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RESEARCH ARTICLE

AN ECONOMIC ANALYSIS OF RICE PRODUCTION ACROSS AUS, AMAN, AND BORO SEASONS: A FARM-LEVEL COMPARATIVE STUDY IN NATORE DISTRICT, BANGLADESH

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ABSTRACT

This study attempts to measure and compare the profitability and output responsiveness differences to changes in input levels for three major rice growing seasons, Aus, Aman and Boro, in Natore district of Bangladesh. A rigorous methodology using farm level cross-sectional data is utilized in the study for measuring the profitability by estimating the per acre value (revenue) of the output and the respective costs involved. Statistical analysis of variance ANOVA is used to find out the significance of the differences in revenue pertaining to the three rice growing seasons is done and by use of the full post-hoc Tukey tests is extended further. To find out the factors generating differences in output it is proposed to use a log-linear regression (with interaction terms) model so that both the main effects of the inputs can be inserted as well as the varying sensitivities of the different rice growing seasons to those inputs can be comprehended. The results showed that the Boro rice gives a revenue that is significantly, greater than the Aus and Aman rice produced principally because of its greater responsiveness to greater input use of fertilizers, irrigation and pesticides and herbicides etc. On the other hand, the Aman is used as a baseline rice season and subsequently is not very sensitive to input use, whilst the Aus is the least responsive of all the different rice growing seasons. Interrelationship of the input-output relationships further shows that the variance in this can be very pronounced for the Boro season particularly with regards to irrigation and ploughing cost. This study contributes to the financial literature by incorporating a profitability analysis along with an elasticity-based production model used for the various rice growing seasons. This study shows farmers how to use the information to produce profitability and how policy makers can be informed about the possibilities of the optimum levels of input use if farmers are to improve profitability.

KEYWORDS

Economic performance, Farm-level analysis, Rice Cultivation, Bangladesh agriculture

1. INTRODUCTION

Agriculture is a vital sector for Bangladesh's economy, significantly affecting food production, rural income and employment. This sector's contribution to the national GDP was about 11.5 percent (at constant prices) in 2021-2022 and about 40.6 percent of the labour force engaged in agriculture (BBS, 2022a). Agriculture is, therefore, necessary not only for economic reasons, but also as an essential source of income for rural areas, is the stimulus to the growth of small and medium-sized agro-based enterprises and combines that labour-intensive production methods can be adopted with relatively small capital inputs, making it an essential part of sustainable economic growth (Quddus, 2018). Therefore, increasing agricultural productivity and profitability is not only a desirable aspect, but a necessity of sustainable advancement, reduction of poverty, source of food product. In Bangladesh rice is not only the predominant agricultural crop, but also the focal point of the nation's agriculture. The major rices, Aus, Aman and Boro, are grown in different periods during the year. Rice constitutes over 45% of the expenditure on food in the rural areas and 33% of that of the urban population (Siddique et al., 2020). This in itself shows the importance of rice both economically and in the nutrition sense. Despite the importance of rice to the Bangladeshi economy, food shortages are a severe drawback, and the nation has to import immense amounts of rice. In 2021-22, rice imported for Bangladesh was to the amount of 987.41 thousand metric tons (MoF, 2022). Population is increasing, preferences in food products are altered (as more wheat and maize is being produced (Timsina et al., 2018). Thus rice security is essential to ensure that Sustainable Development Goals (SDG) are relevant, particularly Goal No. 1: 'No Poverty', and no. 2: 'Zero Hunger'. Bangladesh is faced with enormous problems in providing for agricultural output. High population density, urbanisation and environmental destabilisation are factors which limits the amount of cultivable lands available, whilst climate change adds to the effects. With an increase in annual growth rate of population of 1.22% (BBS, 2022b), the demands for production of food will progressively increase. Annually, the nation is losing about 0.19% of its arable land through industrialisation, urbanisation and increase in infrastructure (Rai et al., 2017; BBS, 2022b). There are now competing land requirements through items like jute and cotton (which are high economic crops) and the establishment of commercial vegetable orchards, including such fruits as

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mango and guava, and beef production extended (Rakibuzzaman et al., 2018 ; MoA, 2022 ; Datta et al., 2019). Under these circumstances the efficient use of exploitable land is a prime necessity.

It is, therefore, important to get information on the most profitable and efficient rice. It is this information that will enable policy makers and farmers to utilize land in a most profitable way. In earlier research works, the important roles played by rice, as a food staple, as a means of employment and as an important item of trade have been stressed (Dawe, 2010 ; FAO, 2003). But, as yet, there exists a full lack of empirical evidence on the comparative profitability and input responsiveness of the major rice crop seasons in the natural farming conditions of Bangladesh. This study is trying to fill this gap by analysing the economic performance and profitability of the different rice crop seasons. Thus, the aims of the research would be to compare profits, assess the differences in value of outputs and analyse how output varies with change of relevant inputs in the case of the three seasons of the rice crops. This research will show some of the major differences in input/output relationships for the rice crop seasons and lead to important information for the farmer and guide the policy maker to the most advisable directions for the sustainable production of rice in Bangladesh.

The remainder of the paper is organized as follows. Section 2 contains a literature review of relevant studies, discusses important empirical results, identifies gaps in the research that exist, and explains the purpose of this study. Section 3 describes the research site, discusses the collection of data, describes the important variables and the ways in which profitability was measured. Section 4 explains the analytical framework, specifies models used and states the hypotheses. Section 5 gives empirical results and describes the interpretation of results whereas Section 6 concludes the study with summary of findings, implications for policy, and recommendations for future research.

2. Literature Review

Knowledge concerning the relationship of output to input and the profit potential of the agricultural industry is essential in any nation's preparations for agricultural sustainability and the rural economy, especially in the case of overpopulated and badly endowed countries like the Republic of Bangladesh. There has been a large body of research on the factors concerned with farm efficiency including profitability indices and climatic changes and situations for adaptation in rice growing countries throughout the world. On the profitability of rice production in the northern Ghana (Zakaria et al., 2021). The results of this investigation were that there were significant differences in profit possibilities in irrigated rice and rain-fed rice growing. The profits from irrigated rice growing were three times the profits from rain-fed rice growing. The benefit-cost ratio (BCR) in the case of irrigated rice growing was twice as large as that from rain-fed rice growing. Comparative research on the profitability in rice production systems in Kwara State, Nigeria (Oloyede et al., 2021). One hundred and twenty households were used in the investigation. The gross return per hectare was greatest in the case of the combination production system, less in the case of the lowland production system and still less in the case of highland production systems. Enumerative growth analysis and profitability in the case of the state of rice production in India from 2001-2019 (Singh et al., 2021). This state was one of the major rice growing states of India. Both production and productivity growth rates were positive. Almost all of the states had negative profitability in rice production for the preferred census output.

Long and Yabe included environmental factors in their estimations of the profitability of rice growing in the case of Vietnam. Profitability was determined through the use of both the OLS and MLE trans-log profit functions which involved five production factors and four environmental factors, thereby being able to route stochastic profit frontier estimations as well as a two-situation performance in determinations of profit. The results of their investigation and the outcomes shows that environmental factors have a great and definite influence on profit efficiency considering that the average profit performance was almost 75 per cent. Production and productivity studies of rice growing in the various states of India, employing secondary research data from 1970-2016 (Samal et al., 2018). Their results showed that while the cost of production has increased, there has not been a corresponding increasing factor in profits. The use of resources and productivity to rice production in the Terai area of Nepal (Shrestha et al., 2022). Here 360 households were selected at random from three important rice growing areas. The results of their conclusions show that total cost and revenue per hectare were higher in the case of spring production of rice than in the case of the monsoon season rice growing, thereby establishing a BCR of 1.63 as compared to that of the monsoon production. The information showed that such important factors as cost of seed, fertilizers and insecticides have been underutilized in most cases. The economic analysis of rice production in the Rautahat District of Nepal, employing a random sampling of 80 rice producing farmers (Sapkota et al., 2020). The cost-benefit ratio (BCR), in this case gave a figure of 1.11. The return to scale given was also 0.96, meaning a return has been dropping off.

Various studies have been conducted in Bangladesh regarding the profitability of rice cultivation. The profitability varies depending on the size of the farms, region or locality of farms and also according to the various varieties of rice. There is a group of studies in which farmers of different sizes are compared with one another regarding profits. The research proved in their studies that large farmers are more profitable than small and medium farmers (Akter et al., 2019). But on the contrary the study in the coastal Satkhira district shows that small farmers are more profitable than medium and large farmers (Islam et al., 2017). Again, the income and expenditure surveys of households for the period of 2000 to 2010 and have found that small farmers are faced with more decline in profit in emerging course than large farmers (Mottaleb and Mohanty, 2015). Another branch of studies is those, which have been made regarding the regional differences and differences in the conditions of different productions. The profitability of Boro rice cultivation in the regions of North-West of the country and have found wide differences in the profitability of different sites (Mainuddin et al., 2021). The high yielding varieties of rice (HYVs) have had better profitability as a system for out-put. The profits of coastal and agricultural lands (Akter and Islam, 2024). They have found that the agricultural areas are producing profits which are nearly double than those of coastal areas on account of the high costs of production which rise in case of seeds, irrigation and labours, the locations in connection with profitability, while confirming in their studies that the small farms in the wetlands of the Sunamganj district generate greater profits from Boro rice compared with the larger farms (Ahmed et al., 2025). Certain studies have been made regarding profits from different varieties and different types of rice. 400 households of four districts connected with hybrid rice cultivation have observed decreasing cultivated area with a dropping rate of –2.52% because of increasing prices of seeds and pest activities (Anwar et al., 2021).

