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Rice planting technologies and farm performance under different production systems in Ghana

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Abstract

Purpose – This paper examines the performance of smallholder rice farms established using improved planting technologies – broadcasting, dibbling and transplanting – under different production systems – rain-fed and irrigation – in Ghana.

Design/methodology/approach – Using recent cross-sectional data of 200 smallholder rice farmers from the upper east region of Ghana, this study employed multinomial logit model and descriptive and inferential statistics for the analysis.

Findings – The results revealed that rice production under irrigation system contributes significantly to increasing farm productivity and profitability. Rice farmers who adopted dibbling and transplanting technologies under both irrigation and rain-fed production system obtained higher productivity and profitability than those who used broadcasting technology. Adoption of improved rice planting technologies by smallholder farmers is significantly influenced by education, farm size, improved rice varieties, sales outlets, hired labour and percentage of paddy sold.

Research limitations/implications – The sample size is relatively small, even though findings are still very important in terms of policy formulation for improved smallholder farm performance in a developing country like Ghana.

Practical implications – This study calls for collaborative efforts by government, donor agencies and NGOs to establish irrigation facilities and/or expand existing ones, increase sensitization and dissemination of improved planting technologies, as well as intensify the input subsidy programme in Ghana.

Originality/value – To the best of the authors knowledge, this is the first study that focuses on farmers' choice of rice planting technologies under irrigation and rain-fed production systems, and how these technologies impact on smallholder farm performance in Ghana.

Keywords Rice production systems, Improved planting technologies, Farm performance, Multinomial logit model, Ghana

Paper type Research paper

1. Introduction

Rice plays an important role in the economy of Ghana through its contribution to agricultural gross domestic product (GDP). It is the second most consumed cereal staple after maize and contributes massively to enhancing household food security in Ghana (Antwi and Aborisade, 2017; MoFA, 2015). However, rice farmers in Ghana and other African countries face challenges including but not limited to inadequate irrigation facilities, unpredictable rainfall pattern, incidence of pests and diseases, inadequate post-harvest storage facilities, low prices and competition from imported rice. These challenges contribute to low productivity and farm profitability (Chidiebere-Mark *et al.*, 2019). In addition, low productivity and profitability stem from inadequate access to improved production technologies and credit facilities to purchase adequate inputs for increased production (Bidzakin *et al.*, 2018).

Previous studies have noted that farmland intensification is one of the essential ways of increasing rice productivity and profitability in developing countries (Thakur *et al.*, 2009).

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Rice farmland intensification involves constant water supply, transplanting of seedlings, adequate spacing, soil aeration and maintenance of soil fertility, resulting in higher productivity relative to conventional methods like broadcasting of seeds with poor spacing and flooding the field constantly with water (Thakur *et al.*, 2009). Antwi and Aborisade (2017) revealed that many smallholder rice farmers in Ghana still use traditional methods of production including the use of rudimentary farm tools, cultivating indigenous varieties, producing on subsistence basis, broadcasting rice seeds, as well as depending on rainfall, which is generally erratic and unreliable. This contributes to low farm productivity and Ghana's inability to meet the rising demand for domestic rice (Abdul-Rahaman *et al.*, 2021; Antwi, 2016). Rice demand gap in Ghana is usually filled with imported rice from other countries, which increases government expenditure (MoFA, 2015).

The use of improved rice planting methods under irrigation production could be an essential way of ameliorating these challenges faced by smallholder rice farmers in developing countries. Bidzakin *et al.* (2018) and Abdul-Ganiyu *et al.* (2012) found that irrigation increases rice productivity and production to meet demand due to reliable water supply. Fortunately, implementation of government policies towards improving technology dissemination and adoption, as well as ensuring agricultural modernization is already ongoing in Ghana. Notable examples include "one village one dam", input subsidy and other agricultural development policies. However, these policies are still limited in terms of the number of targeted beneficiaries.

A considerable body of previous studies on rice production under irrigation and rain-fed production systems and their associated effects on farm performance has been documented in the empirical literature (e.g. Chidiebere-Mark *et al.*, 2019; Bidzakin *et al.*, 2018; Mabe *et al.*, 2018; Antwi and Aborisade, 2017; Antwi, 2016; Abdul-Ganiyu *et al.*, 2012). Chidiebere-Mark *et al.* (2019) examined the profitability of rice production under swamp, lowland and upland production systems in Ebonyi State of Nigeria. They found viability in profits associated with these three production systems, but the highest profit stemmed from rice production under swamp production system. Bidzakin *et al.* (2018) estimated the impact of irrigation ecology on rice production efficiency in Ghana, whilst Abdul-Ganiyu *et al.* (2012) assessed the efficiency and productivity of irrigated rice production in Ghana. Mabe *et al.* (2018), Antwi and Aborisade (2017) and Antwi (2016) focused on the productivity and profitability associated with rice production under rain-fed conditions in Ghana.

Empirical evidence on rice farm performance under irrigation and rain-fed production systems using different planting methods remain very crucial for policy formulation and targeting in Ghana but lacking in the existing literature. Previous studies focused on rice farm productivity through decomposing total factor productivity into technical and allocative efficiencies, scale effects and technological change in Indonesia (e.g. Mariyono, 2018). The main question that comes to mind is whether or not significant differences in farm performance exist in smallholder rice production under irrigation and rain-fed production systems using different planting technologies. Therefore, this study contributes to the growing body of evidence by examining the performance – farm productivity and profitability – of smallholder rice production under irrigation and rain-fed production systems using different planting technologies in Ghana.

Specifically, this study makes three contributions to the literature. First, we compare productivity and profitability of smallholder rice production under irrigation and rain-fed production systems to ascertain which of these systems contributes significantly to improved smallholder farm performance. Second, under each production system, we examine the contribution of different planting technologies – broadcasting, dibbling and transplanting – to smallholder rice productivity and profitability. Third, the paper examines the factors influencing smallholder farmers' decisions to adopt improved planting technologies for rice production. Findings from this study would contribute to the debate on agricultural modernization and rural economic transformation, as well as policy targeting on increasing smallholder incomes and reducing rural poverty in a developing country like Ghana.

We carried out this study in the Upper East Region of Ghana, which happens to be one of the major producers of rice and a major target for government and private organizations in terms of investment in the rice subsector. For example, the Tono Irrigation Project, located in the Kassena Nankana East District in Upper East Region, is one of the notable irrigation facilities in Ghana (GSS, 2019; ICOUR, 1995). The Tono irrigation dam was constructed between 1970 and 1980 to ensure all-year-round water availability for the cultivation of rice and other crops (soybean and tomato) (ICOUR, 1995). The project is managed by Irrigation Company of Upper East Limited (ICOUR), which was established by the Ghana Government to enhance the production of food crops by smallholders within an organized and managed irrigation scheme (ICOUR, 1995). This ensures that the dam is well-managed, and farmers under the scheme adhere to appropriate agronomic practices. For instance, ICOUR ensures that all rice farmers under the Tono Irrigation Project cultivate improved varieties, nurse and transplant seedlings, and sow seeds in rows.

