.53, 2.37, 2000	0	18
CultPlotArea	D15	The plot area for the cultivated plots per HH.	Numerical	90.71 , 80.98, 1667	4	1000
SeedUseType	B11	Whether the farmers used modern, hybrid or local varieties	MV/Hybrid=1 Local Variety=0	0.89, 0.3, 1667	2	5
			Cost Variables			
PaddyPri	D114:	An average paddy price per HH.	Numerical (Tk/kg)	15.90 , 1.70, 1666	11.25	23.5
Ureapri	D111	The average price of urea aggregated per HH	Numerical (Tk/kg)	17.25, 1.08, 1826	15.5	22

GypsumUsers	B24:	Gypsum used as a chemical input for crop production.	Yes=1,No=0	0.90 , 0.29, 1999	0	1
ZincSulpUsers	B25	Zinc Sulphate used as a chemical input for crop production.	Yes=1, No=0	0.82 , 0.38, 1998	0	1
BoraxUsers	B29	Borax used as a chemical input for crop production.	Yes=1,No=0	0.31 , 0.46, 1,998	0	1
TracU	B32:1	Tractor used as a machinery input for crop production.	Yes=1,No=0	0.18, 0.38, 2000	0	1
PTU	B33:1	Power tiller used as a machinery input for crop production.	Yes=1,No=0	0.97, 017, 2000	0	1
STWU	B35:1	Shallow tubewell used as a machinery input for crop production.	Yes=1,No=0	0.64, 0.48, 2000	0	1

GUappU	B39:1	Guti applicator used as a machinery input for crop production.	Yes=1,No=0	0.02, 0.15, 2000	0	1
SpU	B310:1	Sprayer used as a machinery input for crop production.	Ownership=1,No ownership=0	0.95, 0.22, 2000	0	1
PTO	B33:2	Power tiller ownership as capital input for crop production.	Ownership=1,No ownership=0	0.06, 0.24, 1940	0	1
STWO	B35:2	Shallow tubewell ownership as capital input for crop production.	Ownership=1,No ownership=0	0.38, 0.49, 1276	0	1
SPO	B310:2	Sprayer ownership as capital input for crop production.	Ownership=1,No ownership=0	0.40, 0.49, 1898	0	1