On the other hand, a benefit-cost ratio (BCR) of 1.93 for drought resistant varieties of rice, thus being very profitable (Sultana et al., 2023). In the meantime, there was a good profit from the production of aromatic rice in Dinajpur (Tama et al., 2015). On the other hand, the production of rice seeds in the Dhaka division does not seem to be a good investment (Hoque and Haque, 2014). But the district investigations are, on the whole, an aid to show that rice cultivation is profitable. Otherwise shown that for Boro rice undertaking in Mymensingh BCR is = 1.29 (Rasha et al., 2018). Hence, economic suitability is assured. Likewise, rice cultivation profits were prevalent in Bogura and Gaibandha, the BCR being in the plus luckily on the total cost and variable cost bases (Siddiquee et al., 2018). While investigating a rice procurement program, couldn't but show that the profits of the farmers did better by a good measure if they were participating in the compulsion program as those not in (Rahman et al., 2020). Study of longer period shows satisfactory results. Time series from 1981 to 2011 and shown how area sown to Aus and Aman rice has diminished, while the cultivated area under Boro rice has increased so much, that the total production also, has been considerably raised (Khalique et al., 2019). The cultivation expenses have been increasing all the years past, while the profits have not gone up accordingly (Samal et al., 2018). The totality of these investigations gives a good general view of the rice profits realization in the country, being controlled by the size of the farm, circumstances of culture, kind of rice and changing condition supplying. Rice making is on the whole good profits, seen lightly, but the profits are not of that uniform character. The smaller cultivators, the cultivators along the coasts of the wayside, the cultivators of hybrid rice are at more disadvantage than the others.

Many empirical research works have looked at adaptive and mitigative farm-level strategies in Bangladesh, including areas of crop diversification, Climatic responses and profitability. Adaptation of drought-prone farmers of one of the important regional areas of the West, their profitability and some of the problems one finds (Kabir et al., 2017). Their studies have shown that the climatic perceptions of the farmers about the climatic changes they found (as say for example higher temperatures and lower rain-falls) were in accord with the actual climatic results that the farmers found. Because of this, the effects of climatic change and the agro-ecological conditions and socio-economic characteristics, and their effects upon agricultural productivity and efficiency (Rahman and Anik, 2020). They found that land was the first factor of importance to explain agricultural productivity, while labour and irrigation were the next two important factors. In this study, the effects of Climatic change upon the crops grown by farmers, of the Statistics which were collected from 11,389 households for the years 2000, 2005, and 2010 (Moniruzzaman, 2015). In fact, it was found that the crops grown had a very strong relation with climatic condition. The farmers of the wet-regions adopted the rainfed Aman rice crops in relation to crops grown. While in the drier-regions of the country irrigation was found to be adopted to grow Boro Rice. In the study of the adaptation strategies at the farm level have been carried out, 1,800 households dealing with climatic conditions characterised with drought and aquifer put-resources in three climatic belts, has been looked in their study (Alauddin and Sarker, 2014). The farmers have adopted various strategies to grow the crops of drought resisted rice in various localities. It was found that non-rice crops had been diversification in order to aid the Climatic change as well. The research has also been made in adoptive measures to certain varieties of rice for identifying its result in various alters of climatic conditions. In the case of hybrid rice have shown the use of rice, what are its use factors for adoption, viz., they studied productivity and efficiency of the rice wherein by gross return from lands were great (Azad and Rahman, 2017). These were encouragement for grow easier and also, frequent productivity of rice, which were paternal in its investment procedure, while when trying its proceedings and obstruction of labour and increase of fertilizer of phosphorus. Climatic conditions of Aus, Aman and Boro crops from the years 1972 to 2009, previously to Just-Pope production functions having its crops been found above their level, i.e., there is diversity as regards crop (Sarker et al., 2014). Increase maximum temperature if various conditions of climate is a necessity to improve produces of Aus and Aman rice wherein deals from lesser improvement in principate of productiveness in a lesser yield of Boro's yield.

Most studies have examined the profitability and efficiency of rice farming in Bangladesh, but these have tended to be based on one type of rice or on summarized data without distinguishing between seasons or revelations (Aus, Aman, and Boro). The literature also does not show how these kinds of rice react differently to particular inputs or how the input-output relationships might differ among them. This study is important because it attempts to fill these gaps by making a comparative study of the three rice seasons, which may have a far-reaching effect in improving the agricultural practices of Bangladesh. The specific objectives are to: (i) study the differences in profitability; (ii) study the differences in revenue, particularly pairwise differences between the seasons; and (iii) study the use of inputs and the relationships between inputs and outputs in order to determine the extent to which the increase in the use of particular inputs differs in the various rice seasons.

3. Data Description And Method Of Measuring Profitability

This section examines the various sources of data, the scope of the study, the variables concerned, and the methodology adopted in order to achieve the aims of the study. The hypotheses are also presented under which rice varieties are evaluated in terms of profits, output and output elasticity to amount of inputs used.

3.1 Study area and data collection procedure

This research was carried out in the Gurudaspur Upazila of the Natore district, a significant agricultural area in northern Bangladesh. The region was specifically chosen because of its extensive cultivation of the three primary rice seasons—Aus, Aman, and Boro—facilitating a comparative analysis of their economic outcomes within a similar agro-ecological context. The study used a multistage random sampling method to determine the sample population. Initially, Gurudaspur Upazila was selected based on its characteristics in rice farming. In the final selection stage, a total of 150 households engaged in rice cultivation were randomly chosen for survey interviews.

In the selection of the sample, a purposive method was adopted so that there was a sufficient number of farmers cultivating the Aus, Aman and Boro seasons of rice so that comparative results might be obtained in the research work in other rice seasons. The field work was by structured interviews conducted with a pre-tested questionnaire securing exhaustive information on the production resources (land, seeds, labour and manures) costs, etc., and market value of the outputs in respect of the various rice seasons. The exhaustive character of this collection of information was intended to make sure of what factors were involved. After the collection of the data had been made they were thoroughly cleaned and sorted and the data tested for correctness and completeness before being submitted to the forms of analysis planned for them.

3.2 Descriptive variables and unit of measure

The principal variables engaged in the analysis are given in Table 1 which sets out the units of measure and explains the definitions of the variables used. The variables discussed relate to the outputs, the costs of inputs, land use and co-products. All variables were recorded in BDT (Bangladesh currency) and converted to America dollars (US$) with an average exchange rate for the relevant time period for data collection. This conversion was made to ensure consistency and to facilitate international comparisons.

Output values are primarily determined by the market value received from the rice produced per acre, supplemented by the straw produced which is an important byproduct that adds to the total income of the farm. The main items which cause variations in output are associated with the land area cultivated, seed and seedling expenses and the costs of ploughing and planting and hired labor. The variable cost items include the cost of fertilizers, insecticides, herbicides, irrigation, machinery, harvesting and post-harvest expenditures including drying. In accounting for the land rent or expense we include not only that handicapped, but also the value of land owned as having a rental value. The family labor, though unpaid, has been given a market value of labor prevailing in this vicinity. The result is that all of the elements taken together lead one to an understanding of the economic, production and resource relationship of rice production which is necessary for a thorough comprehension of the profitability of rice production that is not only illuminating, but convincing.

Table 1: Description of Variables and Units of Measurement

Variable	Unit of measurement	Description
Main product (rice)	US$/acre	The market value of rice produced per acre. This is the main measure of agricultural production and is a direct expression of the economic returns from rice farming.
By product (straw)	US$/acre	The market value of straw, a by-product of the rice cultivation process, is an important item in the study of profitability. Being used in various other agricultural practices and as fodder for animals, straw, while assisting in the matter of sustainability, provides a source of additional income from sales of the by-product, such being a very tangible asset to farmers in their efforts to increase levels of his factor of production.
Land	Decimal	The cultivated area is an important factor in deciding the cost and income per acre. The problem of the amount of land utilized, being a fixed factor, has a direct influence on profitability.
Seed and seedling costs	US$/acre	This is the cost of purchasing the seed and all expenses until things are ready for planting. This variable cost's structure influences the growth of the plant, and the quantity and quality of the yield of the crop. Higher standards of seeds may mean a slightly higher cost, but the return usually is greater.
Ploughing and planting costs	US$/acre	This is the cost of preparing the ground before it can be seeded or seedlings planted. This is a variable cost structure implying the operating cost of getting the ground ready for the crop.
Hired labour cost	US$/acre	It represents the cost of hiring external workers to carry out essential farm activities like planting, weeding, harvesting, other field work. It is a significant item in the variable cost analysis and the proportion of total cost attributable to it varies according to the extent of mechanization and the labour market conditions.