However, the Tono irrigation dam can only serve few farming communities in the Kassena Nankana East District. Majority of the farmers in the district still depend solely on rainfall for rice production. Such farmers either broadcast or dibble rice seeds whilst few nurse and transplant seedlings. There could be discrepancies in rice productivity and farm profitability stemming from different planting technologies (MoFA, 2009). Also, environmental, technological and ecological dissimilarities lead to differences in farm outcomes from irrigated and rain-fed production systems (MoFA, 2009).

We structure the subsequent sections of this paper as follows. Section two presents a comprehensive review of literature on rice production systems in developing countries. Section three describes the methodology of the study highlighting on the data, sampling and the analytical framework. Section four presents the results and discussions. Section five highlights the conclusions and policy implications of the study.

2. Rice production systems in developing countries

Global rice production has increased substantially due to major increase in consumer demand, state subsidies and other forms of supports for farmers (FAO, 2018). Asia contributes about 80% of increment in rice production (Karimov *et al.*, 2019). However, rice production in Sub-Saharan Africa (SSA) is far behind global average (Karimov *et al.*, 2019). Production of rice and other food products per capita are growing slowly in SSA, making a lot of people highly susceptible to food insecurity (Meijer *et al.*, 2015). Feeding the growing population in SSA requires good policies and agricultural technologies that enhance production and productivity of food crops. Rice is a major staple and food security crop in Ghana (Antwi and Aborisade, 2017; MoFA, 2015). Construction of irrigation dams/schemes to enhance rice production all-year-round is an example of good agricultural policy, while improved rice planting techniques like transplanting is an example of good agricultural technology.

Though there are wetlands and lowlands which are appropriate for sustainable rice production (Fagnombo *et al.*, 2018), the cultivation and productivity of rice in SSA are negatively influenced by poor technologies (Amfo *et al.*, 2021), poor agricultural policies (Balasubramanian *et al.*, 2007) and low soil fertility (Sileshi *et al.*, 2007; Makumba *et al.*, 2006). In SSA, majority (about 90%) of rice are produced in lowlands, which are seasonally rain-fed. In Ghana and other West African countries, rice is usually produced in swampy areas as a result of inadequate irrigation dams (Amfo *et al.*, 2021). The average paddy yield in SSA, 1.27 tonnes per hectare, is far lower than that of Asia, 4.2 tonnes per hectare (Ishmael *et al.*, 2021). Among other challenges, this gap in rice productivity could be attributed to over-dependence on rain-fed production and poor planting technologies like broadcasting. Therefore, irrigation schemes and improved planting technologies like nursing and transplanting could be useful steps in improving rice productivity and farmers' income in Ghana and other SSA countries.

Rice could be cultivated under rain-fed or irrigated systems. Also, sowing of rice could be through seed broadcasting, dibbling or nursing and transplanting. Three rice cultivation systems are common in Ghana: lowland, upland and irrigated production (Amfo *et al.*, 2021). Rao *et al.* (2017) classified rice production systems and indicated that they affect farm performance. On the bases of soil water conditions, ecosystems for rice cultivation are irrigated upland, irrigated lowland, rain-fed upland, rain-fed lowland and deep water/floating ecosystems. Based on altitude, rice environment is classified as lowland, upland and deep water production systems. Based on source of water, there is irrigated and rain-fed rice production systems. Also, rice is produced under temperate, tropical and sub-tropical climatic conditions, and weather conditions differ, that is humid, sub-humid, arid and semi-arid. Rao *et al.* (2017) further classified rice cultivation systems on the bases of planting technologies: broadcasting, dibbling/direct seeding or nursing and transplanting.

Though the cost of production for irrigated rice system is higher than that of rain-fed, the former leads to higher productivity and profitability than the latter (Ishmael *et al.*, 2021; Hou *et al.*, 2019). Hence, the choice of rice farming systems influences productivity and income of farmers (Ishmael *et al.*, 2021). Thus, there is the need to assess and understand typologies of rice farming systems that enhance production and productivity, and drivers of farmers' decision to choose a rice farming system (Ishmael *et al.*, 2021). In Asia, intensive rice cultivation in irrigated areas is common compared with Africa. Nursing and transplanting of rice seedlings is rifer in Asia than Africa (Rao *et al.*, 2017). This leads to higher profitability through higher net returns per hectare in Asia than Africa (Hou *et al.*, 2019). Furthermore, rice cultivation using transplanting machines minimizes labour intensity and drudgery and enhances optimal rice plant population in Asia than Africa (Rao *et al.*, 2017).

In Ghana and other African countries, poverty reduction and food security essentially depend on sustainable food production (Rao *et al.*, 2017; Roy *et al.*, 2014). However, rice farmers face substantial threats from climate change, reducing availability of agricultural land, and decreasing water for irrigation (Rao *et al.*, 2017). Therefore, there is the need to adopt innovative rice production systems that ensure efficient use of resources, higher productivity and net income. This makes intensification of rice production through irrigation and transplanting essential (Thakur *et al.*, 2009).

A number of studies have investigated the determinants of farmers' choice of rice production systems and adoption of improved rice technologies in Ghana, SSA and beyond (Zakaria *et al.*, 2021; Donkoh, 2020; Abubakar *et al.*, 2019; Awuni *et al.*, 2018; Hagos *et al.*, 2018; Antwi and Aborisade, 2017; Ghimire *et al.*, 2015; Yemane, 2014). These empirical studies used socio-demographic, farm level and institutional characteristics, among others, of rice farmers to determine their choice of farming system and improved rice technologies. For instance, Antwi and Aborisade (2017) used age, gender, education, household size, farm size, price of inputs such as land, fertilizer, weedicides, labour and price of output to examine the factors influencing rain-fed rice farming of smallholder producers and profitability in Ghana. Zakaria *et al.* (2021) used farm size, off-farm income, membership in farmer organizations, contacts with extension agents and other socio-demographic characteristics to assess rice farmers' participation in irrigation in northern Ghana. Donkoh (2020) used sex, age, education, experience, farm size, off-farm, credit, farmer association membership and distance to farm to investigate the adoption of improved rice production technologies in northern Ghana. As a result, we used similar socio-demographic, farm level and institutional characteristics to examine the determinants of farmers' decision to adopt improved rice planting technologies.

