LECTURE 4B NOTES
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August 2025

Contents

1 High Temperatures and Abiotic Stress in Bangladesh

Bangladesh faces recurrent challenges of heat stress and related abiotic pressures in wheat cultivation. The sudden outbreak of wheat blast in 2016 affected nearly 15,000 hectares of land, with yield losses reaching up to 30–50% in affected plots. Immediate responses included the release of blast-resistant and zinc-enriched wheat varieties such as BARI Gom 33, and the establishment of surveillance and training platforms supported by CIMMYT, BWMRI, and international donors [?]. These efforts highlight how rising temperatures and humid conditions exacerbate the vulnerability of wheat to fungal pathogens, with implications not only for food security but also for the economy, given Bangladesh's high dependence on wheat imports.

2 Cropping Season and Intensification Windows

The rice–wheat cropping calendar in Bangladesh leaves a narrow window between the Aman rice harvest in December and Boro transplanting in February. Traditionally, this gap left land fallow for nearly two months. Demonstrations by CSISA showed that short-duration Aman rice varieties (BBRI Dhan49, Bina Dhan7) combined with relay-sown mustard (Tori-7, BARI Sarisha-14, BARI Sarisha-15) allow a profitable third crop without delaying Boro planting. Farmers in Faridpur reported earning an additional USD 316 per hectare, with mustard yields up to 0.94 t/ha within 80 days [?]. This system reduces land-preparation costs by leveraging residual moisture, while enhancing both food and cash crop diversity.

3 Production Fluctuations and Forecasting

Wheat production in Bangladesh has shown long-term variability. Historical data (1971–2005) indicate that a quadratic growth model best describes national wheat production trends, whereas linear and cubic models better fit district-level variations. Specifically, Dinajpur aligns with linear growth, while Rajshahi and Rangpur fit cubic growth trajectories [?]. Forecasts projected that if current trends continued, Bangladesh would reach 1.54 million tons of wheat by 2009/10, with sub-national production between 0.31–0.59 million tons. These variations underscore the heterogeneous performance of wheat across districts, highlighting the need for regionally tailored agricultural strategies.

4 Competing Cereal Imports and Consumption Shifts

Bangladesh's wheat output stagnates at roughly 1 million tons annually, while domestic demand surpasses 7 million tons [?]. Consequently, imports fill over two-thirds of national consumption. Government imports supplement private traders, who bring in approximately 5.5 million tons each year. In July 2019, Bangladesh approved the purchase of 100,000 tons of Russian wheat at USD 267.30 per ton (CIF), with shipments beginning the following month [?]. Consumer preferences are shifting steadily toward wheat-based products such as bread and noodles, partly due to urbanisation and rising incomes. This dietary transition positions wheat as Bangladesh's second most important staple after rice, intensifying dependence on international grain markets.

5 Regional Patterning of Wheat Production

District-level differences remain stark. Dinajpur's production followed a steady linear path, while Rajshahi and Rangpur experienced cyclical fluctuations best captured by cubic models [?]. These variations are consistent with observed cropping system heterogeneity in the northwest wheat belt of Bangladesh, emphasising that uniform policy measures may not fully capture local dynamics. Regional planning is thus crucial for scaling wheat production and integrating wheat into diversified crop rotations.

6 Policy Levers, Procurement, and Institutional Support

Government policy continues to play a central role in stabilising wheat supply. The FY 2022–23 target for food grain production was 484.98 lakh MT, with wheat contributing about 11.6 lakh MT [?]. To bridge supply gaps, the government budgeted 16 lakh MT of imports (9 lakh MT rice, 7 lakh MT wheat), while actual imports reached 11.56 lakh MT (up to February 2023). Subsidies on fertilisers and agricultural equipment amounted to Tk. 16,000 crore, alongside a Tk. 150 crore allocation for seed production. Additionally, concessional agricultural loans and mechanisation incentives were implemented to strengthen farmer resilience [?]. These measures complement international collaborations to manage wheat blast, distribute improved seed varieties, and promote digital agricultural services such as Krishoker Janala and e-Irrigation platforms.