Table 1 (cont): Description of Variables and Units of Measurement		
Fertilizer cost	US$/acre	The fertilizer costs bear upon the expenses incurred on chemical or organic fertilizers which increase soil fertility and thus rice output.
Pesticide and herbicide costs	US$/acre	The pesticide and herbicide costs relate to the expenses incurred on chemicals and organic compounds used to control insects, diseases and weeds which might interfere adversely with rice output.
Irrigation costs	US$/acre	The irrigation costs refer to expenses incurred on account of water irrigation, namely, electricity, fuel and water charges, the level depending on irrigation methods resorted to by farmers.
Machinery costs	US$/acre	The machinery costs refer to expenses relating to machinery, which cover the hire charges on hire purchase or the depreciated value of machinery, like sprayers, tractors, harvesters, etc., which are used in various agricultural operations, such as weeding, ploughing, harvesting, etc.
Harvest costs	US$/acre	The harvest costs refer to the expenses incurred on the harvesting of rice consisting of the actual expense incurred in harvesting and payment for equipment needed during this phase of production.
Drying costs	US$/acre	The drying costs refer to the expenses incurred to remove excess moisture from the harvested crop to an acceptable level for storage or marketing.
Land rents	US$/acre	The land rents refer to the amounts paid for land rented for rice growing purposes or rents given direct to the landowner or an imputed value of owned land without regard to whether any actual payment is made.
Family labour	US$/acre	It corresponds to the estimated costs of the value of labour supplied by members of the family towards the various agricultural operations. The family labour costs are equal to the amounts in the local labour market, though no actual payment is, or may be made.

3.3 Profitability Calculation

The profit or net return of the farm is the difference between total revenue from the output and by product (gross return) and total cost of productions. The total cost of productions is the sum total of total variable cost and total fixed cost. Total variable costs include all production costs, namely seed and seedling cost, ploughing and sowing cost, labour cost, hired, fertiliser cost, pesticide cost, herbicide cost, irrigation cost, machinery cost, harvesting cost and drying cost. Total variable cost includes interest on operating capital, rental for land and family labour cost, interest being calculated for 6 months at 10% level of interest. The cost has been worked out as follows:

Gross Return (GR): The gross return has been calculated per acre, being the total output of rice (in quintals) per acre multiplied by average price of rice per quintal and the value of by product (straw) has been added to it. Mathematically, Gross Return (GR) = Quantity of rice × Average price of rice + Value of straw.

Gross Margin (GM): Gross margin is the difference between gross return and total variable costs. The rationale for employing gross margin analysis is that farmers aim to achieve returns that exceed their variable costs. We calculate the gross margin per acre by deducting total variable costs from gross returns. Specifically, Gross margin (GM) = Gross return (GR)- Total variable cost (TVC).

Net Return (NR)/Profit: The net return, or profit, is calculated by subtracting the total production cost from the gross return. In other words, Net Return (NR) = Gross return (GR)- Total cost (TC), where Total cost (TC) = Total variable cost (TVC) + Total fixed cost (TFC).

The profitability is calculated using the formula established by (Dillon and Hardaker, 1982), detailed as follows:

$$\pi_c = GR_c - TC_c = GR_c - TVC_c - TFC_c, \quad (1)$$

Where,

π_c : average net income (profit) per acre from rice c.

GR_c: average gross income per acre from rice c.

TC_c : average total cost per acre of rice c (sum of variable and fixed costs).

TVC_c : average variable cost per acre of rice 0 (sum of 9 variable input costs).

TFC_c: average fixed cost per acre of rice c (sum of 3 fixed costs).

c= rice season (Aus, Aman, Boro).

The gross income (GR_c) could be expressed possibly as:

$$GR_c = P_{mc}.Y_{mc} + P_{bc}.Y_{bc} \quad (2)$$

where,

P_{mc} : average price per quintal of the main product (rice) of rice c.

Y_{mc} : average production of the main product per acre of rice c.

P_{bc} : average price per quintal of the by-product (straw) of rice c.

Y_{bc} : average production of the by-product per acre of rice c.

So, the total variable cost (TVC_c) could be expressed as:

$$TVC_c = \sum_{k=1}^{9}(P_{vc,k}.Q_{c,k}) \quad (3)$$

Where,

$P_{vc,k}$: average price of the k-th variable input into rice c.

$Q_{c,k}$: average quantity of the k-th variable input into rice c.

In a similar fashion, we can express total fixed cost (TFC_c) as:

$$TFC_c = \sum_{j=1}^{3}(P_{fc,j}.Q_{c,j}) \quad (4)$$

Where,

$P_{fc,j}$: average price of the j-th fixed factor of production for rice c

$Q_{c,j}$: average quantity of the j-th fixed factor of production for rice c

Thus, the current profit (net return) equation can be formulated by combining equations (2), (3) and (4) and adding them with equation (1).

$$\pi_c = (P_{mc}.Y_{mc} + P_{bc}.Y_{bc}) - \sum_{k=1}^{9}(P_{vc,k}.Q_{c,k}) - \sum_{j=1}^{3}(P_{fc,j}.Q_{c,j}) \quad (5)$$

4. Analytical Framework, Model Specifications And Hypothesis Formulation

4.1 Analytical Framework

To achieve the objectives of the study, the first step was to calculate basic descriptive statistics cost, returns and profitability per acre to make a comparison of the economic performances of Aus, Aman and Boro seasons. At this stage of the study profitability measures viz. gross return, gross margin, net return, benefit-cost ratio and returns to scale have been calculated and estimated under three seasonal conditions of rice growing according to the descriptive statistics of input costs and output revenue per acre. This profitability study is very necessary to find out the rice-growing season wherein farmers would be getting the largest economic return and providing the base for further investigations.

Secondly, to determine if a significant difference exists in output value among Aus, Aman, and Boro seasons, we conduct an analysis of variance (ANOVA). In the third stage of the analysis, we conduct post-hoc analysis to determine which pairs (e.g., Aus vs. Aman, Aus vs. Boro, Aman vs. Boro) exhibit significant differences in output value.

In the fourth stage, we calculate the elasticity of output with respect to input for each crop season using the Cobb-Douglas production function. This will demonstrate how sensitive the output is to changes in the input. The Cobb-Douglas production function provides specific elasticities essential for analysing the impact of various inputs on profitability and productivity across rice-growing seasons. We examine and visually illustrate the comparison of output elasticity in relation to the inputs used in the production process using two separate methods. Initially, we assess the output elasticity of Aus, Aman, and Boro seasons in relation to each specific input. Secondly, we compare output elasticity by crop season across the inputs. These comparisons of elasticity (the responsiveness of output to changes in input) facilitate exploration of the underlying causes of profitability differences across crop seasons.

In the concluding stage of the analysis, a pooled log-linear regression model is employed with interaction terms of the crop season indicators with the input variables. This enables the study of the relationships between inputs and outputs of each rice-Growing season as well as the different responsiveness of the inputs to the different crops. It indicates what is the general responsiveness of output to inputs for the reference crop season, Aman, and what are the different effects for Aus and Boro seasons through the interaction terms. The significance of the interaction term indicates whether or not the elasticities of the inputs differ significantly in the rice-growing seasons.

4.2 Model specification

4.2.1 Cobb-Douglas production function

We specify the Cobb-Douglas production function for each crop season c ∈ {Aus, Aman, Boro} as follows:

$$lnY_{c,i} = \beta_{0c} + \sum_{k=1}^{9} \beta_{kc}\, lnX_{kc,i} + \epsilon_{c,i}, \tag{6}$$

a given input, we can formulate the function as follows:

$$lnY_{c,i} = \beta_{0c} + \beta_{1c} lnX_{1c,i} + \beta_{2c} lnX_{2c,i} + \beta_{3c} lnX_{3c,i} + \beta_{4c} lnX_{4c,i} + \beta_{5c} lnX_{5c,i} + \beta_{6c} lnX_{6c,i} + \beta_{7c} lnX_{7c,i} + \beta_{8c} lnX_{8c,i} + \beta_{9c} lnX_{9c,i} + \epsilon_{c,i} \tag{7}$$

variety (Aus, Aman, or Boro)

Where,

i: the household farms (i = 1, 2, …, 150)

$Y_{c,i}$: the value of production for crop c in household i

β_{0c}: intercept term for crop season c

β_{kc}: the elasticity of output concerning input *k* for crop *c* (k= 1, 2, …,9)

$X_{kc,i}$: input *k* for crop *c* in household *i*, where k ∈ {land rent, seed and seedling cost, ploughing & planting cost, hired labour cost, fertilizer cost, pesticide & herbicide cost, irrigation cost, machinery cost, family labour cost}

$\epsilon_{c,i}$: disturbance term for crop c in household i

Summing the output elasticities with respect to all inputs determines the returns to scale in a Cobb-Douglas production function. We calculate the returns to scale (RTS_c) for crop c in the following way:

$$RTS_c = \sum_{k=1}^{9} \beta_{kc} \tag{8}$$

where,

$if\ RTS_c 1, it\ indicates\ increasing\ returns\ to\ scale, meaning\ that$ the output increases at a rate that exceeds the increase in inputs.