In addition, others (Chidiebere-Mark *et al.*, 2019; Bidzakin *et al.*, 2018; Mabe *et al.*, 2018; Antwi and Aborisade, 2017; Antwi, 2016; Abdul-Ganiyu *et al.*, 2012; Mariyono *et al.*, 2010) examined farm performance under different rice production systems (irrigation and rain-fed) or planting technologies (broadcasting and transplanting) or swamp, upland and lowland production. For instance, Mabe *et al.* (2018), Antwi and Aborisade (2017) and Antwi (2016) focused on productivity and profitability of rain-fed rice. Chidiebere-Mark *et al.* (2019) assessed rice profitability under swamp, lowland and upland production systems. Bidzakin *et al.* (2018) investigated production efficiency of irrigation rice ecology. Abdul-Ganiyu *et al.* (2012) examined productivity and efficiency of irrigated rice in Ghana. These studies found variations in productivity, profitability and efficiency of rice under various production systems. Nonetheless, these studies did not provide empirical evidence on rice farm performance (productivity and profitability) of different production systems (rain-fed and irrigated) under different planting methods (broadcasting, dibbling and transplanting). This is very crucial for policy formulation and implementation in Ghana but lacking in the literature. Thus, this study contributes to knowledge by investigating rice productivity and profitability of irrigation and rain-fed production systems under broadcasting, dibbling and transplanting in northern Ghana.

3. Methodology

3.1 Data and sampling

The data employed in this study were gathered from a recent household survey of smallholder rice farmers in Kassena Nankana East District in the Upper East Region of Ghana in November, 2020. This district was selected because of the intensity of rice production in the area. Rice production is a predominant economic activity for majority of households in this district (GSS, 2019). As mentioned earlier, the district is blessed with the Tono irrigation dam, which is utilized by smallholder farmers to undertake all-year-round rice production. Nevertheless, the dam serves only few farming communities. Thus, some smallholder farmers engage in rain-fed rice production in the district.

In gathering the data, we employed a multistage sampling approach in selecting the rice farmers. In the first stage, a list of major rice farming communities in Kassena Nankana East District was obtained from the district Ministry of Food and Agriculture (MoFA) office. Simple random sampling was then employed in selecting 10 communities from the district. In the second stage, stratified sampling was used to categorize rice farmers in each community into two strata: rain-fed and irrigated rice farmers. Simple random sampling was further employed in selecting 20 rice farmers from each community. This constituted 10 each of rain-fed and irrigated rice farmers. In total, we sampled 200 rice farmers, constituting 100 each of rain-fed and irrigated farmers. A semi-structured questionnaire was used in collecting primary data through personal interviews with rice farmers. Six agricultural extension officers who were natives of Kassena Nankana East District assisted in the data collection after taking them through training on the survey instrument. During the data collection, all coronavirus (COVID-19) protocols like social distancing and wearing of face mask were observed by the enumerators and respondents.

3.2 Analytical framework

We used descriptive and inferential statistics (mean-comparison test like *t*-test), gross margin analysis, profitability ratios and multinomial logistic model (MNL) for the data analysis.

3.2.1 Profitability analysis and ratios. Following Boateng *et al.* (2016) and Aidoo *et al.* (2012), gross and net margins/returns were used as a measure of profitability.

Fixed assets were depreciated using straight line method without salvage value approach. With this approach, cost price was divided by useful life of asset.

Average prices and useful lifespan (years) of fixed assets obtained from rice farmers were used for computing depreciation (see Table 1).

Furthermore, financial viability and performance of rain-fed and irrigated rice production were assessed using profitability ratios – gross, operating and fixed ratios.

Profitability ratio of less than 1 implies a viable and profitable rice production business. Also, gross ratio and net margin ratio (%) were calculated to determine the contribution of each dollar (US$) of sales revenue to gross profits and net profits, respectively.

3.2.2 Multinomial logistic (MNL) regression. MNL regression is appropriate for categorical response variables with more than two outcomes, and the outcomes have no natural ordering (StataCorp, 2015). The response variable for the MNL regression is the various planting technologies (0 = broadcasting, 1 = dibbling, and 2 = transplanting). Hence, there are three outcomes, 0, 1, 2, recorded in y. According to StataCorp (2015), MNL regression estimates a set of coefficients, $\beta^{(0)}$, $\beta^{(1)}$, and $\beta^{(2)}$, corresponding to each outcome. This is expressed as follows:

$$\Pr(y=0) = \frac{e^{X\beta^{(0)}}}{e^{X\beta^{(0)}} + e^{X\beta^{(1)}} + e^{X\beta^{(2)}}} \quad (1)$$

$$\Pr(y=1) = \frac{e^{X\beta^{(1)}}}{e^{X\beta^{(0)}} + e^{X\beta^{(1)}} + e^{X\beta^{(2)}}} \quad (2)$$

$$\Pr(y=2) = \frac{e^{X\beta^{(2)}}}{e^{X\beta^{(0)}} + e^{X\beta^{(1)}} + e^{X\beta^{(2)}}} \quad (3)$$

However, the model is unidentified, since there are more than one solution to $\beta^{(0)}$, $\beta^{(1)}$and $\beta^{(2)}$, which results in the same probabilities for $y=0$, $y=1$ and $y=2$. Broadcasting of rice is an indigenous planting method, while dibbling and transplanting are improved planting methods. Thus, broadcasting was used as the base category (for comparison). To identify the model, $\beta^{(0)}$ was arbitrarily set to 0. The remaining coefficients, $\beta^{(1)}$(dibbling)and $\beta^{(2)}$(transplating), measure changes in rice planting method relative to $y=0$ (broadcasting). To better interpret the results, we compute marginal effects for the explanatory variables with respect to each planting technology.

4. Results and discussion

4.1 Socio-demographic and farm-level characteristics of rain-fed and irrigated rice farmers

Table 2 presents socio-demographic and farm-level characteristics of rain-fed and irrigated rice farmers under the three planting methods – broadcasting, dibbling and transplanting. The mean-comparison tests (*t*-tests) show statistically significant differences with respect to majority of these characteristics among rain-fed and irrigated rice farmers. Male farmers dominate rice production under both irrigation and rain-fed conditions, as well as under each of the planting technologies. This is attributable to the fact that male farmers are more likely to own productive resources – strength and capital – for rice production than females.

Table 1. Useful life (years) of fixed assets for computing depreciation

Fixed asset	Useful life (years)
Cutlass	3
Hoe	3
Knapsack sprayer	6
Wellington boot	3
Sickle/harvesting knife	4

Table 2. Socio-demographic and farm-level characteristics of rain-fed and irrigated rice farmers

