Journal of Agriculture and Environment for International Development - JAEID 2025, 119 (1): 369 - 392
DOI: 10.36253/jaeid-16721

How did Bangladesh Quintuple Rice Output and Quadruple Its Yield in Seven Decades? An Analysis of Seasonal Land-Use Changes and Implications for Economic Development

MOHAMMAD ALAUDDIN[1], CLEMENT A. TISDELL[1], MD ABDUR RASHID SARKER[2], ZEENATUL ISLAM [2,*]

[1] *School of Economics, The University of Queensland, Brisbane, Australia*

[2] *Department of Economics, University of Rajshahi, Rajshahi, Bangladesh*

**Correspondence details: zeenat_econ@ru.ac.bd*

Submitted on: 2024, 19 October; accepted on 2025, 23 April; Section: Research Papers

Abstract: Despite the critical importance of rice production in Bangladesh, linking productivity trends and the annual and seasonal dimensions of land use in rice farming remains largely unexplored This study addresses this gap by employing seventy-four years of national data, up to 2020, to examine the significance and implications of rice farming and land use changes for Bangladesh's economic development. Increased irrigated rice areas contributed to total (wet and dry season combined) rice output and yield. We found evidence of different time trajectories of the seasonal diffusion of high-yielding variety (HYV) rice; and a varying pace of production and yield growth of dry and wet season HYV rice. The paces of growth of total and dry season HYV rice outputs and yields have been tapering off more recently, in contrast to those for the wet season. Seasonal land-use changes over time have resulted in more even agricultural employment and the availability of foodgrains throughout the year. Results show that agriculture's share in total employment declined from < 70% to ≈38% and the declining trend was faster during 2000-2006. The percentage shares of the industry and service sectors increased to 21.32% and 40.38%, respectively, in 2019. However, the quadrupling of rice yield and rising labor productivity have placed Bangladesh on a higher economic growth path. Our findings suggest that despite eco-environmental challenges in intensification methods, agriculture, including rice production, will continue to be an essential part of Bangladesh's economy.

Keywords: Agricultural intensification, Bangladesh, Economic development, Green Revolution, Rice Land use by season.

Introduction and Background

Since the mid-1960s, the agricultural sectors of Asian countries that grow rice, which are characterized by high population density and limited land, have begun to experience a significant transformation. This period coincided with the Green Revolution, which led to substantial increases in rice output bolstered by increases in yield. Farmers relied more on groundwater resources. They also used more chemical inputs, such as fertilizers and pesticides. However, technology change alone may not induce sustained yield improvement. For example,

** [1] made a significant contribution to this paper before his passing.

the cultivation of modern varieties coupled with a crop diversification strategy stipulated yield increase in India (Paltasingh et al., 2017). Intensive agriculture is characterized by practices such as sequential multiple cropping within a year (Dalrymple, 1971) and intercropping, where two or more crops (including rice) are grown simultaneously (Andrews & Kassam, 1976, p.2).

The gross area cropped relative to its area of arable land makes Bangladesh the most rice-intensive country. In 2019, this figure for Bangladesh stood at about 145% (Cf. Vietnam, 110%, the Philippines 83%, China 25.1%, and India 28.1%, (FAOSTAT accessed 29 July 2021)). A high dependence on rice makes the average Bangladeshi the highest among the rice-consuming population (Bishwajit et al., 2013; Yunus et al., 2019). The population of about 170 million people and their dietary dependence on rice require sustaining and increasing its current production level (Alauddin et al., 2021a). Despite a decline in Bangladesh's population growth rate to 1.03% in 2020 (from 3.01% in 1965) (Alauddin et al (2021b, p.5), the absolute population level will continue to rise in the coming decades (BBS, 2015).

Rice in Bangladesh is grown under complex technological and natural conditions. These factors affect its output and yield in both time and space. Irrigation has been the key driver of the adoption and diffusion of HYV cereals in Bangladesh and other South and Southeast Asian countries and beyond (Pingali & Xuan, 1992; Ali & Byerlee, 2002; Foster & Rosenzweig, 2004). Increased rice crop yields have resulted from multiple cropping on extensively irrigated land. For example, in Vietnam, the improved irrigation system facilitated the increase in the yield of modern varieties (Thi Ut & Kajisa, 2006).

Rice culture in Bangladesh experienced spectacular changes as manifested by quintupling its output and quadrupling its yield over 74 years to June 2021. Due to access to complete irrigation and complementary inputs (Tisdell et al., 2019) the rice crops in the dry season yield higher output ha-1. By 2020, more than 89% of all rice lands were under HYV cultivation (dry season: nearly 100%; wet season: >83%) accounting for more than 96% of the total rice output (BBS, Various Issues A).

From the late 1940s to the late 1950s, cropping intensity2 remained relatively stable at around 130%, partly due to population pressure and partly to static agricultural practices and technology (Boserup, 1965; 1981). Cropping intensity refers to multiple rounds of crop cultivation on the same land within a year. The extension of the cultivation margin to the fallow and culturable areas caused their decline to 1.3 m ha from about 2.8 m ha between the late 1940s and late 1950s declining to 0.75 m ha a decade later. It shrunk further to 0.65 m ha more recently (2015-2019)3.

After the extensive margin was exhausted by the early 1960s, Bangladesh had little option but to intensify its agriculture. Since the introduction of mechanized irrigation and chemical fertilizers in the early 1960s, cropping intensity steadily increased to 137% by 1966. Subsequent introduction of HYVs afforded a spurt in cropping intensity reaching 160% by the mid-1980s and approaching almost 200% by 2019. After the Green Revolution, agricultural intensification has been critically dependent on chemical fertilizers, irrigation, and HYV inputs (Binswanger et al., 1993). HYV seeds, particularly, were the most remarkable technological change for an increase in yield, and farm income, and improvement in food security and food diversity. (Rahman & Connor, 2022). Domestic consumption of fertilizer increased by 114.22% and the consumption of pesticides reduced by 12.46% in 2009-2022 (BBS, 2012; BBS, 2024). The late 1960s and 1970s period was characterized by the overwhelming dominance of the surface water irrigation mode (80% of the total irrigated area, >1 m ha). In sharp contrast, by 2020, 80% of 7.9 m of the total irrigated area exploited groundwater resources (BBS, Various Issues A). This process represented a remarkable transformation within the irrigated ecosystem, illustrating a

[2] *Cropping intensity = [Gross area under cropping (= Area cropped once x 1+ Area cropped twice x 2 + Area cropped three times x 3 + 4 x Area cropped four times x 4) within a single year] ÷ [Net area under cropping (= (Area cropped once + Area cropped twice + Area cropped three times + Area cropped four times) x 1) within a single year] x 100 (see Alauddin et al., 2021b, p.40).*

[3] *Land utilization data are only available until 2019 (July 2019-June 2020).*

significant shift toward increased environmental intensity in agriculture (Alauddin, 2004; Alauddin & Quiggin, 2008). Inter-season rice cultivation in Bangladesh has significant implications for changes in resource use over time and the speed of technological advancements.

Employing long-term (1947-2020) Bangladeshi national data, this paper examines the annual and seasonal dimensions of land use in rice farming and the importance of this process for economic development. Specifically, it investigates:

The extent to which the extension of rice cultivation into the dry season influenced total rice output and yield during a given year and any causal relationships.

Any inter-season differences in the trajectory of the diffusion of the HYV rice technology.

Whether total and seasonal rice outputs and yields reveal any slowdown in any sub-period within the 74 years.

Whether any sub-period is characterized by slower or faster growth in total and seasonal HYV rice outputs and yields.

The significance and implications of this process on Bangladesh's economic development.

This study makes two contributions to the existing body of knowledge: (1) it investigates land use change in Bangladeshi rice farming by irrigated and rainfed ecosystems; (2) it assesses the significance and implications of the process for economic development. This contrasts with the existing literature which lacks a comprehensive and rigorous investigation of the process of this change and its broader implications.

The remainder of this paper proceeds as follows. Section 2 presents and explains analytical frameworks. Section 3 investigates the seasonal diffusion of technology and rice supply. Section 4 examines the significance and implications of the results for economic development, while Section 5 sets out the study's conclusions.

Resources and analytical frameworks

Resources

The resources that form the empirical basis of this study were sourced from BBS (1975, 1976), BBS (2018), BBS (Various Issues, A) supplemented by information from Hamid (1991); BBS (Various Issues, B), and BBS (Various Issues, C). The significance and implications of the process of seasonal land-use change examined in Section 4 rely on information from sources with attributions.

Analytical frameworks

Sub-period detection

We adopted a two-stage approach to identify sub-periods within the time series. First, scatter plots approximately identified probable breakpoints (Asteriou & Hall, 2015 pp.17-18). Second, the Wald test confirmed the most probable breakpoints from scatter plots by rejecting the no structural break null hypothesis at $p < .01$ (Asteriou & Hall 2015, pp.219-220).

OLS regression model

Equation (1) specifies the general form of the ordinary least squares (OLS) regression model with the continuous variable, Y (output or yield - the regressands), and time (T, - the regressor). The 1947-2020 period focuses on the output and yield trends of the combined HYV and non-HYV rice and by cropping season (Section 3.1). On the other hand, the 1968-2020 period concentrates exclusively on the output and yield trajectories of HYV rice output and productivity by cropping seasons and, their aggregates, (Section 3.2).

$$Y = \alpha_1 + \beta_1 T + \alpha_i D_{Ti} + \beta_i D_{Ti} T + \varepsilon \qquad (1)$$

where

$i = 2,\ldots n$ (number of sub-periods).

α_1 and β_1 symbolize the sub-period 1 (reference) intercept and slope respectively while α_i and β_i respectively represent the same for sub-period i compared to sub-period 1. D_{Ti} represents a dummy variable for sub-period i, and ε signifies a random error.

$T = 1, 2 \ldots$ for 1947, 1948, and so on during 1947-2020; or $T = 1, 2 \ldots$ for 1968, 1969, and so on, during 1968-2020.

The estimated regressions[4] for different sub-periods are:

Sub-period 1 (reference): $\hat{Y} = \hat{\alpha}_1 + \hat{\beta}_1 T$ (2)

Sub-period i: $\hat{Y}_i = (\hat{\alpha}_1 + \hat{\alpha}_i) + (\hat{\beta}_1 + \hat{\beta}_i)T$ (3)

The OLS regression model of rice output or yield over time allows us to capture the influence of any new technology or policy changes on the outcome variables (output or yield) and the amount of changes that occur in the outcome variable per year.