1 Import Dependence and Cereal Competition

Bangladesh's food economy is dominated by rice, but wheat has steadily grown in importance as both a staple and a traded commodity. The Bangladesh Economic Review (2023) reports rice output at 391.8 lakh MT and wheat at 10.86 lakh MT in FY 2021–22, with a wheat target of 11.60 lakh MT in FY 2022–23. Wheat consumption, however, exceeds 7 million tons, necessitating large imports. In FY 2022–23, up to February, total food grain imports reached 29.09 lakh MT, of which 19.12 lakh MT were wheat. To stabilise supply, the government approved procurement such as the 2019 tender for 100,000 tons of Russian wheat at USD 267.30 per ton (CIF). Private traders typically import 5.5 million tons per year. These figures highlight the persistent gap between domestic wheat output and national demand.

2 Cropping Calendar and Intensification Windows

The rice–wheat system is constrained by the Aman-to-Boro window. CSISA demonstrations in Faridpur introduced short-duration Aman rice (e.g., BBRI Dhan49, Bina Dhan7) followed by relay-sown mustard (Tori-7, BARI Sarisha-14, BARI Sarisha-15). This combination saves nearly 20 days, allowing a profitable third crop without delaying Boro planting. Farmers reported mustard yields of 0.94 t/ha within 80 days, generating additional incomes of USD 316 per hectare. This intensification is supported by digital agriservices such as e-Irrigation and Krishoker Janala, and policy scaffolding including a 97-point action plan covering short-, medium-, and long-term production stability.

3 Production Fluctuations and Forecasting

Wheat production trends have historically been non-linear. National-level production (1971/72–2004/05) follows a quadratic growth model, while district-specific growth differs: Dinajpur aligns with linear trends, Rajshahi and Rangpur with cubic patterns. Forecasts projected national output at 1.54 million tons by 2009/10, though actual production stagnated around 1 million tons in the following decade. Historical consumption exceeded 4.5 million tons annually, with per-capita intake around 28–30 grams/day, confirming the structural demand–supply gap.

4 Heat Stress and Wheat Blast

Bangladesh wheat production is highly vulnerable to abiotic stress, especially rising temperatures and humidity. In 2016, wheat blast struck nearly 15,000 hectares in southwest Bangladesh, with yield losses of 30–50%. In response, institutions rapidly deployed BARI Gom 33, a blast-resistant and zinc-enriched variety, alongside large-scale farmer training. Seed multiplication pipelines through BADC and surveillance systems funded by CGIAR have strengthened preparedness. These measures show how climate stress interacts with plant-health risks to destabilise wheat production.

5 Regional Patterning and District-Level Dynamics

The Dinajpur–Rajshahi–Rangpur cluster, highlighted in Lecture 4B, demonstrates heterogeneous growth paths. Dinajpur's wheat followed a linear trajectory, while Rajshahi and Rangpur experienced cyclical growth better captured by cubic models. These regional variations emphasise that a uniform national wheat strategy cannot succeed. Instead, tailored interventions at the district level—differentiated varieties, sowing calendars, and machinery support—are needed to address sub-national heterogeneity.

6 Policy Levers and Institutional Mechanisms

Government interventions stabilise supply through import management, subsidies, and credit. In FY 2022–23, the government budgeted 16 lakh MT of imports (9 rice, 7 wheat), with actual imports up to February at 11.56 lakh MT. Fertiliser and equipment subsidies were Tk. 16,000 crore, seed production support Tk. 150 crore, and concessional agricultural loans expanded. The PFDS (Public Food Distribution System) uses these imports to stabilise markets and provide safety nets. Mechanisation, seed development, and climate-adaptive R&D are institutionalised through MoA and BWMRI programmes.

7 Historical Baseline from Crop Summaries

Crop statistics from BBS (2008–09) show rice dominating with 28.9 million tons against wheat at 0.84 million tons on 388,000 hectares. This baseline highlights the long-run imbalance between rice and wheat. Minor cereals (barley, maize, cheena) and pulses (masur, mung, khesari) show steady growth, while oilseeds (rape & mustard, soybean) also increased. The expansion of Boro rice (17.7 million tons in 2008–09) has further constrained wheat's cropping space, reinforcing its dependence on imports.