$if\ RTS_c = 1$, it indicates constant returns to scale, meaning that the output increases in direct proportion to the increase in inputs.

$if\ RTS_c 1, it\ indicates\ decreasing\ returns\ to\ scale, meaning\ that$ the output exhibits a smaller increase in relation to the increase in inputs.

4.2.2 Interaction Models for Crop Season-Specific Input Elasticities

This interaction model performs its function as satisfactory framework of analysis, showing the relationships between the elements of input and their relationship to the varieties of rice produced. A log-linear regression form is used in the analysis, using interaction terms to show the relationship of responsiveness of outputs of the various inputs through the three rice crops. The total equation is given by:

$$\text{l n}(Y_{ij}) = \alpha + \sum_{m=1}^{k} \beta_m ln(X_{m,ij}) + \sum_v \gamma_v D_v \sum_{m=1}^{k} \sum_v \delta_{vm} \left(D_v . ln(X_{m,ij})\right) + \varepsilon_{ij} \tag{9}$$

Where,

Y_{ij} : output value for household i and rice season j.

$X_{m,ij}$: the m^{th} input used by household i for rice season j.

D_v : a dummy representing variety v∈ {Aus, Boro}, Aman season being the base.

δ_{vm} : the interaction coefficients representing the different marginal effects (elasticities) of input m for Aus/Boro season, v Aman season; and

ε_{ij} : the stochastic error term.

4.3 Formulation of the Hypotheses

In order to examine empirically our research objectives and ascertain the significance of differences between the rice-growing seasons, we formulate and test three sets of hypotheses. These hypotheses are intended to test (1) differences in profitability, (2) differences in mean outputs, and (3) differences in input-output relationships between the Aus, Aman, and Boro seasons. The formal expressions of these hypotheses are set out in detail below.

Hypothesis 1: Suppose the profitability of Aus, Aman, and Boro seasons is π_{Aus}, π_{Aman}, and π_{Boro}, then

Null Hypothesis (H_0): There are no substantial differences in the profitability of cultivating among Aus, Aman, and Boro seasons, which can be expressed as

H_0: $\pi_{Aus} = \pi_{Aman} = \pi_{Boro}$

Alternative Hypothesis (H_1): There are significant differences in the profitability of cultivating Aus, Aman, and Boro seasons. i.e.,

H_1 : There is at least one π difference between the Aus, Aman, and Boro seasons.

Hypothesis 2: Suppose the mean output value of the Aus, Aman, and Boro seasons is

μ_{Aus}, μ_{Aman}, and μ_{Boro}

Null Hypothesis (H_0): $\mu_{Aus} = \mu_{Aman} = \mu_{Boro}$

Alternative Hypothesis (H_1): There is at least one μ difference between the Aus, Aman, and Boro seasons.

Hypothesis 3: Suppose the interaction coefficients that capture the differential marginal effects (elasticities) of input m for Aus/Boro season, v, relative to Aman season are δ_{vm}

Null Hypothesis (H_0): There is no significant variation in output elasticity regarding any input across rice-growing seasons.

$$H_0: \delta_{vm} = 0 \;\; for\ all\ v \in \{Aus, Boro\}, m = 1, \dots, k$$

Alternative Hypothesis (H_1): At least one input shows a significantly different elasticity across rice-growing seasons.

$$H_1: \exists\ \delta_{vm} \neq 0 \;\; for\ at\ least\ one\ v, m$$

5. Result And Discussion

This section presents and interprets the empirical findings based on the thorough analyses conducted to address the research objectives. The findings are structured in a logical sequence, starting with the comparison of profitability across Aus, Aman, and Boro rice-growing seasons using descriptive statistics, followed by differences of revenue among seasons, identifying pairwise differences of output value (revenue), analysing output elasticity, and finally, assessing whether the responsiveness of output to inputs significantly differs across rice-growing seasons.

5.1 Comparison of Profitability of Rice Growing Seasons

It is important to know about the profit variation of the different rice growing seasons from the viewpoint of understanding of the farmers for taking effective decision by the farmers and also for priority setting in the policy. Table 2 presents a comparison of profitability across three rice-growing seasons.

The comparative analysis of net return per acre reveals vary remarkable profit differences of the different rice growing seasons in Aus, Aman and Boro. Boro shows the maximum profit among the rice seasons. The net return in the case of Boro rice comes to US$ 193.38 per acre, while that of Aman rice stands at US$124.26 and that of Aus rice at US$100.56 per acre. The above figures show the excess of return by the farmers after covering all production expenditures including variable as well as fixed costs. The larger profit of Boro rice is due mainly to the fact that the gross return per acre from this rice is more per acre, which is US$997.46, which covers to a great extent avoid total production expenditure which is US$804.08 per acre.

The net return is the major measure of profitability, but it is necessary to look at a number of other ratios to get an idea of the efficiency of use of resources. One useful measure is the gross margin which is the gross return minus variable costs of production, since this indicates the amount of income that is available to meet fixed costs and returns over these costs. The gross margins for Boro, Aman and Aus respectively are US$505.18, US$349.86 and US$316.89 per acre.

The Benefit-Cost Ratio (BCR) is a measure of efficiency since it indicates the relationship between the returns and costs. The profits can be derived from the use of either total or variable costs. The BCRs for Boro, Aman and Aus in the case of total costs are 1.24, 1.23 and 1.20 respectively. This means that in each case the rice returns exceed the costs of production.

Table 2: Profitability comparison among rice-growing seasons

Rice Season→	Aus				Aman				Boro			
Variable↓	Mean	Min	Max	Std. Dev.	Mean	Min	Max	Std. Dev.	Mean	Min	Max	Std. Dev.
Seed and seedling cost	20.33	17.18	22.95	.84	22.20	20.30	25.53	1.24	27.93	25.03	32.02	1.26
Ploughing and planting cost	45.40	34.72	60.24	3.84	49.36	37.19	66.88	6.66	63.53	51.33	87.81	7.23
Hired labour cost	24.99	12.23	35.15	5.55	26.37	20.05	37.14	2.58	65.89	53.00	86.55	6.85
Fertilizer cost	42.15	27.34	56.36	6.07	48.17	40.65	59.20	4.43	79.50	71.12	96.93	7.32
Pesticide and herbicide cost	9.47	6.56	15.33	1.62	14.36	10.58	22.21	2.79	25.43	18.13	35.83	3.24
Irrigation cost	13.17	10.97	17.80	1.36	20.57	17.14	26.51	1.88	77.10	65.43	95.01	5.00
Machinery cost	5.42	4.30	6.76	.47	6.59	5.75	8.46	.59	11.91	9.64	16.27	1.36
Harvest cost	108.97	78.31	147.65	12.82	110.54	85.69	145.02	13.58	131.77	87.89	177.97	18.85
Drying cost	5.32	4.10	6.75	.50	5.53	4.19	7.53	.62	9.22	7.62	11.43	.74
A. Total variable cost (TVC)	275.22				303.69				492.28			
Interest on operating capital (TVC)@ of 10% for 6 months (a)	13.76				15.18				24.61			
Land rent (b)	188.31	180.32	198.8	3.87	198.68	190.32	207.82	3.93	236.53	230.30	248.41	3.42
Family labour cost (c)	14.26	8.62	25.94	3.96	11.74	7.80	14.99	1.37	50.66	41.28	67.44	5.61
B. Total fixed cost (TFC): (a+b+c)	216.33				225.60				311.80			
C. Total cost (TC): (A+B)	491.55				529.29				804.08			
Rice revenue (d)	542.52	485.84	612.08	25.32	568.74	525.71	622.45	18.63	929.15	844.19	1066.98	50.70
Straw revenue (e)	49.59	29.79	63.56	7.62	84.81	62.29	103.22	11.42	68.31	32.92	104.11	16.41
D. Gross return (GR): (d+e)	592.11				653.55				997.46			
Gross margin (GM): (D-A)	316.89				349.86				505.18			
Net return (NR)/Profit: (D-C)	100.56				124.26				193.38			
Benefit cost ratio (BCR): Total cost basis (D/C)	1.20				1.23				1.24			
Benefit cost ratio (BCR): Total variable cost basis (D/A)	2.15				2.15				2.03			

For example, with a BCR of 1.24 every dollar invested produces a profit to the farmer of 24 cents from a return of 1.24 dollars, however when we consider the case of variable costs it is to be noted that Aus and Aman show an efficiency somewhat better in that their BCRs are 2.15 each, Boro having a BCR of 2.03. This indicates that despite Boro producing the greater total profit its more effective use of variable inputs in profit is not so high as in the case when Aus and Aman are considered, the reason is probably being due to a greater expenditure in the case of Boro in respect to irrigation, labour and fertilizer.