Logistic model

Since the pioneering work of Griliches (1957), logistic models have been widely used to explore the trajectory of the technological diffusion process (see e.g., Dixon, 1980, Marra et al., 2003; Xiao et al., 2015; Cedric et al., 2022; Masi et al., 2022; Wang et al., 2024). Logistic models help to predict technology adoption decisions and processes based on the factors that increase or decrease the likelihood of adoption. Therefore, in this study, we specify the logistic models to predict the adoption of two types of ecosystems using Equation (4).

$$Y = \frac{\beta_1}{(1+\exp(-\beta_2 * (T - \beta_3))} \qquad (4)$$

where

Y (regressand) = % of HYV area in rainfed (wet) or irrigated (dry) ecosystems in respective rice areas.

T = Time (regressor)

β_1 = limit

β_2 = rate of growth

β_3 = intercept

As T becomes large, Y approaches β_1

While logistic models allow for the estimation of adoption decisions and processes, they may not capture external effects, including climate shocks, policy changes, and farm-level socioeconomic characteristics. However, time trends capture such external effects and changes in farming technology over the study period.

Trends in technology diffusion and rice supply - Overall trend during 1947-2020

The aggregate of rainfed and irrigated rice outputs and yields, and disaggregated (by rainfed and irrigated ecosystems) rice outputs and yields.

Figures 1 (a-c) illustrate trends in the annual and seasonal (dry and wet) rice outputs (000 MT) for the four sub-periods. The sub-periods corresponding to annual, dry, and wet season

---

[4] *Based on robust standard errors (Wooldridge, 2020, pp. 419-420).*

DOI: 10.36253/jaeid-16721

outputs are dissimilar for the first two instances but similar for the last sub-period. Sub-period 3 appears almost identical for the dry (irrigated) and aggregate rice output. At the same time, the wet (rainfed) ecosystem overlaps with the other two only for a decade at the end of Sub-period 3. This is plausible because:

- the rainfed rice output was driven only by the extensive margin due to the static nature of the technology for a significant length of time;
- the traditional rice varieties overwhelmingly dominated for nearly five decades (*circa* until the late 1990s); and
- rapid growth in the dry season rice output from a low base characterized its time trajectory for a significant part of the time series.

The sub-period trend lines illustrated in Figures 1 (a-c) were derived from estimated Equation (1) presented in Table 1 employing the procedure stipulated in Equations 2 and 3 (Section 2.2) for seasonal [dry (irrigated) and wet (rainfed)] and aggregate rice outputs. Per annum output growth in the dry season crop increased steadily in all four sub-periods, peaking in the 1998-2007 sub-period with a yearly average growth of 664,000 MT. Output growth drastically declined by 406,000 MT to 258,000 MT during the 2008-2020 sub-period. Increasing seed cost and varieties' vulnerability to pests could be two crucial factors in such declining growth, as Anwar et al. (2021) observed for four districts in Bangladesh. The rice output in the wet season recorded a positive but varying annual average growth in all sub-periods (1947-1959: ≈47,000 MT; 1960-1974: ≈75,000 MT; 1975-2008: ≈32,000 MT; 2009-2020: ≈253,000 MT). The annual average increase in the last sub-period is particularly striking due primarily to the wider diffusion of the HYV technology under rainfed conditions. The aggregate rice output (dry + wet season combined) peaked with an increase of ≈ 654,000 MT per year during the 1999-2008 sub-period. However, it slowed to 557,000 MT (a reduction of 97,000 MT per annum) during the 2009-2020 sub-period (Cf. 1947-1974: ≈214, 000 MT; 1975-1998: ≈294, 000 MT).

Figures 1(a) and 1(c) show that per-year growth in the dry season and annual aggregate outputs appeared stable during the first three sub-periods. In the last sub-period, the dry season rice output appeared more variable. The opposite is the case for the wet season rice output, with the first three sub-periods showing greater variability significantly moderated in the last sub-period. Rainfall variability and irrigation management affect the yields of these varieties across dry and wet seasons (Assefa et al., 2021). This pattern in variability warrants a rigorous examination of exogenous shocks (e.g., variability in temperature and rainfall and occurrence of extreme climate events) not within the scope of the present research.

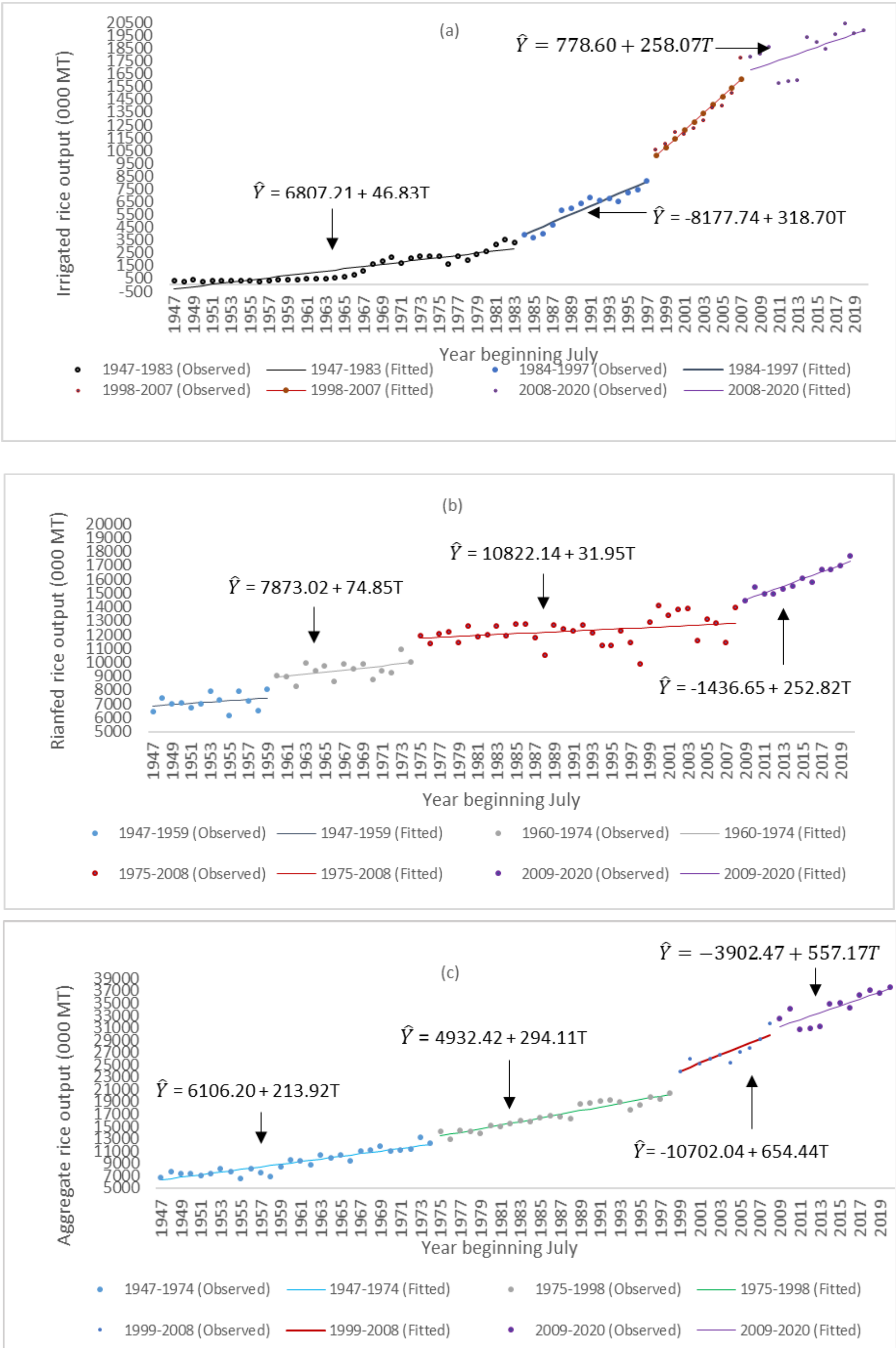

Figure 1: Trends in (a) irrigated, (b) rainfed, and (c) aggregate rice output (000 MT) in different sub-periods, Bangladesh 1947-2020.

Table 1. Estimated Equation (1) for the dry season, wet season, and their aggregate rice outputs (000 MT) by sub-periods, Bangladesh 1947-2020.

Dry season ($R^2 = 0.9909$; F – statistic (7, 66) = 1172.54; N = 74)							
Intercept				Slope			
$\hat{\alpha}_1$	$\hat{\alpha}_2$	$\hat{\alpha}_3$	$\hat{\alpha}_4$	$\hat{\beta}_1$	$\hat{\beta}_2$	$\hat{\beta}_3$	$\hat{\beta}_4$
1947-1983	1984-1997	1998-2007	2008-2020	1947-1983	1984-1997	1998-2007	2008-2020
-399.24[a]	-7778.50[a]	-24030.04[b]	1187.84	87.31[a]	231.39[a]	576.68[a]	170.76[b]
Wet season ($R^2 = 0.9397$; F – statistic (7, 66) = 495.36; N = 74)							
1947-1959	1960-1974	1975-2008	2009-2020	1947-1959	1960-1974	1975-2008	2009-2020
6807.21[a]	1065.81	4014.94[a]	-8243.86[a]	46.83	28.02	-14.88[a]	205.99[a]
Aggregate ($R^2 = 0.9915$; F – statistic (7, 66) = 1300.69; N = 74)							
1947-1974	1975-1998	1999-2008	2009-2020	1947-1974	1975-1998	1999-2008	2009-2020
6106.20[a]	-1182.78[b]	-16808.24	-10009.67[a]	213.92[a]	80.19[a]	440.52[b]	343.24[a]

[a] $p < .01$; [b] $p < .05$.

Figures 2 (a-c) illustrate the time trajectories of the aggregate and seasonal rice yields in the four sub-periods. The first turning points for the wet season and annual rice yields occurred in the early 1980s, for the dry season it occurred in 1967. To put it into a proper perspective, until the mid-1960s the dry season's share in total rice area was ≤5% and stayed below 10% until 1980. Therefore, any alteration by increased dry season HYV rice area did influence the time trajectory of its yields. Wet season rice was the dominant rice crop until 2003 (area share in the high 50%; output share in the low 50%). It took until 2005 when the wet season HYV rice adoption rate crossed 50%. Thus, a prominent manifestation of its yield effect was not evident until the late 1990s.