Variable	Description	Rain-fed rice production (n = 100) Broadcasting (n = 53)	Dibbling (n = 35)	Transplanting (n = 12)	Aggregate (N = 100)	Irrigated rice production (n = 100) Dibbling (n = 22)	Transplanting (n = 78)	Aggregate (N = 100)	Full sample (N = 200)	Mean-comparison test (t-test)
Sex	Females	18.87	17.14	16.67	18.00	13.64	11.54	12.00	15.00	8.04***
	Males	81.13	82.86	83.33	82.00	86.36	88.46	88.00	85.00	
Age	Years	45.30	47.00	43.50	45.68	43.36	43.60	43.55	44.62	52.46***
Formal education	Years	4.87	10.09	12.25	7.58	4.18	7.81	7.01	7.30	19.38***
Farm size	Hectares	4.74	2.06	2.17	2.99	1.91	1.90	1.91	2.45	9.89***
Variety of rice	Local/ indigenous	71.70	34.29	0.00	35.33	27.27	5.13	10.00	30.00	4.16***
	Improved	28.30	65.71	100.00	64.67	72.73	94.87	90.00	70.00	
Sowing	Random	100.00	85.71	0.00	83.00	81.82	0.00	18.00	50.50	−0.10
	Rows	0.00	14.29	100.00	17.00	18.18	100.00	82.00	49.50	
Production system	Rain-fed	100.00	100.00	100.00	100.00	n.a	n.a	0.00	50.00	n.a
	Irrigated	n.a	n.a	n.a	0.00	100.00	100.00	100.00	50.00	
Planting method	Broadcasting	100.00	n.a	n.a	53.00	0.00	0.00	0.00	26.50	10.02***
	Dibbling/	n.a	100.00	n.a	35.00	100.00	n.a	22.00	28.50	
	Transplanting	n.a	n.a	100.00	12.00	n.a	100.00	78.00	45.00	
Production purpose	Subsistence	94.34	42.86	8.33	66.00	63.64	12.82	24.00	45.00	1.00
	Commercial	5.66	57.14	91.67	34.00	36.36	87.18	76.00	55.00	
Main labour source	Family	90.57	48.57	8.33	66.00	81.82	28.21	40.00	53.00	−0.60
	Hired	9.43	51.43	91.67	34.00	18.18	71.79	60.00	47.00	
Sales outlet	Wholesalers	54.72	77.14	25.00	59.00	72.73	61.54	64.00	61.50	−2.33**
	Retailers	45.28	22.86	75.00	41.00	27.27	38.46	36.00	38.50	
Marketing outlet	Farm gate	98.11	17.14	8.33	59.00	100.00	47.44	59.00	59.00	−1.81*
	Marketplace	1.89	82.86	91.67	41.00	0.00	52.56	41.00	41.00	

Note(s): n denotes number of observations. n.a. Denotes not applicable. *, **, and *** denote statistical significance at 10%, 5% and 1%, respectively

However, a higher proportion of female farmers are engaged in rain-fed rice production than irrigated production. The average age of a rice farmer is about 45 years. Rain-fed rice farmers appear older than farmers who produce under irrigation. Farmers who produce rice under rain-fed system are more educated and cultivate relatively larger farm sizes than those who produce under irrigation system for all the planting technologies. Education plays an important role in enhancing people's ability to process information, cognitive ability and propensity to undertake innovations (Amfo and Ali, 2020; Umidjon *et al.*, 2014). Education can enhance the adoption of improved technologies like transplanting (Mariyono, 2019b). Small farm sizes associated with irrigated rice production could be attributed to the extra costs of irrigation and labour intensive nature of dibbling and transplanting rice seedlings.

Generally, we observe widespread use (70%) of improved rice varieties by smallholder rice farmers. This could be due to the continuous efforts of agricultural extension officers, research institutions and non-governmental organizations (NGOs) in educating farmers on the benefits of cultivating improved crop varieties. Rice farmers under irrigation production system constitute a higher proportion (90%) who plant improved rice varieties, relative to those who cultivate improved varieties under rain-fed rice production system (65%). Farmers who dibble and transplant mostly planted improved rice varieties under both rain-fed and irrigation production systems. Local rice varieties are mostly (71%) planted by farmers who broadcast seeds.

Table 2 also reveals that irrigated rice farmers mostly plant in rows, carry out transplanting of seedlings and mostly depend on hired labour for their production activities as compared to rain-fed farmers. They also produce on commercial basis relative to subsistence production by rain-fed rice farmers. Rice farmers under most irrigation schemes in Ghana (like the one in the study area) are monitored by organizations to ensure that they undertake recommended agronomic practices like cultivation of improved varieties, sowing in rows and nursing and transplanting.

Also, extension officers, research institutions and NGOs educate farmers on the productivity impacts of planting improved rice varieties, row sowing and nursing and transplanting seedlings through awareness creation and field demonstrations. Nevertheless, the labour intensive and tedious nature of nursing and transplanting make some farmers still broadcast rice seeds. As shown in Table 2, majority of rain-fed and irrigated farmers sell rice to wholesalers, and at farm gate. Farmers prefer wholesalers because they purchase farm produce in bulk compared with retailers. Selling at farm gate reduces costs associated with transportation, loading and offloading, and market levies.

4.2 Productivity and revenue from rain-fed and irrigated rice production under different planting technologies

Table 3 presents productivity and revenue per hectare from rain-fed and irrigated rice production under various planting technologies. The *t*-tests show statistically significant differences with respect to productivity, revenues, quantity sold and paddy prices for rice production under rain-fed and irrigated systems. As shown, rice production under irrigation generates higher productivity (4,567 kg/ha), relative to productivity (2,086 kg/ha) derived from rain-fed production. In addition, farmers who adopted dibbling and transplanting technologies under irrigated rice production obtained significantly higher productivity compared to rain-fed producers. These findings suggest that rice production under irrigation using dibbling and transplanting technologies contributes significantly to improved farm productivity. This is due to availability of sufficient water throughout the critical stages of rice growth (CARD, 2010). According to Bidzakin *et al.* (2018), irrigated rice ecology leads to higher productivity than rain-fed ecology. Abdul-Ganiyu *et al.* (2012) also observed that rice yield is higher under irrigation due to reliable water supply.

Table 3. Productivity and revenue per hectare from rain-fed and irrigated rice production under different planting technologies

Item	Description	Rain-fed rice production (n = 100) Broadcasting (n = 53)	Dibbling (n = 35)	Transplanting (n = 12)	Aggregate (N = 100)	Irrigated rice production (n = 100) Dibbling (n = 22)	Transplanting (n = 78)	Aggregate (N = 100)	Full sample (N = 200)	Mean-comparison test (t-test)
Total output (kg)	Mean	10107.92	11383.26	18643.75	11578.59	16561.36	13287.44	14007.70	12793.14	15.05***
	Standard deviation	11670.97	7775.18	18849.93	11790.21	13023.81	11936.65	12192.55	12024.70	
	Minimum	2400.00	3000.00	4125.00	2400.00	3400.00	2250.00	2250.00	2250.00	
	Maximum	84000.00	37500.00	67500.00	84000.00	52800.00	67500.00	67500.00	84000.00	
Yield per hectare/productivity (kg)	Mean	1512.11	2384.40	3747.55	2085.67	3513.64	4863.85	4566.80	3326.23	28.04***
	Standard deviation	647.30	665.07	1102.93	1024.49	580.06	1194.76	1223.77	1677.48	
	Minimum	800.00	1200.00	1650.00	800.00	3000.00	3000.00	3000.00	800.00	
	Maximum	4500.00	4500.00	6000.00	6000.00	5000.00	7000.00	7000.00	7000.00	
Total quantity of rice sold (kg)	Mean	7856.79	9123.14	16907.50	9386.10	15161.82	12400.90	13008.30	11197.20	12.99***
	Standard deviation	12026.01	7041.71	19005.51	11885.37	13520.55	11928.37	12278.64	12189.19	
	Minimum	230.00	2300.00	700.00	230.00	2000.00	2000.00	2000.00	230.00	
	Maximum	83000.00	34000.00	66800.00	83000.00	52000.00	67200.00	67200.00	83000	
Quantity of rice sold per hectare (kg/ha)	Mean	1012.65	1869.46	3177.80	1572.35	2897.45	4371.67	4047.34	2809.85	24.31***
	Standard deviation	560.16	503.40	1113.15	949.14	610.27	1087.20	1172.63	1634.42	
	Minimum	96.64	1000.00	280.00	96.64	2000.00	2400.00	2000.00	96.64	
	Maximum	2333.33	3500.00	4600.00	4600.00	3893.33	6800.00	6800.00	6800.00	
	Mean % sold	66.97	78.40	84.80	75.39	82.46	89.88	88.63	84.48	39.87***
Price per kg (US$)	Mean	0.26	0.30	0.31	0.28	0.30	0.33	0.32	0.30	26.97***
	Standard deviation	0.09	0.07	0.06	0.08	0.04	0.06	0.06	0.07	
	Minimum	0.11	0.19	0.21	0.11	0.21	0.17	0.17	0.11	
	Maximum	0.51	0.54	0.41	0.54	0.38	0.54	0.54	0.54	