8 Structural Role of Rice–Wheat Competition

The seasonal rice area maps (uploaded separately) show how Aman, Boro, and Aus occupy most arable land. Wheat's role is restricted to limited winter niches, often competing directly with Boro. Expansion of Boro HYVs (from 14.7 million tons in 2007–08 to 17.7 million tons in 2008–09) has displaced wheat, reinforcing the structural imbalance between rice and wheat in Bangladesh's agriculture.

1 V_1 Import Dependence and Cereal Competition

- **Domestic output:** Wheat production remains around 1.0–1.1 million tons annually versus nearly 40 million tons of rice.
- **Import reliance:** Annual wheat demand is 7–8 million tons, meaning 80–85% is imported.
  - FY2022–23: Foodgrain imports 29.09 million tons, of which 19.12 million tons were wheat.
  - 2019: Govt contracted 100,000 tons from Russia at USD 267/ton; first 52,000 tons shipped in August.
- **Fiscal weight:** Imports cost over USD 700 million annually, straining foreign exchange reserves.

– Wheat demand is tied to changing diets (bread, noodles, bakery products). – *Analysis:* Wheat security is externally anchored in global markets, unlike rice self-sufficiency. – **Class cue:** Should Bangladesh invest more in import diplomacy or domestic production?

2 V_2 Cropping Calendar and Intensification Window

- **Seasonal squeeze:** Aman harvested in Dec; Boro transplanted in Feb → gap of only 50–60 days.
- **Relay innovations:** Short-duration Aman (BRRI Dhan49, Bina Dhan7) with relay mustard saves 20 days.
  - Mustard yields ∼1 t/ha, adding USD 300+/ha.
  - Cropping sequence: Aman → Mustard → Boro within one year.
- **Technology need:** Mechanisation (seed drills, harvesters) critical to hit narrow windows.

– *Analysis:* Wheat can only re-enter if Aman harvests are shortened and calendars synchronised. – **Class cue:** Is wheat best seen as a main crop or as part of a relay package?

3 V_3 Production Fluctuations

- **Trend modelling:**
  - National wheat: quadratic curve (1971–2005).
  - Dinajpur: linear trend (steady adoption).
  - Rajshahi & Rangpur: cubic curves (boom–bust cycles).
- **Forecast gap:** 2009/10 projection = 1.5 Mt, actual output ∼1.0 Mt.

- **Consumption rise:** Per-capita intake ∼30 g/day; demand above 4.5 Mt annually.

– *Analysis:* Forecasts misfired because land, water, and crop competition constrained expansion. – **Class cue:** Why do Rajshahi and Rangpur show cyclical swings while Dinajpur is steady?

4 V_4 Heat Stress and Wheat Blast

- **2016 blast outbreak:** ∼15,000 ha affected in southwest; yield loss 30–50%.
- **Varietal response:** Rapid release of BARI Gom 33 (blast-resistant, zinc-enriched).
- **Institutional actions:**
  - Seed multiplication via BADC.
  - Blast surveillance and mobile alerts piloted with CGIAR partners.

– *Analysis:* Shows vulnerability of monocropping and climate-linked fungal shocks. – **Class cue:** How did institutions adapt quickly, and what gaps remain in plant health systems?

5 V_5 Regional Patterning of Wheat

- **Core wheat belt:** Dinajpur, Rajshahi, Rangpur.
- **District differences:**
  - Dinajpur: steady linear growth, stable technology adoption.
  - Rajshahi & Rangpur: cubic cycles, vulnerable to shocks/market swings.
- **Rice context:** Rajshahi Aman yield ∼2.9 t/ha; Dhaka Boro yield >4.1 t/ha, crowding wheat.

– *Analysis:* Wheat policy must be district-specific; "one-size-fits-all" won't work. – **Class cue:** Why is Dinajpur more stable for wheat compared to Rangpur?

6 V_6 Policy Levers and Institutions

- **Import budgets:** FY22–23: 16 lakh MT target (9 rice, 7 wheat). Actual by Feb = 11.56 lakh MT (5.73 wheat, 5.83 rice).
- **Subsidies:** Tk 16,000 crore on fertiliser & machinery; Tk 150 crore for seed support.
- **Credit & digital tools:**
  - Ag loans scaled up.