The absolute increase in the dry season and annual rice yields per annum peaked at 71 and 65 kg $ha^{-1,}$ respectively during the 1997-2006 and 1999-2008 sub-periods. This change slowed when they declined to 29 kg ha^{-1} during the (2007-2020) sub-period and 44 kg ha^{-1} during the (2009-2020) sub-period respectively. In contrast, the wet season rice yield recorded a steady annual increase in all sub-periods without any slowdown. By the last sub-period (2010-2020), it registered a yearly average increase of 39 kg ha^{-1} (28 kg ha^{-1} during 1999-2009). Despite this momentum, the dry season rice yield (> 4000 kg ha^{-1}) remains around 1.6 times as high as its wet season counterpart (> 2500 kg ha^{-1}).

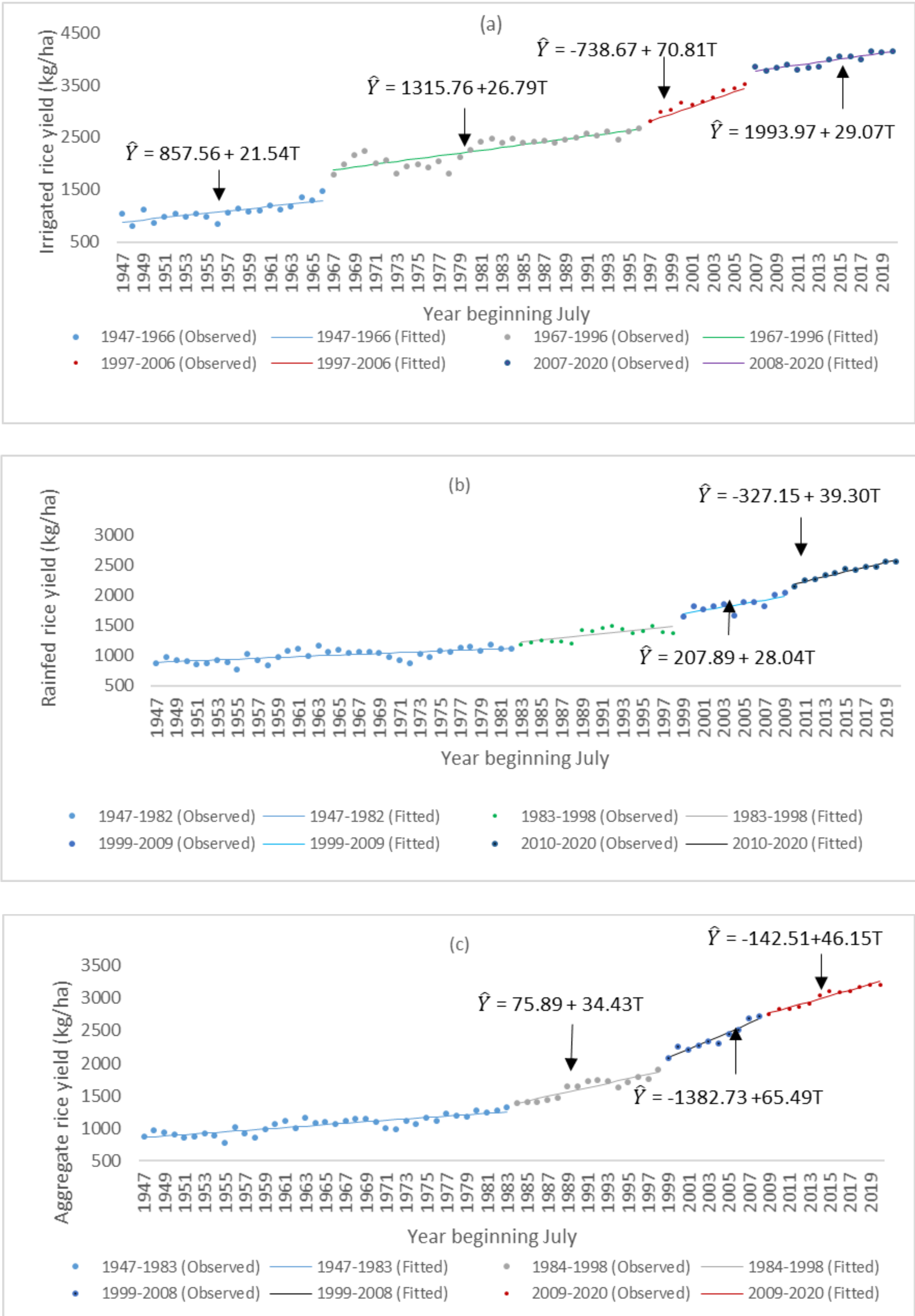

Figure 2: Trends in (a) irrigated, (b) rainfed, and (c) aggregate rice yields, in various sub-periods Bangladesh 1947-2020.

Table 2. Estimated Equation (1) for the dry and wet seasons, and their aggregate rice yields (kg ha^{-1}) by sub-periods, Bangladesh 1947-2020.

DRY SEASON ($R^2 = 0.9898$; $F-$STATISTIC $(7, 66) = 1804.25$; $N = 74$)							
Intercept				Slope			
$\hat{\alpha}_1$	$\hat{\alpha}_2$	$\hat{\alpha}_3$	$\hat{\alpha}_4$	$\hat{\beta}_1$	$\hat{\beta}_2$	$\hat{\beta}_3$	$\hat{\beta}_4$
1947-1966	1967-1996	1997-2006	2007-2020	1947-1966	1967-1996	1997-2006	2007-2020
857.56[a]	458.21[a]	-1596.23[a]	1136.41[a]	21.54[a]	5.25	49.27[a]	7.53
WET SEASON ($R^2 = 0.9815$; $F-$STATISTIC $(7, 66) = 1888.11$; $N = 74$)							
1947-1982	1983-1998	1999-2009	2010-2020	1947-1982	1983-1998	1999-2009	1999-2009
881.97[a]	-298.37[c]	-674.08[c]	-1209.73[c]	6.59[c]	10.60[c]	21.44[c]	32.71[c]
AGGREGATE ($R^2 = 0.9935$; $F-$STATISTIC $(7, 66) = 2454.82$; $N = 74$)							
1947-1983	1984-1998	1999-2008	2009-2020	1947-1983	1984-1998	1999-2008	2009-2020
848.03[a]	-772.14[a]	-2230.76[a]	-840.20[a]	10.98[a]	23.45[a]	54.51[a]	32.91[a]

[a] $p < .01$; [b] $p < .05$; [c] $p < .10$.

Figure 3a tracks the time paths of the dry season's shares in total rice area and output. Dry season's area share experienced a steady increase over decades. It gathered momentum during the three decades to 1997. Since 1998 it has trended upward from a low 30% and stabilized at the low 40% mark. Dry season's output share grew gradually until the mid-1980s peaking during 1987-1997 (Figure 3a). This pace tapered off during the 1998-2020 period. The dry season's output share crossed 50% in 2004 and stabilized in the mid-50% in recent years making it the major rice output season. During the same period, the wet season's shares in rice area and output underwent corresponding declines stabilizing at around the high 50% and the mid-40% respectively (Figure 3b). This makes the wet season the dominant area under rice.

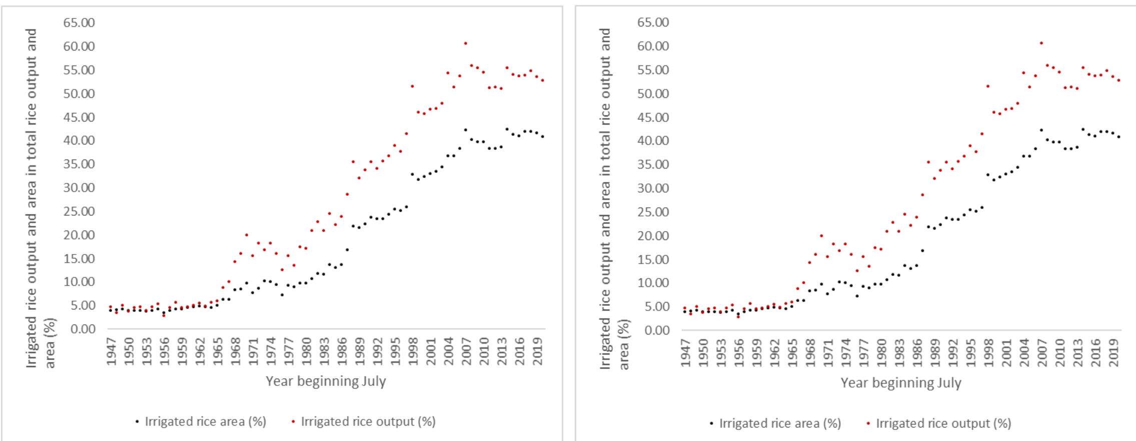

Figure 3: Trends in (a) irrigated rice output and area; and (b) rainfed rice output and area as percentages of total rice output and area, Bangladesh 1947-2020.

The preceding discussion indicates that the increased rice area in the dry season has historically propelled Bangladesh's aggregate rice output and yield, critically underpinned by the extension of irrigated and HYV areas. We ran two quadratic regression equations[5] with

[5] *After trying linear and exponential forms.*

annual rice output (*AOUTPUT*) and yield (*AYIELD*) as the dependent variables and dry season rice area in total (*DSPCRA*) as the independent variable. The estimated regressions reported and illustrated in Figures 4 (a-b) demonstrate the significant positive influence of *DSPCRA* on *AOUTPUT* and *AYIELD*. However, a strong correlation does not necessarily imply a causality. We conducted a Granger causality test to explore whether the strong association involving *DSPCRA*, *AOUTPUT*, and *AYIELD* implied causality. Our tests confirmed the evidence of one-way causality running from *DSPCRA* to both *AOUTPUT* and *AYIELD* with a two-period lag (p<.001).