(*continued*)

Table 3.

Item	Description	Rain-fed rice production ($n = 100$) Broadcasting ($n = 53$)	Dibbling ($n = 35$)	Transplanting ($n = 12$)	Aggregate ($N = 100$)	Irrigated rice production ($n = 100$) Dibbling ($n = 22$)	Transplanting ($n = 78$)	Aggregate ($N = 100$)	Full sample ($N = 200$)	Mean-comparison test (t-test)
Total revenue (US$)	Mean	2004.02	2610.11	5603.59	2648.10	4429.29	4092.38	4166.50	3407.30	11.73***
	Standard deviation	3884.66	1672.67	6557.00	3865.97	4065.48	4284.43	4219.34	4107.47	
	Minimum	77.97	779.66	213.56	77.97	564.95	576.27	564.95	77.97	
	Maximum	28135.59	8103.81	22644.07	28135.59	15952.54	22779.66	22779.66	28135.59	
Revenue per hectare (US$/ha)	Mean	217.58	542.01	977.74	422.35	841.67	1405.31	1281.31	851.83	21.47***
	Standard deviation	85.67	121.67	347.96	295.45	137.98	382.38	415.72	561.06	
	Minimum	32.76	384.18	85.42	32.76	564.95	847.46	564.95	32.76	
	Maximum	401.94	779.66	1340.04	1340.04	1015.34	2166.78	2166.78	2166.78	

Note(s): n denotes number of observations. *** denotes statistical significance at 1%. *Exchange rate: US$1 = GH₵ 5.9 (GH₵ denotes Ghana cedis, the currency of Ghana)

However, lower rice productivity is associated with the use of broadcasting technology under rain-fed conditions. A number of reasons account for this finding. First, broadcasting impedes effective execution of recommended agronomic practices like control of weeds, pests and diseases, fertilizer application and replacement of seeds/seedlings that fail to germinate. Second, broadcasting of rice leads to lower plant density, resulting from poor germination, and overcrowding compared with dibbling and transplanting technologies. Conversely, agronomic practices can be carried out effectively under irrigated rice production, given the relatively small farm sizes, and the fact that dibbling and transplanting allow for easy execution of agronomic practices. As mentioned earlier, production activities of rice farmers under the irrigation project in the study area are monitored by ICOUR to make sure that farmers cultivate improved varieties, sow in rows and nurse and transplant seedlings.

As shown in Table 3, there are similar patterns of results in terms of the quantity of rice sold per hectare. Farmers who produce rice under irrigation sold significantly higher quantities of rice per hectare (89%), relative to the quantities sold by farmers under rain-fed production (75%). Moreover, irrigated rice farmers who used dibbling and transplanting technologies sold higher quantities than their counterparts engaged in rain-fed rice production. Rice farmers who transplanted under both irrigation and rain-fed systems sold about 90% and 85% of their harvested produce, respectively. Similarly, farmers who adopted dibbling under irrigation and rain-fed production sold about 82% and 78% of rice produce, respectively. Conversely, lower rice quantities per hectare (67%) were sold by farmers who used broadcasting under rain-fed conditions.

These findings confirm the important role of irrigated rice production system, as well as dibbling and transplanting in enhancing the commercial orientation of smallholder farmers in a developing country like Ghana. Our results are consistent with the findings by Abdullah *et al.* (2019), who reported that 63% of rice farmers participate in commercialization. Similarly, Martey *et al.* (2012) observed that commercialization of farm produce in Ghana is between 53% and 72%.

We also observe from Table 3 that higher paddy prices are received by farmers who produce under irrigation and also used transplanting than those who used broadcasting and dibbling under rain-fed production. This could be attributed to the fact that the latter probably sell their paddy during the harvesting period, and at farm gate, during which prices are relatively low. Revenue per hectare generated from irrigated rice production is higher (US$1281) than that of rain-fed production (US$422). Dibbling and transplanting under both irrigation and rain-fed conditions significantly contribute to increased revenue per hectare. However, the highest revenue per hectare is associated with these planting technologies under irrigated rice production. Farmers who broadcast rice under rain-fed system earned the lowest revenue per hectare (US$210). This could be attributed to the fact that the former undertakes agronomic practices effectively to obtain higher productivity, sell higher proportions of rice and sell at fairly higher prices than the latter.

4.3 Cost of rain-fed and irrigated rice production under different planting technologies

Table 4, Tables A1 and A2 report the cost per hectare of rain-fed and irrigated rice farmers under the various planting methods. We observe statistically significant differences in cost per hectare among rain-fed and irrigated rice farmers as indicated by the *t* tests. Total cost per hectare incurred in rice production under irrigation (US$515) is higher than that of rain-fed production (US$327). The cost per hectare of transplanting (US$541) and dibbling (US$423) under irrigated rice production is significantly higher than that of transplanting (US$465) and dibbling (US$375) under rain-fed production. The lowest cost per hectare is associated with broadcasting under rain-fed production. This suggests that irrigated rice farmers could

Table 4.
Cost per hectare of rain-fed and irrigated rice production under different planting technologies

Rice planting system	Labour cost	Input cost	Marketing cost	Total variable cost	Depreciated fixed cost	Total cost
	Mean amount (US$)					
Rain-fed						
Broadcasting	84.70	163.09	14.89	262.69	1.44	264.13
Dibbling	141.57	188.13	43.65	373.35	1.67	375.03
Transplanting	172.67	224.29	65.11	462.07	2.51	464.58
Aggregate	115.16	179.20	30.99	325.35	1.65	327.00
% Share	35.22	54.80	9.48	99.50	0.50	100.00
Irrigated						
Dibbling	134.71	244.23	41.79	420.72	2.57	423.30
Transplanting	165.24	295.33	75.97	536.54	4.67	541.21
Aggregate	158.52	284.09	68.45	511.06	4.21	515.27
% Share	30.77	55.13	13.28	99.18	0.82	100.00
Full sample	136.84	231.64	49.72	418.20	2.93	421.13
% Share	32.49	55.00	11.81	99.30	0.70	100.00
Test-statistics	48.98***	36.28***	22.68***	42.73***	13.37***	42.62***

Note(s): *** denotes statistical significance at 1%

purchase the required inputs and also undertake agronomic practices more effectively, which increase their production cost compared with rain-fed farmers.