5.2 Evaluation of the variations in revenue for different rice seasons

An ANOVA test was conducted to assess whether the mean output values (that is the revenue from rice) differed significantly among different rice seasons when rice season was taken as the group factor. The results (shown in Table 3) indicated significant differences ($F = 5903.32$, $p < 0.001$), which showed that the mean revenue differed highly significantly among the Aus, Aman and Boro rice growing seasons. This indicated possible differences in production conditions, differences in factor usage, or specific characteristics of the different seasons warranting a further investigation into their individual input-output relationships.

Table 3: ANOVA result of revenue by rice season

Number of obs. = 450	R-squared = 0.9635
Root MSE = 34.44	Adj R-squared = 0.9634

Source	Partial SS	d.f.	MS	F	Prob>F
Model	14003112	2	7001556.1	5903.32	0.0000
Rice season	14003112	2	7001556.1	5903.32	0.0000
Residual	530158.39	447	1186.04		
Total	14533271	449	32368.09		

The model reveals an impressive alignment with the data, capturing almost all the variation in rice revenue across seasons (Adjusted R^2=0.9635). This compelling evidence underscores the crucial role that the rice season plays in driving the observed fluctuations in revenue, and thereby significantly impacting profitability across different rice cropping seasons.

5.3 Comparison of Revenue Between Rice Seasons (Paired Comparison)

The preliminary ANOVA indicates a highly significant variation in revenue across the rice seasons. The post hoc analysis identifies which specific rice seasons differ in revenue. This analysis involves paired comparisons of revenue per acre based on marginal linear predictions for each rice season and examines both the direction and magnitude of the differences.

Following the significant ANOVA results, we conducted a Tukey post hoc test to precisely identify which pairs of rice seasons showed substantial differences in revenue. This detailed analysis underscores the need for understanding revenue variation across rice seasons for strategic decision-making. Table 4 illustrates the differences in mean revenue between the various rice-growing seasons.

Table 4: Comparisons of marginal linear predictions of the revenue of Aus, Aman and Boro seasons

Rice Season	Contrast (mean differences)	Std. Err.	Tukey 95% Conf. Interval [lower, upper]
Aman vs. Aus	26.22***	3.98	[16.87, 35.58]
Boro vs. Aus	386.63***	3.98	[377.28, 395.98]
Boro vs. Aman	360.41***	3.98	[351.05, 369.76]

Note: The standard errors for each of two equivalent comparisons are the same (SE = 3.98), which is characteristic of the Tukey Honestly Significant Difference (HSD) procedure. This tests for significant differences using a pooled estimate of error variance derived from the ANOVA model and therefore an equivalent standard errors for all comparisons, although the magnitude of the mean differences and CI varies as they are based on the group means.

The Tukey value at the 95% confidence interval for the comparison of two rice seasons in all three groups indicates that the differences in revenue between the two rice-growing seasons are statistically significant. The contrast column shows the difference in the mean revenue per acre between the two rice seasons. For example, for Aman vs. Aus, the mean revenue for Aman is $26.22 per acre higher than for Aus. The findings reveal that all pairs compared — Aman and Aus (mean difference = 26.22, $p < 0.05$), Boro and Aus (mean difference = 386.63, $p < 0.05$), and Boro and Aman (mean difference = 360.41, $p < 0.05$) — showed statistically significant differences. These results indicate that the average revenue per acre significantly differs among rice-growing seasons, with Boro having the highest revenue, followed by Aman and Aus.

5.4 Comparison of output elasticities of inputs among the rice-growing seasons

The output elasticities of each input for a crop season are computed by the Cobb-Douglas production function. This indicates the output's sensitivity to change in inputs. The results are given in Table 6.5. We have also presented a pictorial as well as diagrammatic comparison of output elasticities relative to the inputs used in the production process, in two ways. The output elasticity is first examined for each of the Aus, Aman and Boro rice season in relation to the respective input (Figure 6.1). The output elasticity is also separately examined by means of each rice-growing season by specific inputs (Figure 6.2). The elasticity is examined for the purpose of indicating the sensitivity of output to changes in inputs to indicate the primary causes for the difference in profitability of the rice seasons.

Table 5 presents the estimated elasticities of output with respect of various input costs for the Cobb-Douglas production function in the Aus rice season, the Aman rice season and the Boro rice season. Each coefficient represents the output change which results from a 1% change in the input cost referred to in each case. The p-value provides a measure of significance for each coefficient. Where the value is below 0.05 the coefficient is significant at the 5% confidence level. Returns to scale (RTS) is the total of all elasticities of input, indicating whether the process has increasing, constant or decreasing returns to scale.

In Aus rice production, the expenditure on land rent, fertilizers, irrigation, machinery, and family labor have an important influence upon the value of the produce, in every case the effect being favourable. In other words, the increase in the value of the production is respectively 0.538, 0.049, 0.098, 0.131, and 0.056 percent. for a 1 percent increase in the cost of land rent, fertilizers, irrigation, machinery, and family labor. Expenses on account of seeds and seedlings, ploughs and planting and of hired labor, and of pesticides and herbicides have no appreciable significance. There are increasing returns to scale (RTS = 1.09) in the production of Aus rice. In other words, a 1 percent increase in costs of production (expenditures on land rent, fertilizers, irrigation, machinery, family labor) does cater for increases in rate of value of production in excess of 1 percent. This is in accord with what experience has shown, that it is to the benefit of production to increase it, and with the increased utilization of inputs efficiency improvements also take place.

Increased investment in ploughing and planting, fertilisers, pesticides & herbicides, irrigation, and machinery enhance Aman rice production in the approved sense. Output rises in the amounts of 0.062, 0.110, 0.042, 0.080, and 0.068 percent for every 1 percent increase in their costs, respectively. There is, however, no statistically significant effect of changes in the expenditure of such items as land rent, seeds and seedlings, hired labour, and family labour on the production of Aman rice. The Returns to Scale are 0.52, indicating declining returns to scale. A 1 percent increase in the total number of items increases the output of such products received by a percentage increase of only 0.52 percent. Consequently, a greater percentage use of the various items that go into producing the required rice would be an improper and inefficient way to generate profit.

For Boro rice, irrigation costs greatly increase the value of Boro rice production. The cost of seed and seedlings also has a large contribution (0.221), while the input costs for fertilizers, pesticides, and labor have low or negative elasticities, but are statistically not significant. On the other hand, the cost of ploughing and planting reduces the value of Boro rice production.

Table 5: Estimated coefficients and related statistics of the Cobb-Douglas production function							
Rice Season →	Aus		Aman		Boro		
Variable	Coefficient	95% lower and upper C.I.	Coefficient	95% lower & upper C.I.	Coefficient	95% lower and upper C.I.	
ln land rent	0.538*** (0.163)	0.215 0.860	0.116 (0.611)	-0.114 0.346	0.436 0.295	-0.147	1.019
ln seed & seedling cost	0.182 (0.118)	0.051 0.414	0.004 (0.059)	-0.113 0.121	0.221* 0.132	-0.040	0.481
ln ploughing & planting cost	-0.005 (0.058)	-0.119 0.110	0.062*** (0.024)	0.015 0.108	-0.141*** 0.054	-0.248	-0.034
ln hired labour cost	0.012 (0.0150	-0.017 0.041	0.026 (0.024)	-0.022 0.074	-0.013 0.046	-0.104	0.078
ln fertilizer cost	0.049** (0.022)	0.005 0.093	0.110*** (0.026)	0.059 0.162	-0.019 0.047	-0.112	0.075
ln pesticide & herbicide cost	0.029 (0.022)	-0.014 0.072	0.042*** (0.012)	0.018 0.067	-0.031 0.034	-0.098	0.036
ln irrigation cost	0.098*** (0.034)	0.030 0.165	0.080*** (0.025)	0.030 0.131	0.277*** 0.067	0.143	0.410
ln machinery cost	0.131*** (0.039)	0.055 0.208	0.068*** (0.027)	0.015 0.121	0.048 0.038	-0.027	0.124
ln family labour cost	0.056*** (0.014)	0.028 0.083	0.012 (0.021)	-0.029 0.053	0.040 0.041	-0.041	0.121
_cons	2.046 0.930	0.208 3.883	4.453 (0.618)	3.231 5.676	3.056 1.695	-0.294	6.406
Returns to scale (RTS)	1.09		0.52		0.82		

Note: Standard errors in parentheses

* p<0.10, ** p<0.05, *** p<0.01

The RTS for Boro rice is found to be 0.82, indicating decreasing returns to scale, but not as severe as in Aman cultivation.