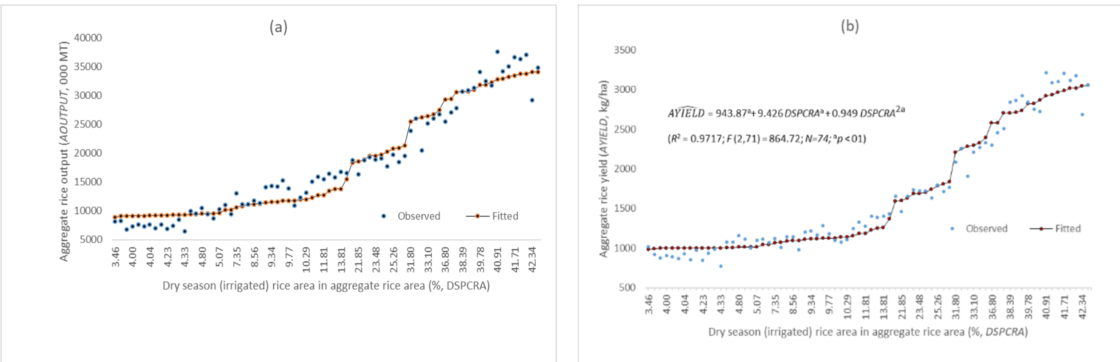

Figure 4: The influence of dry season (irrigated) rice area in aggregate rice area (%, DSPCRA) on aggregate rice (a) output (AOUTPUT), and (b) yield (AYIELD), Bangladesh 1947-2020.

The Green Revolution period: 1968-2020

Time trajectories of diffusion of HYVs by seasons (or irrigated and rainfed ecosystems)

The annual area cropped with HYV rice (total of dry and wet season rice HYVs) increased slowly until the mid-1980s. It accelerated during the 1986-1997 period (increasing by 217,000 ha per annum). This pace, however, progressively declined in the two subsequent decades (209,000 ha during 1998-2007, more sharply to 127,000 ha during 2008-2019; see Alauddin et al., 2021b, p.19). The rice HYV area in the dry season (irrigated ecosystem) increased by much smaller absolute amounts than for the wet season in all sub-periods. In the last twelve years of the time series, the dry season HYV area increase has tapered off quite noticeably in contrast to its percentage share (Alauddin et al., 2021a). These findings are relevant to debating the impacts of the Green Revolution in Bangladesh. BRRI introduced 40 rice varieties, among which 1990 ones were of improved quality (Hossain et al., 2006). The authors demonstrated the importance of relaxing the imports of agricultural inputs and an extended irrigation network contributing to the growth in rice yield during this period. However, early modern rice varieties were not well-suited for rainfed environments, whereas in Bangladesh, most rice was cultivated during the wet season until the late 1970s (Orr, 2012).

Agricultural transformation in Bangladesh after the Green Revolution relied on the use of modern inputs and the resulting productivity growth (Rahman & Salim, 2013). The authors also observed that growth in total factor productivity from 1947 to 2008 occurred because of increased land concentration for cereal production and investments in research and development. However, their findings do not elucidate the land use dimension in dry and wet seasons separately. In this study, we probe the diffusion paths of HYVs in dry and wet seasons from 1967 through 2020.

Figure 5 illustrates the estimated logistic models specified in Equation (4) in Section 2.2 for the diffusion rates of HYVs in both dry (irrigated) and wet (rainfed) ecosystems. Differing intertemporal trajectories emerge for the diffusion of rice HYVs in two ecosystems. The slopes of the irrigated and rainfed ecosystems are 0.1545 and 0.0874 respectively, indicating how quickly the ecosystems' percentages change as T changes. The rate of diffusion in the irrigated ecosystem was almost twice as fast as that of the rainfed ecosystem as evidenced by the respective absolute values of the rate of spread [$\hat{\beta}_2$ (0.1545 vs 0.0874)]. As of 1993, 2.335 m ha (90%) of the rice area came under HYV cropping in the irrigated ecosystem. In contrast, HYVs spread to 2.731 m ha (33%) of the rainfed ecosystem rice area. It should be noted that the increase of HYV area in rice land in the irrigated ecosystem is attributable to HYVs entirely to the spread of irrigation. The rainfed ecosystem aggregate rice area comprising HYVs and non-HYVs settled to an average of 6.7 m ha during the decade to 2020 (Cf. 1993: 8.4 m ha). The declining denominator, i.e., the total rice area in this ecosystem created a demonstrable impact on its HYV diffusion rate typified by the steeper slope (Figure 5). By 2020 the HYVs spread to > 83% (5.778 m ha) in the rainfed ecosystem and 97% approximately in the irrigated ecosystem.

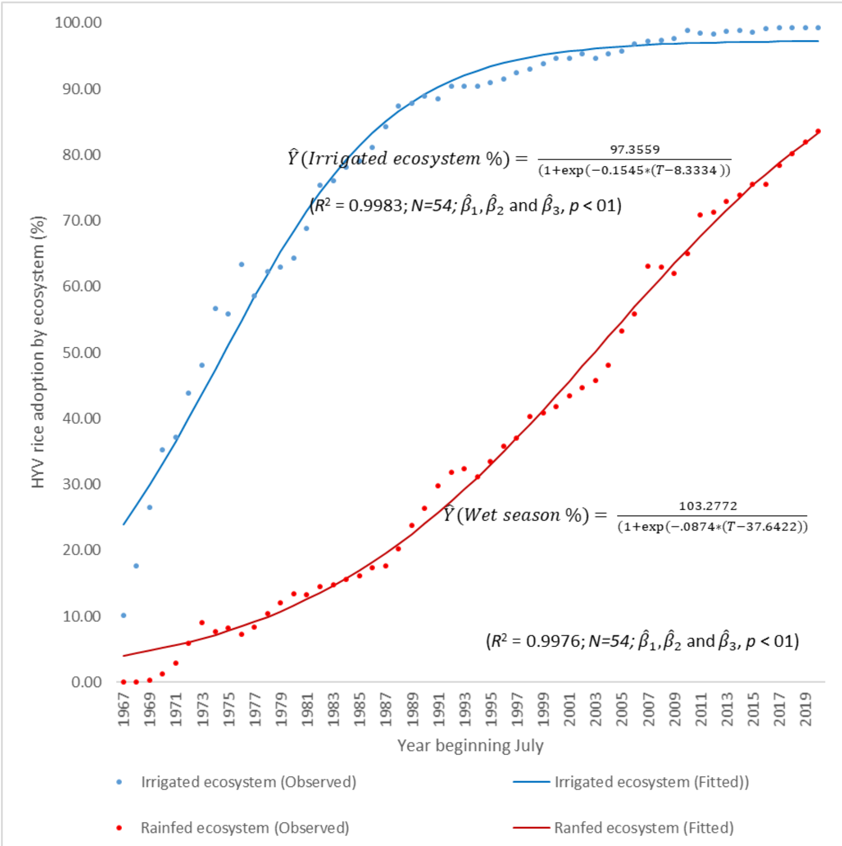

Figure 5: Time paths of diffusion of rice HYVs in Bangladesh by ecosystem, 1967-2020.

Trends HYV rice outputs and yields by ecosystems and their aggregates

Table 3 presents trends in HYV rice output in different sub-periods. The irrigated ecosystem output recorded positive average yearly increases in all sub-periods (1968-1986: ≈ 52,000 MT; ≈ 1987-1997: ≈258,000 MT; 1998-2006 ≈ 532,000 MT; and 2009-2020 ≈ 236,000 MT). However, the final sub-period witnessed a drastic fall from its peak achieved during the preceding sub-period (by ≈ 297,000 MT). The rainfed ecosystem HYV output grew in all sub-periods (1968-1988: ≈ 170,000 MT; 1989-1999: 159,000 MT). However, it experienced successively greater per annum average increases in the next two sub-periods (2000-2009: ≈ 316,000 MT; 2010-2020: ≈ 421,000 MT). The aggregate HYV rice output experienced a positive per annum average growth in all sub-periods. While each successive sub-period until 2006 experienced growing yearly average increases, it slowed down in the last sub-period (1968-1987: ≈ 343,000 MT; ≈ 1988-1998: ≈515,000 MT; 1999-2006: ≈ 722,000 MT; and 2007-

2020: ≈ 707,000 MT). The minor 15,000 MT decline in per annum average output growth between the third and the fourth sub-periods is due largely to the counterbalancing effect of the drastic fall in output growth in the irrigated ecosystem by sustaining the growth momentum in the rainfed ecosystem.

Table 3. Estimated Equation (1) for the dry and wet seasons, and their aggregate HYV rice outputs (000 MT) by sub-periods, Bangladesh, 1968-2020.

DRY SEASON ($R^2 = 0.9908$; $F-$STATISTIC $(7, 45) = 1476.14$; $N = 53$)							
1968-1986	1987-1997	1998-2006	2007-2020	1968-1986	1987-1997	1998-2006	2007-2020
Intercept				Slope			
$\hat{\alpha}_1$	$\hat{\alpha}_2$	$\hat{\alpha}_3$	$\hat{\alpha}_4$	$\hat{\beta}_1$	$\hat{\beta}_2$	$\hat{\beta}_3$	$\hat{\beta}_4$
404.76[a]	-632.89	-6805.73[a]	6813.79[b]	151.93[a]	105.61[b]	379.77[a]	83.85
WET SEASON ($R^2 = 0.9913$; $F-$STATISTIC $(7, 45) = 1105.48$; $N = 53$)							
1968-1988	1989-1999	2000-2009	2010-2009	1968-1988	1989-1999	2000-2009	2010-2020
312.73	998.50	-3481.62	-6925.90[a]	169.69[a]	-11.197[a]	146.15[a]	251.31[a]
AGGREGATE ($R^2 = 0.9955$; $F-$STATISTIC $(7, 45) = 1890.30$; $N = 53$)							
1968-1987	1988-1998	1999-2006	2007-2020	1968-1987	1988-1998	1999-2006	2007-2020
567.05[b]	-1963.89	-5782.65[c]	-1927.84	342.71[a]	172.35[b]	379.79[a]	364.41[a]

$^a p < .01$; $^b p < .05$; ; $^c p < .10$.