Cost of planting was highest for rice farmers who transplant seedlings followed by those who dibble, whilst the cost of broadcasting was the lowest. This highlights the labour intensiveness of nursing and transplanting rice seedlings. Sowing and harvesting constituted the highest proportion of labour cost. Labour cost was highest for farmers who transplant rice seedlings, followed by those who dibble, and lowest for those who broadcast. Labour accounted for 35% and 30% of total cost of rain-fed and irrigated rice production, respectively. This highlights the relevance of labour in rice production. Irrigated rice farmers incurred higher cost of ploughing (tractor hiring) per hectare (US$95) than rain-fed farmers (US$46). This is because majority of irrigated rice farmers carry out rotavation, which is more expensive than ploughing. Costs of fertilizers and ploughing account for the highest proportion of input cost for rain-fed and irrigated rice production. Irrigation adds 6% to total production cost per hectare. Irrigated farmers incurred higher input cost (US$280) than rain-fed farmers (US$180). Cost of inputs accounted for more than half (55%) of production cost of irrigated and rain-fed rice farmers. This highlights the relevance of government and NGO support for rice farmers like fertilizer subsidy programmes, farm mechanization/tractor services, irrigation schemes (like "one village one dam"), subsidy on improved seedlings and other forms of input subsidies.

Rice shelling/threshing/winnowing and transportation (to store room, house or buyer/market) were the principal marketing costs (cost associated with post-harvest activities). Rice marketing cost of irrigated producers per hectare (US$68, 13% of total cost) was higher than that of rain-fed producers (US$30, 9% of total cost). Rice farmers in the study area produce on family, community or their own lands (usually inherited). Therefore, cost on land renting/hiring was zero. Fixed cost contributed less than 1% of total cost of rice production. Comparably, inputs contributed the highest proportion of rice production cost, followed by labour and marketing costs respectively, while fixed cost was the lowest.

4.4 Profitability of rain-fed and irrigated rice production under different planting methods

Table 5 presents the profitability of rain-fed and irrigated rice production under different planting technologies. The profitability measures considered in this study include gross

Table 5. Profitability of rain-fed and irrigated rice production under different planting technologies

Rice planting system	Gross margin	Net margin	Gross ratio	Operating ratio	Fixed ratio	Gross margin ratio (%)	Net margin ratio (%)
Rain-fed							
Broadcasting	−45.11	−46.55	1.214	1.207	0.0066	−20.73	−21.39
Dibbling	168.66	166.98	0.692	0.689	0.0031	31.12	30.81
Transplanting	515.67	513.16	0.475	0.473	0.0026	52.74	52.48
Aggregate	97.00	95.35	0.774	0.770	0.0039	22.97	22.58
F-statistic	78.32***	78.04***	8.50***	8.55***	3.56**	8.55***	8.50***
Irrigated							
Dibbling	420.95	418.37	0.503	0.500	0.0031	50.01	49.71
Transplanting	868.77	864.10	0.385	0.382	0.0033	61.82	61.49
Aggregate	770.25	766.04	0.402	0.399	0.0033	60.11	59.79
Test-statistics	21.05***	20.98***	−31.27***	−31.37***	−42.67***	48.50***	47.92***
Full sample	433.63	430.70	0.494	0.491	0.0034	50.91	50.56
Test-statistics	13.45***	13.40***	4.24***	4.19***	−13.96***	3.82***	3.69***

Note(s): **, and *** denote statistical significance at 5%, and 1% respectively margins, net margins, gross ratio, operating ratio, fixed ratio, gross margin ratio and net margin ratio. There were statistically significant differences in profitability among rain-fed and irrigated rice farmers, as well as profitability from the three rice planting technologies. Irrigated rice farmers earn significantly higher net margin per hectare (US$766) than rain-fed rice farmers (US$95). Moreover, farmers who carried out dibbling and transplanting under irrigation rice production generated significantly higher net margins, relative to those who dibble and transplant under rain-fed production. However, the highest net margins are received by rice farmers who transplant seedlings (US$864), followed by those who dibble (US$418) under irrigated production. Farmers who broadcast under rain-fed production experienced a net loss of US$46 per hectare. These findings are consistent with the study by Antwi and Aborisade (2017), who indicated that rice production in Ghana is profitable.

The plausible explanation for this finding is that irrigation ensures constant and adequate supply of water for proper growth and development of rice compared with rain-fed production which is mostly erratic and unpredictable (Abdul-Ganiyu *et al.*, 2012). Also, rice farmers who cultivate under the irrigation project in the study location are monitored by ICOUR who ensures that farmers cultivate rice timely, adopt improved varieties, sow in rows, nurse and transplant, and carry out other recommended agronomic practices as indicated earlier. Moreover, farmers who broadcast rice seeds are likely to obtain lower productivity due to poor plant germination rate and overcrowding compared with dibbling and transplanting technologies. These result in lower productivity of rain-fed production and broadcasting compared with irrigated production and transplanting. Rice farmers with higher productivity are more likely to sell higher quantities and thus, higher net margins. This explains why agricultural extension officers, research institutions and NGOs continuously educate farmers to nurse and transplant rice seedlings instead of broadcasting.

Profitability ratios – gross, operating and fixed ratios – have also been computed to assess the financial viability and performance of rain-fed and irrigated rice farmers under the various planting methods (Table 5). Generally, a profitability ratio of less than 1 suggests viability and a profitable farming venture. The gross ratio, operating ratio and fixed ratio computed under both irrigation and rain-fed rice production systems are positive and less than 1, although higher for rain-fed production. This finding suggests that farmers under these production systems have generated sufficient revenue to cover their production costs.

Similar trend of results has been observed with regards to the profitability ratios associated with the various planting technologies. In particular, the gross ratio, operating ratio and fixed ratio of farmers who dibble and transplant rice seedlings under irrigated and rain-fed production are positive and less than 1. This implies that such category of farmers have the ability to generate sufficient revenue to cover production cost (variable and fixed costs). The results in Table 5 further show that farmers who broadcast could only generate sufficient revenue to cover fixed cost. The computed gross ratio and operating ratio for such category of farmers are greater than 1, suggesting their inability to generate sufficient revenue to cover their production cost. These findings further confirm that rice farming is profitable. Our results is consistent with Adams *et al.* (2020) and Haruna *et al.* (2012), who found profitability ratios of less than 1 for tomato producers in Ghana and Nigeria, respectively. Darko-Koomson *et al.* (2020) and Wongnaa *et al.* (2019) reported higher profitability associated with cassava and vegetable production in Ghana, respectively.