– E-platforms (Krishoker Janala, e-Irrigation, e-Fertiliser).

– *Analysis:* Policy-driven stability ensures supply but creates fiscal dependence. – **Class cue:** Should policy focus on stabilising imports or incentivising local wheat?

7 V_7 Historical Baseline (Crop Summaries)

- **2008–09 BBS:** Rice = 28.9 Mt; Wheat = 0.84 Mt.
- **Boro dominance:** Boro jumped by 3 Mt in a year (2007–08 to 2008–09).
- **Wheat squeeze:** Area shrank due to labour scarcity, water competition, and low profitability.

– *Analysis:* Wheat marginality is structural, not cyclical. Rice (esp. Boro) dictates land allocation. – **Class cue:** Can wheat policy succeed if rice continues to expand?

8 V_8 Aman as Seasonal Anchor

- **Timing:** Sown July–Aug, harvested Nov–Dec; accounts for 37–40% rice area.
- **Production:** 14–15 Mt annually.
- **Early varieties:** BRRI Dhan49, Bina Dhan7 cut harvest time by 15–20 days.

– *Analysis:* Aman defines feasibility of inserting mustard/wheat before Boro. – **Class cue:** Should policy incentivise short Aman to allow wheat re-entry?

9 V_9 Aus as Early-Season Constraint

- **Timing:** Sown Mar–Apr, harvested Jul–Aug.
- **Share:** <10% of rice output (∼2.6 Mt).
- **Overlap:** Directly competes with pulses, jute, and early wheat niches.

– *Analysis:* Aus contributes to food security but reduces diversification space. – **Class cue:** Is Aus an opportunity cost against wheat and pulses?

10 V_{10} Boro Irrigation Pressure

- **Timing:** Sown Jan, harvested May; yields 4–5 t/ha.
- **Dominance:** By 2008–09, Boro produced 17.7 Mt (>60% of rice output).
- **Water use:** Consumes 80% of dry-season irrigation.

– *Analysis:* Boro is a "hydrological trap" pushing wheat out of dry-season land. – **Class cue:** Should Bangladesh regulate irrigation water pricing to rebalance wheat?

1 APO Application to Pakistan: Wheat–Rice (RWS) System

V1. Import dependence & cereal competition

- Pakistan's agriculture added 1.55% to GDP in 2022–23 with important crops down 3.2% due to 2022 floods; wheat expanded and rice contracted.[1]
- Wheat: area 9,043 kha; production 27.63 Mt; yield 3,056 kg/ha (2022–23).
- Rice: area 2,976 kha; production 7.32 Mt; yield 2,460 kg/ha (2022–23).
- Policy stance: Kissan Package (credit, subsidized inputs); higher MSP for wheat to stabilize producer incentives.

V2. Cropping calendar & intensification window

- RWS zones concentrate in Punjab's irrigated plains; monsoon (Jul–Nov) aligns with rice, leaving the rice→wheat turnaround as the critical bottleneck.
- Late wheat sowing after rice drives a *linear* yield penalty of ≈1–1.5% per day past mid-November; March–April heat further compresses grain filling.
- Puddling for transplanted rice destroys macroporosity; wheat that follows suffers from poor soil structure and delayed sowing.

V3. Production fluctuations

- 2022 floods damaged ∼4.4 M acres crops and ∼1 M livestock; rice output fell 21.5% y/y while wheat rebounded 5.4% in 2022–23 as Rabi normalized.
- Surface water availability fell to 43.3 MAF in Kharif 2022 (well below the 67.1 MAF average); Rabi 2022–23 improved to 29.4 MAF.

V4. Heat/abiotic stress and water productivity

- Field water inputs for conventional rice averaged **1,458 mm** vs potential crop requirement **532 mm**; the gross depleted fraction ≈0.40 indicates ∼60% losses as seepage/deep percolation.
- Water productivity (grain per gross inflow): **rice 0.23 kg/m^3** (i.e., ∼4.35 m^3/kg) vs **wheat 1.48 kg/m^3** (∼0.675 m^3/kg).
- Groundwater EC at surveyed watercourses commonly 0.8–1.2 dS/m; conjunctive use patterns vary by watercourse and season.