The estimates of returns to scale (RTS) indication as regards the cost efficiency show differences in efficiency of cost of the crops in the different seasons, for Aus rice shows a slight increase in returns to scale indicating that the expansion of production would cause profit increases. But the Aman and Boro rice show a decrease in the returns to scale indicating that the use of input should be optimized instead of expansion to attain the cost efficient and profitably.

5.5 Graphical representation of the output elasticities of the inputs for different rice-producing seasons

The elasticities of the different inputs in the rice seasons under reference are given in diagrammatic form in Fig. 1, while in Fig. 2 on the other hand, again in diagrammatic form, the elasticities of each input in the analysis of output elasticities of the first section of the rice crops under reference are depicted.

The elasticities of the production of the different inputs are set out in Fig. 1 for the three different season crops. The different dimensions of the figure give the elasticities for a particular set of input combination used for each of the rice seasons under reference. The important purpose of the diagram is the comparison brought out in the light of the use of different inputs, as to how the marginal effect of the use of each input affects the total of output from the different rice-producing seasons. A high elasticity for any of the inputs would mean that the response of total production is very large to any variation in the use of any particular input.

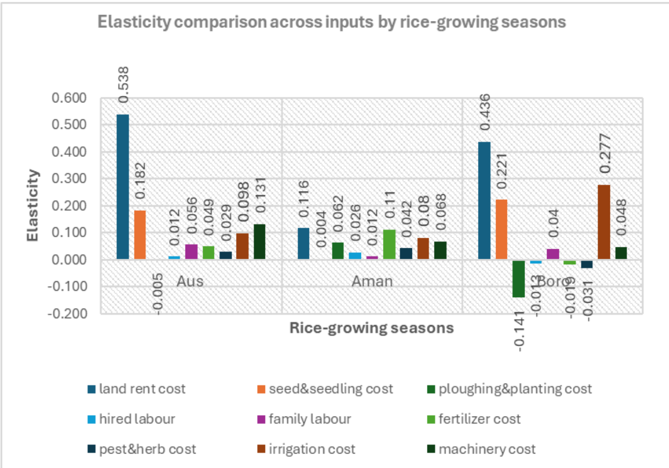

Figure 1: Elasticity comparison across inputs by rice-growing season

In the case of Aman rice the different inputs show elasticities of a very low order, which means in other words that the susceptibility of production to the variations of amounts of the inputs used is low. Of the different inputs fertilisers, irrigation, land and machinery show up with slightly higher positive elasticities in the case of Aman rice output. This shows they are relatively important items in Aman production. In contradistinction with these we find that the use of family labour and seedlings does not show elasticities of positive value but nearly zero, which goes to emphasise that these two inputs are not used effectively in Aman growing.

In the case of Aus rice, we find that land is a very important factor, having a considerably higher elasticity than any other of the variables considered. This shows that the output of Aus rice is very susceptible to variations in the use of land, and therefore that land is a very important factor in the production of Aus rice. In addition to this we find that the other inputs, such as irrigation, machinery and seedlings, show in the elasticities, slightly positive but nevertheless real figures demonstrating their greater importance of the inputs to the total production. In the case of such items as labour, pesticides, herbicides, together with ploughing and planting costs we find that their elasticities give very small results, showing their slight contribution to the output of total production, which tends to suggest their under-use, or small marginal productiveness.

In the case of Boro rice, a different state of affairs appears. In this graph we find that the elasticities of the different variables considered in the case of Boro rice are still of considerable positive value. Items such as irrigation, land and seedlings have strong positive elasticities, which means they are essential providers to the efficient culture of Boro rice which is in reality essentially important. Fertilizers on the other hand present a negative elasticity, which suggests their over-culture as a possible reason why they are prejudicial to total production.

Likewise, family labour, pesticides and herbicides show low or adverse effects on production, hence the need for more suitable substitutes for the input and better efficiency. The figure shows that land is the input which is uniformly of greatest importance in the rice seasons of Aus and Boro, it shows greater production effects. The differences in elasticity values between the rice seasons, indicate that there are important differences in efficiency of inputs and production methods. Further the negative or small elasticities of some inputs, particularly fertilizer in Boro, give rise to questions of mismanagement of the input, and emphasize the necessity of special work for the more proper utilization of the inputs applicable to each rice season.

The responses of output to various specific inputs during the three growing seasons of rice - Aman, Aus, and Boro - are shown in Figure 2. The results obtained are supplementary to the discussion of inter-season differences, where various inputs were dealt with under the heading of differences between seasons (Figure 1).

The elasticity figures for family labour show a low elasticity for all seasons of rice, indicating that this input is of little stress to output when cultivating the three seasons of rice, Aman, Aus, and Boro. This may be due to the small volume or efficiency of family labour in rice cultivation. The elasticity attributable to the input of fertiliser is reasonable for Aman and Aus, but of little response for Boro. This may mean that fertiliser is more effectively used in Aman and Aus, but that in Boro it is perhaps used inefficiently, due possibly to over-doses or diminishing returns.

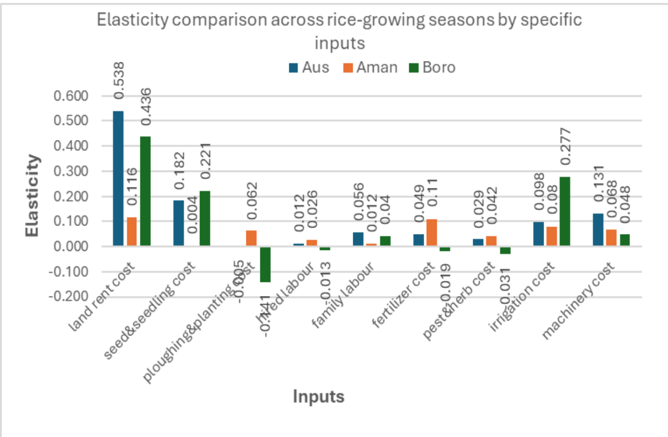

Figure 2: Elasticity comparison across rice seasons by specific inputs

In the case of hired labour in rice, the elasticity is very small in the three rice crops, and this denotes that, even with an increase of hired labour, the production of rice does not become much larger. This may either denote over-production of labour or separation of the factors of labour from the technological factors for the rice crops. Irrigation plays a larger part in Boro than the other seasons of rice, as shown in the higher elasticity, indicating a higher elasticity than for Aman and Aus. The agronomic necessities of Boro indicate that there must be more irrigation used for its growth as it is also cultivated in the dry season. Land proves the most effective of inputs for all three seasons of rice, the elasticity for Aus rice being highest and that of Boro next highest. The elasticity for Aman rice for land is, however, less than that of Boro, for output of rice is most affected by the land input generally. The importance of the input of machinery which shows a low elasticity in each of the seasons of rice indicates the small contribution that this input makes to increases of output.

Yet the similarity in elasticities points to a potential common technological bottleneck or not fully developed state of mechanization throughout the rice systems. The elasticities associated with pesticide and herbicide application are also low and relatively uniform throughout all seasons showing also that it is not a factor of prominence in the output. It might point to inefficiencies in the application of chemical inputs or timing and method of application. For ploughing and planting, the elasticities of Aman and Boro are slightly higher than that of Aus which might point to the fact that successful forms of tillage or mechanization have a more important effect on output in Aman and Boro cultivation than in Aus. The inputs of seed and seedlings have a higher elasticity in Aus and Boro than in Aman showing that the better quality of the seed or the better management in regard to seed rate has the effect of aggravating the returns in Aus and Boro possibly on account of varietal differences in response or better management. This diagram shows in conclusion that there is a considerable difference in the responsiveness with which the three rice seasons meet the different inputs, which goes to verify the necessity of different plans for the efficient management of inputs to secure a better efficiency of output and supply for rice cultivation.

5.6 Variation of input-output relationship among rice seasons

To examine how the impact of inputs on output varies (output elasticity of input) across different rice seasons, we used a log-linear regression model with interaction terms. The dependent variable represents the natural logarithm of output value, and the model features interaction terms that connect rice season indicators with the log-transformed input variables.

Aman served as the reference category for the rice seasons. Table 6 presents the regression results in three sections. (1) The main effects illustrate the output elasticity for each input for the Aman variety, treated as the reference variety in this model. (2) Crop dummy effects demonstrate the initial differences in output levels between Aus or Boro seasons compared to Aman when all input effects are considered zero (i.e., at their average values in log-linear models). (3) Interaction effects indicate how the output's responsiveness to each input (i.e., elasticity) varies for Aus and Boro in comparison to Aman. Statistically significant interaction terms highlight the variability in input-output relationships among rice seasons.