We also computed gross margin ratio and net margin ratio, which are key performance indicators of profitability of farming enterprises. They were used to assess the contribution of each dollar (US$) of sales revenue to gross profits and net profits, respectively. The results are also presented in Table 5. Higher gross margin ratio and net margin ratio are always desirable since they indicate that rice farmers are generating more profits. Farmers under irrigation rice production experienced significantly higher gross margin ratio (60%) and net margin ratio (59%) than the gross margin ratio (23%) and net margin ratio (23%) obtained by rain-fed farmers. This means that every dollar of sales revenue contributes significantly higher percentage towards the gross profits and net profits for irrigated rice farmers relative to rain-fed farmers. We also observe significantly higher gross margin ratio and net margin ratio associated with dibbling and transplanting under irrigation rice production relative to these planting technologies under rain-fed production. In particular, under irrigation rice production, the results of the gross margin ratios indicate that every dollar of sales revenue contributes 50% and 62% to gross profits for farmers who adopted dibbling and transplanting, respectively, whilst rain-fed farmers experienced 31% and 53% contribution to gross profits for every dollar of sales revenue received.

Similar pattern of net margin ratio results has been obtained for farmers under irrigation and rain-fed rice production. The negative gross margin ratio (−21%) and net margin ratio (−21%) for rain-fed rice farmers who broadcast seeds implies negative percentage contribution to gross profits and net profits for every dollar of sales revenue, respectively. These findings indicate that as long as overhead costs is controlled, irrigated rice farmers and those who transplant seedlings can make reasonable net and gross profits on sales of rice than rain-fed farmers and those who dibble or broadcast seeds. Thus, the former is more efficient in the production and marketing of rice than the latter. This is consistent with Bidzakin *et al.* (2018) and Mariyono (2019a), who found that farm production under irrigation ecology are more efficient than rain-fed production. Mariyono *et al.* (2010) also observed that in Asian countries (e.g. Indonesia), wetland rice farming system is more productive than that of dry land.

4.5 Determinants of adoption of improved rice planting technologies

Table 6 presents the MNL results for the factors influencing farmers' decisions to adopt rice planting technologies – broadcasting, dibbling and transplanting. To better interpret the results, marginal effects have been computed for the explanatory variables. Based on the diagnostic model tests like the Wald test of combining adoption choice options and the suest-based Hausman test of independent of irrelevant alternatives (IIA), we fail to reject the null hypotheses. This suggests that rice farmers have been categorized appropriately based on the rice planting technology options.

Table 6. Determinants of adoption of rice planting technologies

	Rice planting technologies		
Variable	Broadcasting (base outcome) Marginal effect (*z*-value)	Dibbling Marginal effect (*z*-value)	Transplanting Marginal effect (*z*-value)
Sex (1 = male)	−0.046 (−0.84)	0.083 (1.28)	−0.036 (−1.09)
Age (years)	0.002 (1.16)	−0.002 (−1.15)	0.0001 (0.19)
Education (years)	−0.011 (−2.12)**	0.028 (3.13)***	−0.018 (−2.34)**
Farm size (hectares)	0.013 (2.18)**	−0.002 (−0.20)	−0.012 (−2.49)**
Variety cultivated (1 = improved)	−0.131 (−2.98)***	−0.009 (−0.12)	0.140 (2.42)**
Sowing (1 = rows)	−1.581 (−0.01)	0.415 (0.00)	1.166 (0.08)
Main labour source (1 = hired)	−0.048 (−0.75)	−0.099 (−1.15)	0.148 (2.61)***
Sales outlet (1 = retailers)	0.122 (2.87)***	−0.295 (−3.40)***	0.173 (2.29)**
Percentage of rice sold (%)	−0.006 (−1.26)	−0.003 (−2.15)**	0.004 (2.69)***
Number of observations			200
LR χ^2 (18)			307.000***
Pseudo R^2			0.718
Log likelihood			−60.299

Note(s): ** and *** denote statistical significance at 5% and 1% respectively

Education variable, which is measured by the number of years of schooling, exerts a significantly positive effect on dibbling of rice and significantly negative effect on broadcasting and transplanting. This suggests that farmers with higher number of years of schooling are more likely to dibble seeds and less likely to broadcast or transplant. This finding is in line with intuition as education plays an important role in informed decision making like adoption of improved technologies. Farmers with relatively higher farm sizes are more likely to adopt broadcasting and less likely use dibbling and transplanting. This is indicated by the positive marginal effect of farm size on broadcasting and negative effects on dibbling and transplanting. This finding reaffirms the labour intensive nature of dibbling and transplanting technologies, relative to broadcasting.

Table 6 also reveals the essential role of improved rice varieties in farmers' planting technology adoption decisions. In particular, rice farmers who plant improved rice varieties are more likely to adopt transplanting and less likely adopt broadcasting. This finding in line with intuition as adoption of improved varieties should be complemented with using improved planting methods for increased farm performance. The use of hired labour is associated with the adoption of transplanting, relative to broadcasting and dibbling, a finding that further confirms the labour intensive nature of transplanting. Also, farmers who sell their paddy to retailers are more likely to adopt broadcasting and transplanting and less likely to adopt dibbling. We also featured a variable representing percentage of rice sold by smallholder farmers to indicate the extent of commercialization. The results suggest that farmers who sold higher percentage of paddy are more likely to adopt transplanting and less likely to use dibbling and broadcasting. This is attributed to the fact that transplanting contributes to increased productivity and, consequently, higher quantities of paddy sold. In the context of this study, variables like age, sex and sowing (row sowing or random) play minor roles in improved rice planting technology adoption.

5. Conclusions and policy implications

Improved agricultural technologies continue to play important roles in enhancing agricultural modernization, ensuring poverty reduction, rural economic transformation, as well as improving farm performance in developing countries including Ghana. This study has contributed to the growing body of evidence by examining the role of improved rice planting technologies in enhancing smallholder farm performance – productivity and profitability – under rain-fed and irrigation production systems. The study also examined the factors determining the adoption of rice planting technologies – broadcasting, dibbling and transplanting – by smallholder farmers. The study relied on cross-sectional data obtained from a recent survey of 200 smallholder rice farmers in the Kassena Nankana District in the Upper East Region of Ghana. Descriptive and inferential statistics as well as MNL were used in the analysis.

The results revealed that rice production systems – rain-fed and irrigation – and improved rice planting technologies play essential roles in enhancing the performance of smallholder farmers in Ghana. Rice production under irrigation contributes significantly to increasing productivity and profitability measures such as gross margins, net margins, gross ratio, operating ratio and fixed ratio, as well as gross margin and net margin ratios, relative to rice production under rain-fed system. Irrigated rice farmers incurred higher production costs, received higher prices, sold higher quantities of paddy and generated higher revenue per hectare than rain-fed rice farmers.