Trends HYV rice yields by ecosystems and their aggregates

Trends in HYV rice yields by irrigated (dry) and rainfed (wet) ecosystems and their aggregates in the four sub-periods during 1968-2020 are presented in Table 4. The dry season HYV rice yield increased rapidly from 10 kg ha^{-1} during the 1975-1996 sub-period to > 65 kg ha^{-1} during 1997-2006. This pace of yield growth slowed to 26 kg ha^{-1} during the 2007-2020 sub-period. Note that during the sub-period spanning (1968-1974), it declined by ≈203 kg ha^{-1} per annum. After shrinkages of ≈227 (1968-1974) and 7 (1975-1998) kg ha^{-1}, the rainfed ecosystem HYV rice yield trend moved into the positive territory by recording a small annual increase of about 5 kg ha^{-1} during 1999-2009 (sub-period 3). The yearly increase in this variable more than quintupled to about 28 kg ha^{-1} during the last sub-period (2010-2020) albeit from an extremely low base value. The contrasting pace of yearly increase in dry (slow down) and wet season (acceleration) of HYV rice yields notwithstanding, the latter hovers about two-thirds of the former.

The time trajectory of the aggregate yield of HYV rice commenced with -246 kg ha^{-1} per annum during the initial sub-period (1968-1974). In all the three remaining sub-periods, it demonstrated positive per annum increases of 3.6 (1975-1997), 42 (1998-2006), and 24 (2007-2020) kg ha^{-1}. The negative trends in all three measures of HYV rice yields during the 1968-1974 sub-period warrant to be placed in the proper context. Several factors might have been at work for this suggested pattern. First, the varieties introduced in the initial years were directly imported without much adaptation to local agro-ecological conditions. The high yield of the initial year could not be sustained. Secondly, farmers themselves were not used to the new technology. After initial setbacks, learning by doing from institutions and farmers' experience and knowledge led to a significant turnaround in the following sub-periods. The former could be attributable to strengthening institutional capacity building, which is geared toward better adaptation and indigenous development of HYVs more suitable for the local conditions. The latter resulted from an interaction of more appropriate technology and farmer's experience in cottoning on to the new technological regime.

Table 4. Estimated Equation (1) for the dry and wet seasons, and their aggregate HYV rice yields (kg ha-1) by sub-periods, Bangladesh, 1968-2020.

Dry season ($R^2 = 0.9772$; F – statistic $(7, 45) = 461.97$; $N = 53$)							
1968-1974	1975-1996	1997-2006	2007-2020	1968-1974	1975-1996	1997-2006	2007-2020
Intercept				Slope			
$\hat{\alpha}_1$	$\hat{\alpha}_2$	$\hat{\alpha}_3$	$\hat{\alpha}_4$	$\hat{\beta}_1$	$\hat{\beta}_2$	$\hat{\beta}_3$	$\hat{\beta}_4$
3948.57[a]	-1500.95[a]	-2939.81[a]	-1182.17[a]	-202.68[a]	212.73[a]	268.17[a]	228.87
Wet season ($R^2 = 0.8561$; F – statistic $(7, 45) = 134.11$; $N = 53$)							
1968-1974	1975-1998	1999-2009	2010-2020	1968-1974	1975-1998	1999-2009	2010-2020
3585.29[a]	-1403.07[a]	-1450.36[a]	-2241.23[a]	-226.96[a]	220.31[a]	232.12[a]	254.81[a]
Aggregate ($R^2 = 0.9552$; F – statistic $(7, 45) = 447.36$; $N = 53$)							
1968-1974	1975-1997	1998-2006	2007-2020	1968-1974	1975-1997	1998-2006	2007-2020
3923.57[a]	-1681.28[a]	-2574.18[a]	-1575.18[a]	-245.79[a]	249.36[a]	287.82[a]	269.75[a]

[a]*$p < .01$.*

Significance and Implications for Economic Development

Land-use changes across ecosystems or cropping seasons over the last seven decades, particularly the last five and half decades epitomize a process with considerable significance and implications for the overall economic development of Bangladesh. This is somewhat akin to what Schultz (1964) famously coined as 'transforming traditional agriculture'.

As Ahmed et al. (2000, p. 1) stated:

"The transformation in Bangladesh from traditional agriculture to a dynamic and progressively commercial agrarian society is a fascinating process that should interest many developing countries. This change is occurring despite monumental constraints and an adverse natural environment, providing lessons not only for the contemporary leaders of Bangladesh but for actors all across the developing world".

Over the years, Bangladesh's agricultural sector also integrated well with the rest of the economy. Quddus (2021, pp.14-15) reported that agricultural sub-sectors like paddy, jute, cotton, livestock, and forestry were characterized by high backward linkage, while wheat, rice milling, flour milling, and fish processing featured high forward linkages. One notable aspect of the intersectoral linkages is that fertilizer and machinery in crop production were key sectors for both types of linkages. This contrasts sharply with Alauddin and Mules (1980, based on the 1972-1973 input-output table) who found that the agricultural sector displayed extremely high retention ratios indicating weak backward linkages.

Significance

Higher per capita production, availability, and decreasing global hunger index

Per capita, rice production in Bangladesh has increased noticeably from a low and highly volatile base in the 1950s through to the mid-1960s where it became a low but more stable base until the late 1990s. However, during the last two decades, per capita rice production has reached a higher level with greater stability. This is despite Bangladesh's population more than quadrupling from 38 m in 1950 to 163 m in 2019 (World Development Indicators). Until 1997, rice output per capita during the wet season was the same as the overall rice output per capita. Since 1998, the dry season component increased more rapidly to catch up with the wet season component and since 2004 the former has maintained its dominance. Since the beginning of the available time series data on imports (i.e., 1950) Bangladesh has been a regular importer of significant amounts of rice and wheat. However, its foodgrain imports until the early 2000s were primarily of necessity, but more recently, they have increased stocks to meet unforeseen contingencies. Since 2013, Bangladesh's rice and wheat imports have been growing and reached 14 m MT in 2020, the bulk of which is attributable to wheat. Mottaleb et al. (2019) reported a wheat blast (*Triticum aestivum*) attack in Bangladesh in 2016 and subsequent years leading to a significant decrease in wheat area and production (Hasan et al. 2019). About 200,000 MT of wheat is projected to be used for poultry feed in 2020, constituting about 22% of the total grain used for poultry feed (Islam, 2001, p.26). Increased domestic rice production and imported foodgrains have increased foodgrain availability per capita. Since 2008, per capita availability of foodgrains has consistently exceeded 200 kg. with a coefficient of variation of 1.94%. This is in sharp contrast to preceding decades when it has ranged between 174 and 184 kg. with coefficients of variations between 10% and 4%.

Bangladesh has significantly reduced the incidence of hunger over the last two decades as reported in the Global Hunger Index (GHI) (von Grebmer et al., 2021, p.44). Bangladesh's, GHI has declined from 34.0 (average of 1998-2002) to 19.1 (average 2016-2020). The comparative trends for India and Pakistan represent a much slower decline in GHI (India: from 38.8 to 27.5) and (Pakistan: from 36.7 to 24.7) over the same period (von Grebmer et al., 2021, pp.42-43). Therefore, both Pakistan and India had a higher GHI than Bangladesh. The components of GHI (% of population undernourished, wasting in children <5 years, stunting in children <5 years, and <5 mortality rate) have recorded significant declines over the same period. These compare favorably with those for India and Pakistan (von Grebmer et al., 2021, pp.42-43).

Foodgrain price stability, decreasing import dependence, and poverty

The Green Revolution has lowered the degree of seasonal food grain price instability (Sabur & Elahi, 1993). More recently, Rahman et al. (2021, pp.60-61) reported that while nominal prices of both dry and wet season rice have shown an upward trend since 1990, their real prices have declined (see also Murshid & Yunus, 2018). HYV cultivation allowed farmers to increase their income and improve their balanced nutrition intake (Rahman and Connor, 2022). The authors observed that the increase in farm income was more than double the yield increase in HYV cultivation. However, the rice market is complex and evolving (Murshid, 2015). Due to the influence of powerful business syndicates, market imperfections siphon off much of the benefit to the ultimate consumers (Rahman et al., 2021; Sultana, 2012). Bangladesh has become more dependent on imports of other food commodities, e.g., pulses, edible oils, and spices. This has been facilitated by its considerable expansion of trade and commerce with significant non-farm sector employment creation and livelihood diversification.

The Green Revolution technology has provided Bangladesh with essential opportunities for progress, despite numerous challenges, including a declining per capita supply of arable land, which was 0.049 hectares in 2019 (Cf. from 0.158 ha in 1965; Alauddin et al. 2021b, p.6), high population intensity and susceptibility to and ferocity of natural disasters, and climate change events. As HYV cultivation requires greater mechanization, irrigation, and chemical inputs, it exacerbates GHG emissions and pollution. Hossain (2024) found that agriculture (crop and non-crop) and land under cereal production substantially caused CO2 emissions for the period 1972-2020 (Hossain, 2024). Chemical inputs can decrease soil fertility because their residues accumulate in the soil. Rahman (2013) demonstrated that pesticide and fertilizer use increased with HYV cultivation adoption, while their productivity has declined since the early 1980s. Thus, the cultivation of HYVs presents a productivity paradox that necessitates policy focus on resilient and sustainable farming practices. Notwithstanding these circumstances, rural households have attained a higher standard of living, reflected in a growing per capita income. We concur with the basic tenet of Hayami and Ruttan (1985, pp. 360-361) that "in the absence of the new [agricultural] technology, many developing countries [including Bangadesh] would have moved several steps closer to the Ricardian trap of economic stagnation…" (text in parentheses is ours). The World Bank (2016) recognizes Bangladesh's consistent efforts in poverty reduction and highlights the significant role of the rural sector, with agriculture as a key component. Mellor (2017) identified the agricultural sector's rapid growth in attaining an accelerated economic modernization economy and its importance in ameliorating rural and overall poverty. In 2022, average calorie intake in rural areas was 2424.2 kcal, higher than the urban areas and extreme poverty substantially reduced to 5.6% in 2022 from 34.3% in 2000 (BBS, 2023). As Christiansen and Martin (2018) argued, agricultural growth is *more effective at reducing poverty*, and Bangladesh's experience is supported in the broader context.

Implications for economic development: theory, history, and empirics

Agriculture's contribution: theory and history

Kuznets (1961, p.69) underscored agriculture's contribution to economic development: "… if agriculture itself grows, it makes a product contribution; if it trades with others, it renders a market contribution; if it transfers resources to other sectors, these resources being productive factors, it makes a factor contribution". The two latter contributions of agriculture to economic development are analogous to (a) supporting industrialization via increased rural net cash income; and (b) capital formation (Johnston & Mellor, 1961, pp. 576-580).