[1] Figures sourced from national economic survey; citations maintained outside LaTeX.

V5. Regional patterning (Punjab watercourses)

- Sites with diversified rotations, laser levelling, and zero-tillage showed higher physical and economic water productivity at watercourse scale.
- Seasonal groundwater tables fluctuate with canal deliveries; quality gradients influence feasible RCT packages.

V6. Policy levers & institutions

- Credit targets, input support (urea/DAP facilitation), mechanization subsidies, and concessional schemes featured in 2022–23 to offset flood impacts and input price spikes.
- Oilseed push (rapeseed–mustard) expanded area and output; implications for winter water and wheat area must be managed.

V7. Historical baseline (RWS role)

- RWS spans ∼13.5 Mha in South Asia; contributes roughly a third of regional wheat and a quarter of rice.
- Long-run constraints: salinity affects ∼3.8 Mha in Pakistan; wind erosion ∼10.7 Mha; groundwater depletion in Punjab is a chronic risk.

V8. Seasonal anchor (rice sets the clock)

- Rice scheduling (monsoon-aligned) determines the feasible wheat window; puddling and residue management choices ripple into wheat timeliness and stand quality.

V9. Early-season constraints

- Where early kharif crops or delayed rice transplanting occur, they clash with optimal wheat sowing, amplifying the late-sown penalty and heat exposure.

V10. Winter–spring water squeeze

- Rabi irrigation needs are rising amid variable canal supplies; efficiency gaps at field/farm/watercourse scales widen water stress for wheat relative to rice.

Actionable levers (Pakistan)

- **Calendar discipline:** Bring wheat sowing to ≤15 Nov; expand zero-till wheat into rice residue windows to save 10–20 days and moisture.

- **Water productivity:** Prioritize DSR/beds where weed control and land levelling are reliable; couple with precise irrigation turns to cut non-beneficial losses.
- **Soil & salinity:** Residue retention and raised beds on marginal EC zones; target gypsum and drainage where feasible.
- **Mechanization:** Scale laser levelling, happy-seeder class residue drills, and bed planters; align credit lines with service providers.

2 Bangladesh vs Pakistan: Protocol Layout Comparison

At-a-glance (selected indicators)

	Bangladesh	**Pakistan**
RWS role in South Asia	Core RWS participant; avg wheat and rice yields ∼2.2 and ∼2.8 Mg/ha (regional context)	Core RWS participant; wheat ∼2.2–3.1 Mg/ha; rice ∼2.8 Mg/ha (context)
Wheat water productivity	Typically higher than rice in RWS; sensitive to late sowing/heat	Rice 0.23 kg/m^3 vs wheat 1.48 kg/m^3 (field studies)
Stress profile	Heat episodes; disease (e.g., blast history regionally)	Heat at wheat grain fill; salinity ∼3.8 Mha; variable canal flows
2022 shock	–	Floods cut rice (–21.5% y/y), wheat recovered (+5.4%) in 2022–23
Policy instruments	Procurement/import management; input support (contextual)	MSP hikes, Kissan Package, fertilizer facilitation, mechanization support

Common system constraints (RWS)

- Rice puddling compromises soil structure for wheat; wheat is time and heat sensitive.
- Late sowing penalty ∼1–1.5% yield loss per day after mid-Nov.
- Water productivity gap: rice far more water-intensive than wheat under conventional methods.

3 Wheat vs Rice in the RWS: Theoretical Notes for Class Discussion

Why wheat is structurally disadvantaged after rice

- **Soil physics:** Puddling destroys macropores to reduce percolation for rice; wheat requires aerated seedbeds $\Rightarrow$ higher establishment risk and slower early vigor.
- **Phenology vs climate:** Optimal wheat sowing $\leq$ mid-Nov; delays push anthesis/grain fill into March–April heat, shortening duration and depressing kernel weight; penalty $\sim$1–1.5% per late day.
- **Input response:** Empirical declines in kg grain per kg N under stressed, late-sown contexts reflect structure and heat penalties, not just fertilizer access.
- **Hydrology:** Conventional rice applies $\sim$1.5 m water with only $\sim$0.53 m crop requirement, creating deep percolation; the follow-on wheat then faces tighter, more episodic irrigation budgets.