Table 6: Output Elasticity Estimates with Crop Dummies and Crop Interactions

Variable	Coefficient (Std. Error)	95% Confidence Interval (lower and upper value)
Main Effects		
ln_land	0.0005 (0.0043)	[-0.0079, 0.0089]
ln_seedseedlingcost	0.0166 (0.0886)	[-0.1576, 0.1908]
ln_ploughingplantingcost	0.0570 (0.0357)	[-0.0131, 0.1272]
ln_hiredlabour	0.0282 (0.0369)	[-0.0444, 0.1008]
ln_fert_cost	0.1134** (0.0395)	[0.0358, 0.1909]
ln_pest_herb_cost	0.0426** (0.0191)	[0.0050, 0.0802]
ln_irr_cost	0.0803** (0.0391)	[0.0033, 0.1572]
ln_mac_cost	0.0657 (0.0411)	[-0.0151, 0.1464]
ln_familylabour	0.0074 (0.0307)	[-0.0529, 0.0678]
Crop Dummy Effects		
crop_id		
Aus	-0.0187 (0.3915)	[-0.7883, 0.7508]
Boro	0.3182 (0.5014)	[-0.6675, 1.3038]
Interaction Effects		
crop_id#c.ln_land		

Table 6 (cont): Output Elasticity Estimates with Crop Dummies and Crop Interactions		
Aus	-0.0100 (0.0066)	[-0.0230, 0.0029]
Boro	0.0045 (0.0061)	[-0.0075, 0.0164]
crop_id#c.ln_seedseedlingcost		
Aus	0.1991 (0.1538)	[-0.1033, 0.5014]
Boro	0.2292* (0.1367)	[-0.0395, 0.4979]
crop_id#c.ln_ploughingplantingcost		
Aus	-0.1041 (0.0730)	[-0.2475, 0.0392]
Boro	-0.2018*** (0.0556)	[-0.3111, -0.0925]
crop_id#c.ln_hiredlabour		
Aus	-0.0198 (0.0402)	[-0.0987, 0.0592]
Boro	-0.0346 (0.0526)	[-0.1381, 0.0689]
crop_id#c.ln_fert_cost		
Aus	-0.0588 (0.0460)	[-0.1492, 0.0316]
Boro	-0.1305*** (0.0544)	[-0.2374, -0.0235]
crop_id#c.ln_pest_herb_cost		
Aus	-0.0203 (0.0297)	[-0.0788, 0.0382]
Boro	-0.0670** (0.0331)	[-0.1321, -0.0018]
crop_id#c.ln_irr_cost		
Aus	-0.0111 (0.0521)	[-0.1135, 0.0913]
Boro	0.1824*** (0.0663)	[0.0521, 0.3126]
crop_id#c.ln_mac_cost		
Aus	0.0771 (0.0578)	[-0.0365, 0.1907]
Boro	-0.0231 (0.0509)	[-0.1232, 0.0770]
crop_id#c.ln_familylabour		
Aus	0.0477 (0.0340)	[-0.0192, 0.1145]
Boro	0.0356 (0.0446)	[-0.0521, 0.1232]
_cons	5.039501 (.27652)	[4.4965, 5.5831]

Note: Standard errors in parentheses * p<0.10, ** p<0.05, *** p<0.01

The model provides a reasonable overall fit with R2- and adjusted R2-values of 0.9753 and 0.9736, respectively, indicating that some 97.5 percent of the variation of the log of the output value can be accounted for by the explanatory variables. Furthermore, the total F-statistic is significant (F (29, 420) = 571.55, p < 0.001), thus confirming the total explanatory power of the model.

Main effects: The effects of fertiliser, pesticide/herbicide and irrigation costs use Aman rice as the reference crop. These indicate that fertiliser, pesticide/herbicide and irrigation costs are positively related to Aman rice output even at the 5 percent level of significance. This indicates that the production of Aman rice was very sensitive to expenditure on these factors. In particular, an increase in fertiliser costs of 1 percent, while keeping the others the same, is associated with a change in output value of approximately 0.113 percent. Other independent variables such as land, labour and machines are not statistically significant at conventional levels of significance on Aman rice output.

Dummy effects of crops: The crop dummy variables show the average output differences of Aus and Boro as compared to the reference category, Aman, given inputs. The coefficients for the two dummies are non-significant (Aus = -0.0187; Boro = 0.3182). This means that when inputs are kept constant and no interaction effects entered average outputs of the different crop categories did not differ significantly from those of Aman.

Interaction effects: The interaction terms of the regression model indicate the responsiveness of output to the individual inputs of Aus and Boro compared to Aman the base category. The results show that none of the interaction effects for Aus are significantly different from zero: again, it is evident the relationships of inputs to outputs for Aus are not essentially different from those in Aman. This finding indicates a similarity in the production systems of these two rice seasons and a similarity in the responsiveness with respect to inputs.

On the other hand, there are several statistically significant interaction terms for Boro for which the output elasticities pertaining to the costs for ploughing and planting, fertilisers, pest insecticides and herbicides, and irrigation are different from those of Aman. For example, the significant negative interaction on costs of ploughing and planting (-0.2018***), indicates that the output of Boro is less sensitive to increases in these costs than is the case with Aman. On the other hand, the positive and significant interaction on irrigation costs indicates that the output of Boro is more responsive to irrigation costs (0.1824***) than is the case with Aman. This clearly indicates the more comprehensive use of irrigation of this crop than that of Aman.

6. Conclusion And Implications

In the study, the comparative profitability and input-output relationship of three principal seasons of rice-growing (Aus, Aman and Boro) grown in Bangladesh has been examined. Data have been collected from 150 rice-cultivating households of Gurudaspur Upazila under the Natore District. Multistage sampling has been employed in the enquiry. Necessary detailed information has been collected regarding price of inputs, value of output, household and farm characteristics. Descriptive statistics and econometric modelling methods have been employed in the analysis which consists of gross margins and Cobb-Douglas form of production function with interaction terms to study responsiveness of output with respect to various inputs over various rice seasons.

The results of the study show that the economic performance varies greatly over the three rice seasons. The maximum net returns (US $193.38/acre) are obtained from the Boro rice which proves to be the most profitable, followed by Aman (US $124.26/acre) and Aus (US $100.56/acre). The greater profitability of the Boro variety is associated with a greater input cost that is required. This holds true particularly with reference to irrigation, fertilizer and hired labour. Although Boro gives the maximum net return in terms of cash, the ratio between the gross returns and the variable input costs i.e. the benefit cost ratio based on the payments made to the variable inputs is slightly more for Aus and Aman (both 2.15) than for Boro (2.03) implying more efficient input use in respect of the two latter rice-growing seasons.

It is found that fertilizer, pesticide and irrigation have significant positive elasticity effects on production of Aman rice, a representative variety, indicating the necessity of using these inputs in rice production in order to achieve better productivity and higher profits. The interaction effects, that is, the combination of these inputs on output, indicate that Boro rice is more responsive to the inputs than Aman, indicating a higher input elasticity. Aus, however, does not, observe significant differences in input response, compared to Aman, indicating thereby that all rice crops generally have the same response to changes in the inputs of production.

This study has significant implications for rice-growing farmers, agricultural economists, and policymakers because it provides insight into the economic dimension of rice growing. While it is true that Boro is a fairly profitable crop, there are inherent dangers in its thorough dependence upon resource'" consuming inputs like the use of water for irrigation, chemical fertilisers and the hiring of labour. Hence, we have to think of its sustainability in the future, owing to the increased climatic stress gradually entering in and the increased cost of labour and inputs. Extension work will, therefore, have to be directed in such a way as to intrude the notion of the efficient use of inputs proximate farming. At the same time, enhancing the profitability of Aus and Aman through input support, technology dissemination, and varietal improvement could reduce seasonal dependency and promote more balanced cropping systems.

In conclusion, this research highlights the necessity of diversified policy strategies for enhancing profitability as well as securing sustainability of rice production for all three seasons of rice. These differentiated approaches will help to promote sustainable agricultural development and food security in all three seasons of rice in Bangladesh by taking account of the specific characteristics and problems associated with the growing of rice in each season. The results of this study are expected to be utilized by policy makers, researchers and development agencies in the designing of such identified interventions.

REFERENCES

Ahmed, J. U., Kashem, M. A., Abedien, M. J., Ahamed, T., Jannat, A., and Islam, M. M. 2025. Socio-ecological factors influencing boro rice yield and profitability in Wetland areas of Bangladesh: an integrated assessment. Discover Agriculture, 3(1), Pp. 1–18.

Akter, M., Khatun, M., and Islam, Z. 2024. Comparative Profitability and Productivity Analysis of Rice Production in Coastal and Arable Land Areas of Bangladesh. International Journal of Science and Business, 34(1), Pp. 13-25.

Akter, T., Parvin, M. T., Mila, F. A., and Nahar, A. 2019. Factors determining the profitability of rice farming in Bangladesh: Profitability analysis of rice farming in Bangladesh. Journal of the Bangladesh Agricultural University, 17(1), Pp. 86-91.

Alauddin, M., and Sarker, M. A. R. 2014. Climate change and farm-level adaptation decisions and strategies in drought-prone and groundwater-depleted areas of Bangladesh: an empirical investigation. Ecological Economics, 106, Pp. 204–213.