Three stages that Mellor describes (1962, 711 ff, for low-income countries) characterize the momentous change in Bangladesh's agriculture sector since the late 1940s.

Stage 1 (late-1940s – mid-1960s): Provided agricultural development preconditions characterized, amongst other things, by the static nature of technology, reliance on the application of abundant resources (labor), extending the cultivation margin, and land reform.

Stage 2 (late-1960s – mid-1990s): Agriculture featured prominently in the GDP, and in employment, there was a rising demand for agricultural products due to both demographic and income effects (Johnston and Mellor, 1961, pp. 572-573), and capital scarcity was present for industrialization. Production increase resulted from the rapid expansion of technology even though adaptation to eco-environmental conditions required a significant amount of time.

Stage 3 (from the late 1990s onwards): This period is characterized by rising agricultural production (and productivity per cultivated hectare) and the increased use of capital-intensive and labor-saving technology. This has increased agricultural labor productivity (value added per agricultural worker) in Bangladesh (reported later in this section).

As argued by Gollin et al. (2002), and Timmer (2002), growth in agricultural productivity is often (but not always) critically important for economic development. Timmer and Akkus (2008, p.3) claim that "no country has been able to sustain a rapid transition out of poverty without raising productivity in its agricultural sector". Winters et al. (1998) have claimed that agricultural surplus is central to the theories of the role of agriculture in economic development (Johnston and Mellor, 1961). Historical parallels broadly support these claims. For instance, strong agricultural growth supported industrialization in Japan, the United Kingdom, and Taiwan (Johnston & Mellor, 1961, p. 570; Southgate, 1948; Mellor, 1995, pp. 1-4). However, the Republic of Korea, Burma (Myanmar), and the Philippines (Mellor, 1995, p.1) provide contrasting examples.

Some empirics of Bangladesh agriculture's contribution to the development

Due to greater multiple seasonal cropping, the Green Revolution has resulted in phenomenal success in evening out agricultural employment throughout the year. There is no longer a slack season, unlike the pre-and early Green Revolution periods when only a small amount of work could be found during the dry season. Annual sectoral employment and value-added data since 1991 from World Development Indicators suggest a significant change in the broad occupational distribution of the labor force in Bangladesh over the years.

Figure 6a presents trends in percentage shares of agriculture, industry, and service sectors in the total employment in Bangladesh during 1991-2019. Agriculture's share in total employment declined from < 70% to ≈38%. The declining trend was faster during 2000-2006. This period also witnessed a corresponding increase in the percentage share of the service sector (from 24.49% to 37.41%) after which this pace tapered off to 40.38% in 2019 (16.91% in 1991). Over the first half of the period, the industry's contribution to the GDP sector virtually remained stagnant rising by < 1% from 13.58% in 1991 to 14.52% in 2006. However, since 2006, it has recorded a faster pace of rise to 21.32% in 2019.

Nevertheless, as illustrated in Figure 6(b) the total number of workers employed in agriculture increased marginally from 24.7 m in 1991 to 26.9 m in 2019. Note that during the first decade of this period, the number of workers employed in agriculture rose from 24.7 m to 30.1 m after which it started declining gradually. In the last decade, the workforce employed in agriculture hovered at about 27 million. The employed workforce in the industry sector has more than tripled (from 4.8 m to 15.0 m) while the same in the services sector nearly quintupled (from 6.0 m to 28.3 m). Figure 6b brings these changes to a sharper focus.

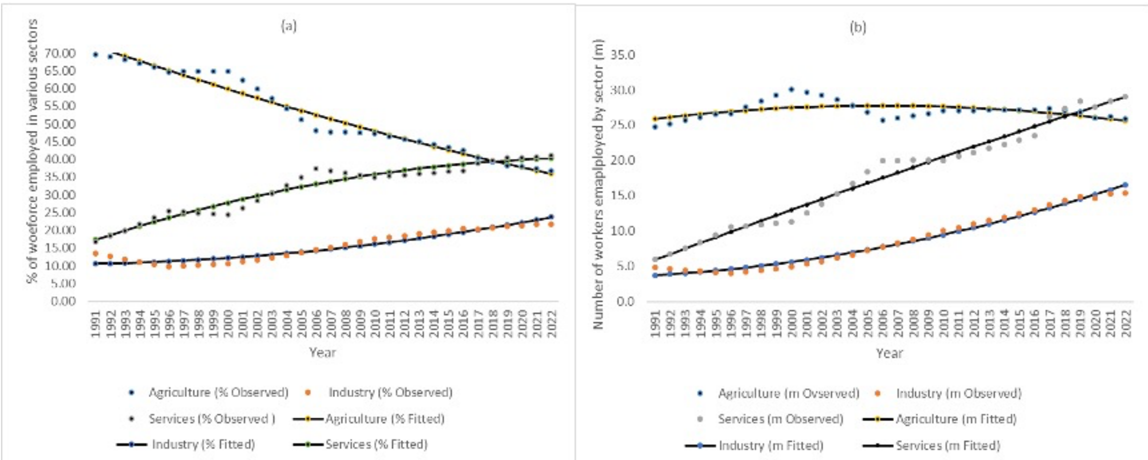

Figure 6: Trends in: (a) percentage of workforce, and (b) number of workers, employed in different sectors, Bangladesh 1991-2020 (Source: Based on data from World Development Indicators Database, accessed 1 January 2025).

Figures 7 (a-b) illustrate trends in labor productivity relative to 1991 and in dollar terms (value added per worker in constant USD 2015) in agriculture, industry, and service sectors during 1991-2019. Labor productivity in agriculture rose steadily from 494 USD in 1991 to around 1200 USD. Labor productivity nearly tripled for industry (from 1808 to 5410 USD). It increased sharply until 1996, then leveled off somewhat until 2010, displaying a stronger upward trend since then. Labor productivity in the services sector showed little increase. Initially, it slowly declined for a decade and a half before beginning to rise since 2006.

DOI: 10.36253/jaeid-16721

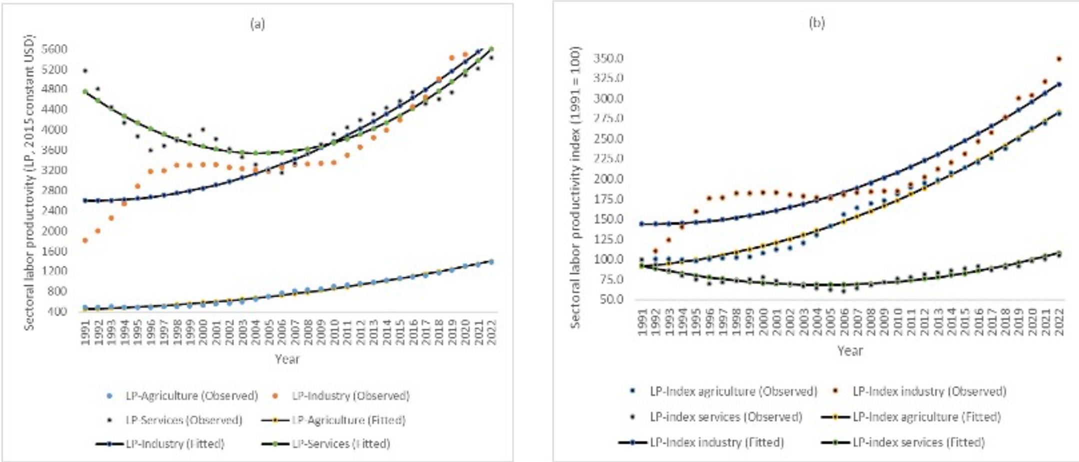

Figure 7: Trends in sectoral labor productivity indices (a) in constant 2015 US$; and (b) relative to the 1991 level Bangladesh 1991-2020. (Source: As in Figure 6).

Table 5. Trends in (a) percentage of workforce; (b) number of workers employed in various sectors, Bangladesh 1991-2022.

SECTOR	INTERCEPT	TIME	TIME^2	DIAGNOSTICS
(a) % of the workforce employed				
Agriculture	73.3928[a]	-1.4319[a]	0.0092[a]	R^2 = 0.966; $F(2,29)$ = 776.11[a]; N = 32
Industry	10.5882[a]	0.0580	0.01106[a]	R^2 = 0.947; $F(2,29)$ = 658.06[a]; N = 32
Services	16.0194[a]	1.3746[a]	-0.0192[a]	R^2 = 0.912; $F(2,29)$ = 135.42[a]; N = 32
(b) Number in the workforce employed				
Agriculture	25.6592[a]	0.2689[a]	-0.0084[a]	R^2 = 0.267; $F(2,29)$ = 6.01[a]; N = 32
Industry	3.6129[a]	0.1108[c]	0.0092[a]	R^2 = 0.981; $F(2,29)$ = 472.51[a]; N = 32
Services	5.1169[a]	0.8077[a]	-0.1118[a]	R^2 = 0.980; $F(2,29)$ = 1540.69[a]; N = 32

[a] p<.01; [b] p<.05; [c] p<.10

Table 6. Trends in sectoral labor productivity indices (a) in constant 2015 US$; and (b) relative to the 1991 level Bangladesh 1991-2020.