Technology pathways & tradeoffs

- **Zero-till wheat into rice residues:** Gains in timeliness/moisture; requires residue-handling seeders and workable straw management.
- **Direct-seeded rice (DSR) & bed systems:** Cut water applied and turnaround delays; yield risk without strong weed control, precise levelling, and irrigation timing.
- **Laser levelling:** Raises application uniformity; improves both yield stability and water productivity at field and watercourse scales.

Policy & scaling

- Align credit and service markets to diffusion of zero-till drills, bed planters, and levelling.
- Target extension on calendar discipline and weed control packages to de-risk DSR and zero-till adoption.
- Manage salinity/EC pockets with beds, drainage where feasible, and crop choices that stabilize RWS profitability without sacrificing wheat.

1 Pakistan: Wheat–Rice System (APO Output)

V1. Import dependence and cereal competition

- Wheat: area about 9,043 thousand ha; production about 27.63 Mt (recent Rabi).
- Rice: area about 2,976 thousand ha; production about 7.32 Mt (recent Kharif).
- Trade posture: Pakistan is typically a rice exporter; wheat balance fluctuates with domestic shocks and procurement policies.
- Price signals: wheat support price increases aided area and harvest recovery; paddy prices rose after flood losses.

V2. Cropping calendar and intensification window

- Kharif (rice): establishment June–August; harvest October–November.
- Rabi (wheat): sowing mid November (optimal) to early December; harvest April–May.
- Window risk: late rice harvest compresses wheat sowing; rule of thumb yield penalty about 1 to 1.5 percent per day after mid November in warm springs.

V3. Production fluctuations

- 2022 floods caused a sharp rice drop (about minus 21.5 percent year on year); wheat rebounded about plus 5.4 percent the following Rabi on stable area and supportive policy.
- Interannual variability is driven by monsoon timing, canal allocations, and input availability (fertilizer, seed, diesel).

V4. Heat and abiotic stress

- Wheat heat risk rises with late sowing; March–April hot spells shorten grain filling.
- Rice water stress occurs where canal rotations are tight and tubewell electrical conductivity is elevated; residue burning and puddling degrade soil structure.

V5. Regional patterning

- Punjab rice–wheat belt dominates; subzones differ in groundwater depth and quality, canal reliability, and adoption of resource conserving technologies.
- Diversified watercourses with laser levelling and zero tillage show higher physical and economic water productivity than non levelled commands.

V6. Policy levers and institutions

- Instruments: minimum support price for wheat; fertilizer facilitation; concessional credit; mechanization support for levelling and planters; flood recovery measures.
- Surface water allocation by the national regulator; conjunctive canal and groundwater use is common where canals undersupply.

V7. Historical baseline

- Green Revolution gains established the rice–wheat sequence; current constraints include water scarcity, soil organic matter decline, and rising pumping costs.

V8. Seasonal anchor (rice sets the clock)

- Monsoon timed rice defines the system pace; keeping rice on time enables on time wheat and stabilizes system productivity.

V9. Early season constraints

- Overlaps with fodder, sugarcane, and pulses limit flexibility; labor bottlenecks and combine straw management affect turnaround.

V10. Winter–spring water demand

- Rabi irrigation demand peaks when canal supplies can be relatively tight; groundwater bridges the gap where water quality permits.

Field and system level water productivity (Pakistan examples)

- Conventional rice: average gross inflow about 1,458 mm versus potential crop water need about 532 mm; gross depleted fraction about 0.40 (non beneficial losses about 60 percent).
- Water productivity (grain per unit gross inflow): rice about 0.23 kg per cubic meter; wheat about 1.48 kg per cubic meter.
- Direct seeded and bed planted rice reduce applied water; yield penalties arise without strong weed control and calibrated irrigation scheduling.