Higher farm performance is associated with the adoption of improved rice planting technologies. Rice farmers who adopted dibbling and transplanting under both irrigation and rain-fed production system obtained higher productivity and profitability than those who used broadcasting. However, the highest productivity and profitability is associated with the use of transplanting under irrigation production system. These findings indicate that smallholder rice farmers who produce under irrigation using dibbling and transplanting significantly benefit from improved farm performance. Adoption of improved rice planting technologies by smallholder farmers is significantly influenced by education, farm size, improved rice varieties, sales outlets, hired labour and percentage of paddy sold. More educated farmers and those planting improved rice varieties and sell higher quantities of paddy to retailers are more likely to transplant rice.

The findings from this study call for a number of policy recommendations to improve smallholder farm performance and overall rice production. The important contribution of irrigation necessitates collaborative efforts by government, donor and private agencies to establish irrigation facilities and/or expand existing ones to ensure all-year-round rice production and increased farm performance in Ghana. Moreover, increased sensitization and dissemination of improved planting technologies by both public and private agricultural extension agents would contribute to ensuring increased farm productivity and profitability of smallholder farmers. Finally, the high input cost identified by this study calls for government intensification of the input subsidy programmes to enhance farm productivity.

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Appendix

Cost item	Mean amount (US$) Rain-fed rice production (n = 100) Broadcasting (n = 53)	Dibbling (n = 35)	Transplanting (n = 12)	Aggregate (N = 100)	% share
Planting/sowing	8.41	53.75	80.37	32.92	10.07
Fertilizer application	8.73	14.72	14.97	11.58	3.54
Weeding application	16.18	18.62	17.73	17.22	5.27
Insecticide application	3.18	3.20	3.11	3.18	0.97
Bird scaring	6.98	6.92	12.15	7.58	2.32
Harvesting	41.22	44.36	44.35	42.69	13.06
Total labour cost	*84.70*	*141.57*	*172.67*	*115.16*	*35.22*
Ploughing (tractor hiring)	43.62	48.82	50.26	46.24	14.14
Irrigation	n.a	n.a	n.a	n.a	n.a
Seeds for planting	22.39	19.15	15.40	20.42	6.24
Fertilizers	63.21	82.45	112.27	75.83	23.19
Herbicides	25.24	30.03	34.96	28.08	8.59
Insecticides	8.64	7.69	11.41	8.64	2.64
Total input cost	*163.09*	*188.13*	*224.29*	*179.20*	*54.80*
Shelling, threshing	6.87	12.67	21.54	10.66	3.26
Sacks for bagging	2.43	5.00	7.12	3.89	1.19
Bagging	1.91	3.52	5.98	2.96	0.91
Loading, offloading, levies	0.03	2.25	4.46	1.34	0.41
Transportation	3.66	20.20	26.01	12.13	3.71
Total marketing cost	*14.89*	*43.65*	*65.11*	*30.99*	*9.48*
Total variable cost	*262.69*	*373.35*	*462.07*	*325.35*	*99.50*
Cutlass	0.35	0.38	0.60	0.39	0.12
Hoe	0.30	0.33	0.40	0.32	0.10
Knapsack sprayer	0.38	0.37	0.50	0.39	0.12
Wellington boots	0.24	0.37	0.73	0.34	0.10
Sickle/harvesting knife	0.18	0.23	0.28	0.21	0.06
Total fixed cost	*1.44*	*1.67*	*2.51*	*1.65*	*0.50*
Total cost	*264.13*	*375.03*	*464.58*	*327.00*	*100.00*

Table A1.
Cost per hectare of rain-fed and irrigated rice production under different planting technologies

Cost item	Mean amount (US$) Irrigated rice production (n = 100) Dibbling (n = 22)	Transplanting (n = 78)	Aggregate (N = 100)	% share	Full sample (N = 200) US$ Cost	% share	Mean-comparison test (t-test)
Planting/sowing	54.70	78.88	73.56	14.28	53.24	12.64	25.63***
Fertilizer application	10.17	16.05	14.75	2.86	13.17	3.13	24.34***
Weeding application	16.91	17.75	17.57	3.41	17.39	4.13	51.32***
Insecticide application	6.59	5.73	5.92	1.15	4.55	1.08	15.21***
Bird scaring	7.74	10.68	10.03	1.95	8.80	2.09	8.44***
Harvesting	38.60	36.16	36.69	7.12	39.69	9.42	54.56***
Total labour cost	*134.71*	*165.24*	*158.52*	*30.77*	*136.84*	*32.49*	*48.98****
Ploughing (tractor hiring)	76.15	101.05	95.57	18.55	70.91	16.84	30.26***
Irrigation	29.32	29.32	29.32	5.69	14.66	3.48	n.a
Seeds for planting	20.65	16.60	17.49	3.39	18.95	4.50	81.25***
Fertilizers	71.60	96.26	90.83	17.63	83.33	19.79	18.04***
Herbicides	30.58	36.21	34.97	6.79	31.53	7.49	22.11***
Insecticides	15.93	15.89	15.90	3.09	12.27	2.91	13.35***
Total input cost	*244.23*	*295.33*	*284.09*	*55.13*	*231.64*	*55.00*	*36.28****
Shelling, threshing	19.64	29.64	27.44	5.33	19.05	4.52	24.20***
Sacks for bagging	7.14	10.89	10.07	1.95	6.98	1.66	19.59***
Bagging	5.46	8.23	7.62	1.48	5.29	1.26	23.91***
Loading, offloading, levies	0.00	3.67	2.86	0.56	2.10	0.50	9.78***
Transportation	9.55	23.53	20.46	3.97	16.29	3.87	19.31***
Total marketing cost	*41.79*	*75.97*	*68.45*	*13.28*	*49.72*	*11.81*	*22.68****
Total variable cost	*420.72*	*536.54*	*511.06*	*99.18*	*418.20*	*99.30*	*42.73****
Cutlass	0.47	0.90	0.81	0.16	0.60	0.14	13.86***
Hoe	0.47	0.81	0.73	0.14	0.53	0.13	12.73***
Knapsack sprayer	0.92	1.39	1.29	0.25	0.84	0.20	9.25***
Wellington boots	0.43	1.13	0.97	0.19	0.66	0.16	7.17***
Sickle/harvesting knife	0.28	0.44	0.41	0.08	0.31	0.07	10.56***
Total fixed cost	*2.57*	*4.67*	*4.21*	*0.82*	*2.93*	*0.70*	*13.37****
Total cost	*423.30*	*541.21*	*515.27*	*100.00*	*421.13*	*100.00*	*42.62****

Note(s): n denotes number of observations. n.a. Denotes not applicable. *** denotes statistical significance at 1%. The mean-comparison test (t-test) gives the statistical differences in cost between rain-fed and irrigated rice production

Table A2.
Cost per hectare of rain-fed and irrigated rice production under different planting technologies

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