SECTOR	INTERCEPT	TIME	TIME^2	DIAGNOSTICS
(a) in constant 2015 US$				
Agriculture	447.3498[a]	5.2451[c]	0.7656[a]	R^2 = 0.988; $F(2,29)$ = 2155[a]; N = 32
Industry	2601.6830[a]	-9.2058	3.3567[a]	R^2 = 0.879; $F(2,29)$ = 96.90[a]; N = 32
Services	4942.0890[a]	-193.9757[a]	6.7025[a]	R^2 = 0.854; $F(2,29)$ = 122.57[a]; N = 32
(b) relative to the 1991 level				
Agriculture	90.4304[a]	1.0682[c]	0.1546[a]	R^2 = 0.988; $F(2,29)$ = 2149.99[a]; N = 32
Industry	144.0386[a]	-0.5081	0.1856[a]	R^2 = 0.879; $F(2,29)$ =96.77[a]; N = 32
Services	95.6270[a]	-3.7537[a]	0.1297[a]	R^2 = 0.854; $F(2,29)$ = 122.69[a]; N = 32

[a] p<.01; [b] p<.05; [c] p<.10

Concluding Comments

The Green Revolution's growth in cereal output, particularly rice, has been a catalyst for Bangladesh's economic development. It has transformed agricultural activities in Bangladesh by enabling more consistent and widespread production throughout the year. We observed that the aggregate rice output peaked with an increase of ≈ 654,000 MT per year during 1999-2008. However, it slowed to 557,000 MT during the 2009-2020 sub-period. The irrigated ecosystem output recorded positive average yearly increases in all sub-periods (highest in 1998-2006 ≈ 532,000 MT). However, in the 2009-2020, there was a drastic fall by ≈ 297,000 MT. The rainfed ecosystem experienced successively greater per annum average increases in the sub-periods 2000-2009: ≈ 316,000 MT; and 2010-2020: ≈ 421,000 MT. Regarding seasonal rice yields, we observed a contrasting pace of yearly increase in dry (slow down) and wet season (acceleration) HYV rice yields. The highest increase in the dry season HYV rice yield was > 65 kg ha^{-1} during 1997-2006 and the same for the rainfed HYV rice yield was about 28 kg ha^{-1} during 2010-2020. The Bangladesh scenario is consistent with the theory, history, and empirics of agriculture's contribution to economic development in the three stages: the late 1940s—mid-1960s, the late 1960s—mid-1990s, and the 1990s onwards. Using the lens of sectoral employment distribution for the three stages, we found that agriculture's share in total employment declined from < 70% to ≈38% and the declining trend was faster during 2000-2006. There was a corresponding increase in the percentage share of the service sector from 24.49% to 40.38% in 2019. Likewise, the industry's contribution recorded a faster pace of rise to 21.32% in 2019.

Agricultural growth has been crucial in driving the country's economic development. Today, Bangladesh is one of South Asia's and the world's fastest-growing economies, consistently achieving annual growth of around seven percent for a decade (except since COVID-19). Bangladesh has met UNCDP's all three eligibility criteria for graduation to a developing nation: income per capita, human assets index (HAI), and economic and environmental vulnerability index (EVI). Importantly, Bangladesh has set its sights on becoming a middle-income country by 2030 and a developed country by 2041.

There is growing concern about increasing agricultural production through intensified methods and more frequent crop diversification. However, this approach may be reaching its limits. The qualities of land and water are key factors that affect agriculture. Eco-environmental issues can impact these resources significantly. Therefore, agriculture is likely to play a reduced role as a driver of economic development in Bangladesh. This is consistent with Mellor's (1966) view that "the faster agriculture grows, the faster its relative size declines". However, this need not hinder the growth, as other sectors, specifically the industrial and service industries, may now grow independently. It appears that the ongoing economic growth in Bangladesh is becoming less reliant on the development of its agricultural sector than it was in the past. However, this does not mean that agriculture, including rice production, will cease to be an important part of the country's economy. Therefore, policy initiatives must focus on improving productivity. Notably, the yield of irrigated rice has remained relatively stagnant since 2007, underscoring the necessity of innovations and interventions to boost productivity and efficiency. Farmers should adopt high-yielding and climate-compatible rice varieties, practice timely transplanting, and implement water-saving technologies such as Alternate Wetting and Drying (AWD) to enhance both productivity and efficiency. Utilizing solar-powered irrigation can reduce water and energy costs. Optimal nutrient application can be achieved through urea deep placement and balanced fertilizer usage. Early weed control and Integrated Pest Management (IPM) are essential for effectively managing diseases and pests. Mechanization, including mechanical transplanters and power tillers, can improve labor efficiency. Additionally, ongoing government subsidies for agricultural inputs, credit facilities with low-interest rates, and access to digital tools and extension services can further boost productivity and sustainability.

In conclusion, this paper, for the first time, employs long-term time series data to examine land-use changes between seasons (dry and wet) in contrast to the existing literature, which focuses on the aggregative nature of land use in rice production. This, however, masks seasonal diversity and renders it less useful for policy purposes. One key feature of this article is that it places the changes in land use, production, and productivity outcomes and their significance and implications in the broader context of economic development.

Acknowledgements

With usual caveats, we gratefully acknowledge constructive comments and suggestions by two anonymous reviewers and the Journal Editor, which helped improve the clarity and quality of this paper. This study made use of the publicly available rice yield, output, and employment and productivity data respectively from the Bangladesh Bureau of Statistics and World Development Indicators. We gratefully acknowledge these institutions for the database.

References

Ahmed, R., Haggblade, S. & Chowdhury, T.E. (2000). Out of the Shadow of Famine: Evolving Food Markets and Food Policy in Bangladesh Baltimore, and London: The Johns Hopkins University Press (published for the International Food Policy Research Institute).

Alauddin, M. (2004). Environmentalizing economic development: A South Asian perspective, *Ecological Economics*, 51, 251-270. https://doi.org/10.1016/j.ecolecon.2004.06.014

Alauddin, M., & Mules, T.J. (1980). Structural interdependence and Bangladesh agriculture: 1972-73 and 1977-78, *Australian Economic Papers*, 19 (Issue 34), 155-167. https://doi-org.ezproxy.library.uq.edu.au/10.1111/j.1467-8454.1980.tb00249.x

Alauddin, M., & Quiggin, J. (2008). Agricultural intensification, irrigation and the environment in South Asia: Issues and policy options, *Ecological Economics*, 65, 111-124. https://doi.org/10.1016/j.ecolecon.2007.06.004).

Alauddin, M., Tisdell, C.A. & Sarker, M.A.R. (2021a). Do trends in Bangladeshi rice yields support Conway's hypotheses about the consequences of modern agroecosystems? *Economic Analysis and Policy*, 71, 342-354. https://doi-org.ezproxy.library.uq.edu.au/10.1016/j.eap.2021.05.009

Alauddin, M., Tisdell, C.A. & Sarker, M.A.R. (2021b). *Seven decades of changing seasonal land use for rice production in Bangladesh, 1947-2019: Trends, patterns and implications* (Working Paper No. 211), Economics, Ecology and the Environment Series, School of Economics, The University of Queensland, Brisbane, Australia.

Ali, M., & Byerlee, D. (2002). Productivity growth and resource degradation in Pakistan's Punjab: A decomposition analysis. *Economic Development and Cultural Change*, 50(4), 839-863. https://www.journals.uchicago.edu/doi/abs/10.1086/342759?journalCode=edcc

Andrews, D.J., & Kassam, A.H. (1976). The importance of multiple cropping in increasing world food supplies In Multiple Cropping, ASA Special Publication Number 27, pp.1-10, (Proceedings of a symposium sponsored by Divisions A-6, S-4, S-6, A-3, A-4 and C-3 of the American Society of Agronomy, Crop Science Society of America and Soil Society of America).

Anwar, M., Zulfiqar, F., Ferdous, Z., Tsusaka, T. W., & 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, 752-758. https://doi.org/10.1016/j.spc.2020.12.035

Assefa, Y., Yadav, S., Mondal, M. K., Bhattacharya, J., Parvin, R., Sarker, S. R., ... & Jagadish, S. K. (2021). Crop diversification in rice-based systems in the polders of Bangladesh:

Yield stability, profitability, and associated risk. *Agricultural Systems*, 187, 102986. https://doi.org/10.1016/j.agsy.2020.102986

Asteriou, D., & Hall, S. G. (2015). *Applied Econometrics*. Macmillan International Higher Education

BBS (2015). *Population Projection of Bangladesh: Dynamics and Trends 2011-2061*, Dhaka: Bangladesh Bureau of Statistics.

BBS (1975). *Statistical Digest of Bangladesh 1973*, Dacca: Bangladesh Bureau of Statistics.

BBS (1976). *Agricultural Production Levels of Bangladesh 1947–72*, Dacca: Bangladesh Bureau of Statistics.

BBS (2012). *Statistical Yearbook of Bangladesh 2011*, Dhaka: Bangladesh Bureau of Statistics.

BBS (2018). *45 Years Agricultural Statistics of Major Crops*, Dhaka: Bangladesh Bureau of Statistics.

BBS (2023), *Household Income Expenditure Survey 2022*, Dhaka: Bangladesh Bureau of Statistics.

BBS (2024). *Statistical Yearbook of Bangladesh 2023*, Dhaka: Bangladesh Bureau of Statistics.

BBS (Various Issues, A). *Yearbook of Agricultural Statistics of Bangladesh (1980, 1983-84. 1984-85, 1987, 1992, 1995, 1997, 2004, 2006, 2008, 2011, 2013, 2018, 2020, 2021)*, Dhaka: Bangladesh Bureau of Statistics.

BBS (Various Issues, B*). Statistical Yearbook of Bangladesh (1979-1982, 1995, 1997, 2002, 2012, 2014)*, Dhaka: Bangladesh Bureau of Statistics.

BBS (Various Issues, C). *Monthly Statistical Bulletin of Bangladesh, (May and November 1986, April 1999)*, Dhaka: Bangladesh Bureau of Statistics.

Binswanger, H.P., Khandker, S.R., & Rosenzweig, M.R., (1993). How infrastructure and financial institutions affect agricultural output and investment in India. *Journal of Development Economics*, 41, 337–366.
https://doi.org/10.1016/0304-3878(93)90062-R

Bishwajit, G., Sarker, S., Kpoghomou, M-A, Gao, H., Jun, L., Yin, D., & Ghosh, S. et al., (2013). Self-sufficiency in rice and food security: A South Asian perspective, *Agriculture & Food Security* (Open Access)
http://www.agricultureandfoodsecurity.com/content/2/1/10 .

Boserup, E. (1965). *The Conditions of Agricultural Growth: The Economics of Agrarian Change under Population Pressure*, London: George Allen and Unwin.
https://doi.org/10.4324/9781315070360

Boserup, E. (1985). *Population and Technological Change*, Chicago, Illinois: University of Chicago Press.

Cedric, L. S., Adoni, W. Y. H., Aworka, R., Zoueu, J. T., Mutombo, F. K., Krichen, M., & Kimpolo, C. L. M. (2022). Crops yield prediction based on machine learning models: Case of West African countries. *Smart Agricultural Technology*, 2, 100049.
https://doi.org/10.1016/j.atech.2022.100049

Christiaensen, L., & Martin, W. (2018). Agriculture, structural transformation and poverty reduction: Eight new insights. *World Development*, 109, 413-416.
https://doi.org/10.1016/j.worlddev.2018.05.027

Dalrymple, D.G. (1971). *Survey of Multiple Cropping in Less Developed Nations*, Washington, D.C.: Economic Research Service, U.S. Department of Agriculture.