Anwar, M., Zulfiqar, F., Ferdous, Z., Tsusaka, T. W., and Datta, A. 2021. Productivity, profitability, efficiency, and land utilization scenarios of rice cultivation: An assessment of hybrid rice in Bangladesh. Sustainable Production and Consumption, 26, Pp. 752–758.

Azad, M. S., and Rahman, S. 2017. Factors influencing adoption, productivity and efficiency of hybrid rice in Bangladesh. The Journal of Developing Areas, 51(1), Pp. 223–240.

BBS 2022a. Statistical Yearbook 2021. Bangladesh Bureau of Statistics, Statistics and Information Division, Ministry of Planning, Government of the People's Republic of Bangladesh, Dhaka. http://203.112.218.65:8008/WebTestApplication/userfiles/Image/latesreport/SYB_2021.pdf , accessed 17 January 2023

BBS 2022b. Population and housing census-2022. Bangladesh Bureau of Statistics, Statistics and Information Division, Ministry of Planning, Government of the People's Republic of Bangladesh, Dhaka.http://203.112.218.65:8008/WebTestApplication/userfiles/Image/latesreport/SYB_2021.pdf , accessed 18 January 2023.

Datta, A. K., Haider, M. Z., and Ghosh, S. K. 2019. Economic analysis of dairy farming in Bangladesh. Tropical animal health and production, 51, Pp. 55-64. https://doi.org/10.1007/s11250-018-1659-7

Dawe. D 2010 The Rice Crisis: Markets, Policies and Food Security. Rome, Italy: Food and Agricultural Organization. https://www.fao.org/3/an794e/an794e.pdf

Dillion, J. L. and Hardaker, J. B. 1993. Farm Management Research for Small Farmer Development, FAO Publication, Rome, Italy.

FAO 2022. The State of Food Security and Nutrition in the World 2022: Repurposing Food and Agricultural Policies to Make Healthy Diets More Affordable. Rome: FAO. https://www.fao.org/3/cc0639en/cc0639en.pdf

Hoque, M. Z., and Haque, M. E. 2014. Socio-economic factors influencing profitability of rice seed production in selected areas of Bangladesh. The Agriculturists, 12(1), Pp. 33–40.

Islam, M. Z., Begum, R., Sharmin, S., and Khan, A. 2017. Profitability and productivity of rice production in selected coastal area of Satkhira district in Bangladesh. International Journal of Business, Management and Social Research, 3(1), Pp. 148–153.

Kabir, M. J., Alauddin, M., and Crimp, S. 2017. Farm-level adaptation to climate change in Western Bangladesh: An analysis of adaptation dynamics, profitability and risks. Land use policy, 64, Pp. 212–224.

Khalique, M. F. B., Touhiduzzaman, S. M., Islam, M. S., Murmu, H., and Rasel, M. 2019. Economic Analysis of Rice Production in Bangladesh. United International Journal of Research & Technology, 1(02), Pp. 8-17

Mainuddin, M., Alam, M. M., Maniruzzaman, M., Kabir, M. J., Mojid, M. A., Hasan, M. M., and Islam, M. T. 2021. Yield, profitability, and prospects of irrigated Boro rice cultivation in the North-West region of Bangladesh. PloS one, 16(4), e0250897.

MoA 2022. Bangladesh agriculture at a glance. Ministry of Agriculture, Government of the People's Republic of Bangladesh. http://www.moa.gov.bd/site/page/4fb627c0-d806-4a7e-a1cd-b67d4bc85159/Bangladesh-Agriculture-at-a-Glance , accessed 17 January 2023.

MoF 2022. Finance division, Ministry of finance, Government of the people's republic of Bangladesh. http://www.mof.gov.bd/sites/default/files/files/mof.portal.gov.bd/budget_mof/e5bf0a95_5158_478a_8024_39b557146e14/chart3_Eng.pdf

Moniruzzaman, S. 2015. Crop choice as climate change adaptation: Evidence from Bangladesh. Ecological Economics, 118, 90–98.

Mottaleb, K. A., and Mohanty, S. 2015. Farm size and profitability of rice farming under rising input costs. Journal of Land Use Science, 10(3), Pp. 243–255.

Oloyede, W. O., Muhammad-Lawal, A., Amolegbe, K. B., Olaghere, I. L., and Joseph, I. A. 2021. Comparative analysis of the profitability of rice production systems in Kwara State, Nigeria. Agrosearch, 20(2), Pp. 82–101.

Quddus, M. A. 2018. Sustainable Development of Agriculture in Bangladesh: Achievement and Challenges. The Bangladesh Journal of Agricultural Economics, 39(1 and 2), Pp. 45-59

Rahaman, M. S., Sarkar, M. A. R., Kabir, M. J., Deb, L., Rahman, M. C., Islam, M. A., and Siddique, M. A. B. 2020. Assessing the Effectiveness of Rice Procurement Programme and Farmers' Profitability in some Selected Areas of Bangladesh. Bangladesh Rice Journal, 24(1), Pp. 31–46.

Rahman, S., and Anik, A. R. 2020. Productivity and efficiency impact of climate change and agroecology on Bangladesh agriculture. Land Use Policy, 94, 104507.

Rai, R., Zhang, Y., Paudel, B., Li, S., and Khanal, N. R. 2017. A synthesis of studies on land use and land cover dynamics during 1930–2015 in Bangladesh. Sustainability, 9(10), 1866. https://doi.org/10.3390/su9101866

Rakibuzzaman, M., Rahul, S. K., Jahan, M. R., Ifaz, M. I., and Uddin, A. J. 2018. Flower industry in Bangladesh. International Journal of Business, Social and Scientific Research, 7(1), Pp. 50-56.

Rasha, R. K., Liza, H. A., Manjira, S., Kazal, M. M. H., and Rayhan, S. J. 2018. Financial profitability and resource use efficiency of boro rice production in some selected areas of Mymensingh in Bangladesh. Research in Agriculture Livestock and Fisheries, 5(3), Pp. 293–300.

Samal, P., Rout, C., Repalli, S. K., and Jambhulkar, N. N. 2018. State-wise analysis of growth in production and profitability of rice in India.

Indian Journal of Economics and Development, 14(3), Pp. 399–409.

Sapkota, N., Yadav, P. K., and Sapkota, S. 2021. An economic analysis of rice production in Rautahat District of Nepal. Food and Agri Economics Review, 1(1), Pp. 1–9.

Sarker, M. A. R., Alam, K., and Gow, J. 2014. Assessing the effects of climate change on rice yields: An econometric investigation using Bangladeshi panel data. Economic Analysis and Policy, 44(4), Pp. 405–416.

Sherestha, L. K., Thapa, Y. B., Dhakal, S. C., and Gauchan, D. 2024. Resource Utilization and Profitability of Rice Production in The Terai Region of Nepal: Rice Production Profitability in Nepal's Terai. SAARC Journal of Agriculture, 22(2), Pp. 153–167.

Siddique, M. A. B., Salam, M. A., and Rahman, M. C. 2020. Estimating the demand elasticity of rice in Bangladesh: An application of the AIDS model. Asian Journal of Agriculture and Rural Development, 10(3), Pp. 721–728.

Siddiquee, A. H., Sammy, H. M., and Hasan, M. R. 2019. Assessing profitability, marketing activities and problems in modern rice production in two northern Districts of Bangladesh. The Agriculturists, 17(1-2), Pp. 31–40.

Singh, K. M., Ahmad, N., Pandey, V. V., Kumari, T., and Singh, R. 2021. Growth performance and profitability of rice production in India: an assertive analysis.

Sultana, R., Rahman, M. H., Haque, M. R., Sarkar, M. M. A., and Islam, S. 2023. Profitability and productivity of drought tolerant rice variety Binadhan-21 in some selected areas of Bangladesh. Bangladesh Journal of Nuclear Agriculture, 37(1), Pp. 111–116.

Tama, R. A. Z., Begum, I. A., Alam, M. J., and Islam, S. 2015. Financial profitability of aromatic rice production in some selected areas of Bangladesh. International Journal of Innovation and Applied Studies, 12(1), 235.

Timsina, J., Wolf, J., Guilpart, N., Van Bussel, L. G. J., Grassini, P., Van Wart, J., and Van Ittersum, M. K. 2018. Can Bangladesh produce enough cereals to meet future demand? Agricultural systems, 163, Pp. 36-44. http://dx.doi.org/10.1016/j.agsy.2016.11.003

Van Long, H., and Yabe, M. 2021. 15 The Impact of Environmental Factors on Profit Efficiency in Rice Production in Northern Vietnam. In Poverty and Development: Problems and Prospects Pp. 218-235. Channel View Publications.

Zakaria, A., Azumah, S. B., Dagunga, G., and Appiah-Twumasi, M. 2021. Profitability analysis of rice production: a microeconomic perspective from northern Ghana. Agricultural Finance Review, 81(4), Pp. 535-553.