Dixon, R. (1980). Hybrid corn revisited, *Econometrica*, 48, 1451-1461.
https://doi.org/10.2307/1912817

Foster, A. D., & Rosenzweig, M. R. (2004). Agricultural productivity growth, rural economic diversity, and economic reforms: India, 1970–2000. *Economic Development and Cultural Change*, 52(3), 509-542.
https://www.journals.uchicago.edu/doi/abs/10.1086/420968

Gollin, D., Parente, S. & Rogerson, R. (2002). The role of agriculture in development, *American Economic Review*, 92, 160-164. DOI: 10.1257/000282802320189177

Griliches, Z. (1957). Hybrid corn: An exploration in the economics of technological change, *Econometrica*, 25, 501-522.

Hamid, M.A. (1991). *A Data Base on Agriculture and Foodgrains in Bangladesh, 1947-48 to 1989-90*, 606 North Shahjahanpur, Dhaka: Ayesha Akhter.

Hasan, M.M., Alauddin, M., Sarker, M.A.R., Jakaria, M., & Alamgir, M. (2019). Climate sensitivity of wheat yield in Bangladesh: Implications for the United Nations sustainable development goals 2 and 6, *Land Use Policy*, 87, 104023. https://doi.org/10.1016/j.landusepol.2019.104023

Hayami, Y., & Ruttan, V.W. (1985). *Agricultural Development: An International Perspective*, Baltimore, Johns Hopkins University Press. https://www.cabidigitallibrary.org/doi/full/10.5555/19721890134

Hossain, M. R. (2024). Killing billions to save millions? Analyzing the double jeopardy of fossil-fuel-led economic development in Bangladesh. *Environment, Development and Sustainability*, 26(8), 20679-20710. https://doi.org/10.1007/s10668-023-03497-2

Hossain, M., Bose, M. L., & Mustafi, B. A. (2006). Adoption and productivity impact of modern rice varieties in Bangladesh. *The Developing Economies*, 44(2), 149-166. https://doi.org/10.1111/j.1746-1049.2006.00011.x

Islam, K.M.N. (2001). Demand projections for poultry feed: Implications for wheat and maize production in Bangladesh, *Bangladesh Journal Agricultural Economics*, 14 (1-20, 1-19.

Johnston, B.F. and Mellor, J.W. (1961). The role of agriculture in economic development, *American Economic Review*, 51, 566-593. https://www.jstor.org/stable/1812786

Kuznets, S. (1961). The role of agriculture in economic development, *International Journal of Agrarian Affairs*, 3(2), 56-75.

Marra, M., Pannell, D. J., & Ghadim, A. A. (2003). The economics of risk, uncertainty and learning in the adoption of new agricultural technologies: where are we on the learning curve? *Agricultural Systems*, 75(2-3), 215-234. https://doi.org/10.1016/S0308-521X(02)00066-5

Masi, M., De Rosa, M., Vecchio, Y., Bartoli, L., & Adinolfi, F. (2022). The long way to innovation adoption: insights from precision agriculture. *Agricultural and Food Economics*, 10(1), 27. https://doi.org/10.1186/s40100-022-00236-5

Mellor, J.W. (1962). The process of agricultural development in low-income countries, *Journal of Farm Economics*, 44, 700-716. https://doi.org/10.2307/1235947

Mellor, J.W. (1966). *The Economics of Agricultural Development*, Ithaca, NY: Cornell University Press.

Mellor, J.W. (1995). Introduction In: John W. Mellor (ed.) *Agriculture on the Road to Industrialization*, pp. 1-22, Baltimore and London: The Johns Hopkins University Press (Published for the International Food Policy Research Institute).

Mellor, J.W. (2017). *Agricultural Development and Economic Transformation: Promoting Growth with Poverty Reduction*, Ithaca, New York: Palgrave Macmillan (Palgrave Studies in Agricultural Economics and Food Policy).

Mottaleb, K.A., Singh, P.K., He, X., & Hossain, A. (2019). Alternative use of wheat land to implement a potential wheat holiday as wheat blast control: In search of feasible cops in Bangladesh. *Land Use Policy*, 82, 1-12. https://doi.org/10.1016/j.landusepol.2018.11.046

Murshid, K.A.S. (2015). Exploring transition and change in a complex traditional market: The case of the rice market in Bangladesh, *Journal of Agrarian Change*, 15, 480–498. https://doi.org/10.1111/joac.12083

Murshid, K.A.S., & Yunus, M. (2018). *Rice prices and growth, and poverty reduction in Bangladesh*, Rome: Food and Agricultural Development Organization of the United Nations. https://openknowledge.fao.org/handle/20.500.14283/I8332EN

Orr, A. (2012). Why were so many social scientists wrong about the Green Revolution? Learning from Bangladesh. *Journal of Development Studies*, 48(11), 1565-1586. https://doi.org/10.1080/00220388.2012.663905

Paltasingh K.R., Goyari P., & Tochkov K. (2017). Indian agriculture after the Green Revolution: An overview. In Goswamy B., Bezbaruah M.P., Mandal R. (eds.) *Indian Agriculture after Green Revolution* (pp. 8-28). Routledge Publication, New Delhi.

Pingali, P. L., & Xuan, V. T. (1992). Vietnam: Decollectivization and rice productivity growth. *Economic Development and Cultural Change*, 40(4), 697-718. https://www.journals.uchicago.edu/doi/abs/10.1086/451973

Quddus, M.A. (2021). Interdependence of industries and key economic sectors based on linkage indices: Emphasis on agriculture, *Bangladesh Journal of Agricultural Economics*, 42, 1-27. http://dx.doi.org/10.22004/ag.econ.320368

Rahman, S. (2013). Pesticide consumption and productivity and the potential of IPM in Bangladesh. *Science of the Total Environment*, 445, 48-56. https://doi.org/10.1016/j.scitotenv.2012.12.032

Rahman, M. M., & Connor, J. D. (2022). The effect of high-yielding variety on rice yield, farm income and household nutrition: evidence from rural Bangladesh. *Agriculture & Food Security*, 11(1), 35. https://doi.org/10.1186/s40066-022-00365-6

Rahman, S., & Salim, R. (2013). Six decades of total factor productivity change and sources of growth in Bangladesh agriculture (1948–2008). *Journal of Agricultural Economics*, 64(2), 275-294. https://doi.org/10.1111/1477-9552.12009

Rahman, M.C., Sarker, M.A.R., Salam, M.A., Alam, J., Molla, M.M.U., Rahman, M.S., Islam, S., Khan, M.R.A., & Rahman, M.M. (2021). Analysis of recent rice price dynamics in Bangladesh: Causes and policy options, *Asian Journal of Agricultural Extension, Economics and Sociology*, 39, 54-69, DOI: 10.9734/AJAEES/2021/v39i1230803

Sabur, S.A., & Elahi, K.Q. (1993). Trend and intertemporal paddy price fluctuation in Bangladesh, *Bangladesh Journal of Agricultural Economics*, 15, 59-69. https://www.cabidigitallibrary.org/doi/full/10.5555/19941801856

Schultz, T.W. (1964). *Transforming Traditional Agriculture*, New Haven, Connecticut: Yale University Press. https://www.cabidigitallibrary.org/doi/full/10.5555/19641802933

Southgate, G.W. (1948). *English Economic History* (New Edition), London: J.M. Dent and Sons.

Sultana, A. (2012). Rice marketing in Bangladesh: From the perspective of village study at Cox's Bazar district, *African Journal of Agricultural Research*, 7(45),5995 -6004, DOI: 10.5897/AJAR12.1840

Thi Ut, T. R. A. N., & Kajisa, K. (2006). The impact of green revolution on rice production in Vietnam. *The Developing Economies*, 44(2), 167-189. https://doi.org/10.1111/j.1746-1049.2006.00012.x

Timmer, C.P. (2002). Agriculture and economic development, in Gardiner, B. and Rausser, G. (eds.) *Handbook of Agricultural Economics*, 2, pp. 1488-1546, Amsterdam: Elsevier. https://doi.org/10.1016/S1574-0072(02)10011-9

Timmer, C.P., & Akkus, S. (2008). *The structural transformation as a pathway out of poverty: Analytics, empirics and politics* (Working Paper No. 150), Centre for Global Development (www.cgdev.org).

Tisdell, C.A., Alauddin, M., Sarker, M.A.R., & Kabir, M.A. (2019). Agricultural diversity and sustainability: general features and Bangladeshi illustrations, *Sustainability*, 11, 6004; doi: 10.3390/su11216004.

von Grebmer, K., Bernstein, J., & Wiemers, M. et al. (2021). *2021 Global Hunger Index: Hunger and Food Systems in Conflict Settings*, Bonn and Dublin: Welthungerhilfe and Concern Worldwide.

Wang, W., Huang, Z., Fu, Z., Jia, L., Li, Q., & Song, J. (2024). Impact of digital technology adoption on technological innovation in grain production. *Journal of Innovation & Knowledge*, 9(3), 100520. https://doi.org/10.1016/j.jik.2024.100520

Winters, P., de Janvry, A., Sadoulet, E., & Stamoulis, K. (1998). The role of agriculture in economic development: Visible and invisible transfers, *Journal of Development Studies*, 34, 71-97. https://doi.org/10.1080/00220389808422537

Wooldridge, J. M. (2020). *Introductory Econometrics: A Modern Approach*. Boston, MA: Cengage Books.

World Bank (2016). *Dynamics of Rural growth in Bangladesh: Sustaining Poverty Reduction*, Agriculture Global Practice Report# 103244-BD, Washington D.C.: The World Bank.

Xiao, R., Su, S., Mai, G., Zhang, Z., & Yang, C. (2015). Quantifying determinants of cash crop expansion and their relative effects using logistic regression modeling and variance partitioning. International *Journal of Applied Earth Observation and Geoinformation*, 34, 258-263. https://doi.org/10.1016/j.jag.2014.08.015

Yunus, M., Rashid, S., & Chowdhury, S. (2019). *Per capita rice consumption in Bangladesh: Available estimates and IFPRI's validation survey results* (Working Paper No. 003). Bangladesh Integrated Food Policy Research Program. Washington, D.C.: International Food Policy Research Institute.