Actionable levers for Pakistan

- Advance wheat sowing (target mid November) via direct seeded rice or timely transplanting; mechanize residue management to avoid burning delays.

- Expand laser land levelling and on farm distribution fixes to cut rice percolation losses.
- Promote zero till wheat with calibrated nitrogen timing; blend canal and tubewell water to manage salinity where feasible.

Table A. Core indicators (recent season)

Indicator	Wheat	Rice
Area (thousand ha)	about 9,043	about 2,976
Production (Mt)	about 27.63	about 7.32
Typical sowing window	November	June–August
Water productivity (kg per cubic meter)	about 1.48	about 0.23

Table B. Rice establishment and irrigation use

Method	Relative irrigation	Notes
Transplanted flat	High	Puddling and deep percolation common
Direct seeded flat	Medium	Weed control program is critical
Transplanted on beds	Medium	Better drainage and field access
Direct seeded on beds	Lower	Highly sensitive to levelling and irrigation timing

2 Bangladesh vs Pakistan: APO Protocol Comparison

V1. Imports and cereal competition

- Bangladesh: wheat output about 1.0 to 1.3 Mt; high reliance on wheat imports; rice remains the calorie anchor.
- Pakistan: wheat is mostly domestically supplied with year to year swings; rice is usually surplus and export oriented.

V2. Calendar and intensification

- Bangladesh: Aman to Boro timing governs; a short gap can be managed with relay crops in some districts.
- Pakistan: Kharif rice timing drives Rabi wheat; late rice harvest compresses wheat sowing unless zero tillage or bed systems are used.

V3. Fluctuations

- Bangladesh: imports buffer wheat shocks; irrigated Boro rice stabilizes totals.
- Pakistan: climatic shocks such as the 2022 floods hit rice; policy and minimum support price stabilize wheat outcomes.

V4. Stress

- Bangladesh: heat and disease management experience; seed pipeline responded with resistant lines when needed.
- Pakistan: heat during wheat grain filling; rice faces water scarcity and salinity pockets; weeds like Phalaris minor are important.

V5. Regional patterning

- Bangladesh: northwest districts lead wheat; irrigated Boro concentrates east and central.
- Pakistan: Punjab rice–wheat belt with canal and tubewell contrasts; adoption varies by watercourse.

V6. Policy

- Bangladesh: import management and safety nets more prominent for wheat.
- Pakistan: minimum support price, input subsidies and credit; flood recovery packages; export management for rice.

Instructor prompts for the comparison

- How do import policies versus minimum support prices alter farm incentives across the two systems?
- Which calendar constraint is more binding: the Aman to Boro gap or the late Kharif to Rabi turnaround?

3 Wheat vs Rice in the Rice–Wheat System: Theory and Practice

A. Agronomic contrasts

- Root zone physics: puddled rice favors low percolation but degrades macroporosity; wheat needs an aerated seedbed and timely sowing.
- Thermal time: wheat yield responds strongly to sowing date; rice yield is tied to transplanting date and monsoon timing.

B. Water and energy

- Under conventional practice, rice typically uses two to three times more irrigation per hectare than wheat; direct seeding and beds reduce applied water.
- Wheat irrigation events are fewer; canal rotations and rainfall timing matter; groundwater quality can constrain supplemental irrigation.

C. Management technologies

- Laser levelling: reduces percolation losses in rice and improves wheat emergence uniformity.
- Zero till wheat: preserves moisture and advances sowing; requires residue handling seeders.
- Direct seeded rice: saves water and labor; needs strong weed control and careful nitrogen timing.

D. System trade offs

- Advancing wheat sowing often gives higher system net returns than marginally higher late rice yields.
- Residue retention improves soil organic matter but demands machinery and adjustments in weed and pest management.

E. Practical rules of thumb

- Target wheat sowing by mid November; each week of delay can cost several percent yield in warm springs.
- For rice, use intermittent irrigation after establishment; monitor infiltration and adjust set times to reduce deep percolation.
- Blend canal and tubewell water where electrical conductivity is moderate to maintain root zone salinity within tolerance.

F. Quick discussion cases

- Case 1: a watercourse adopts laser levelling and zero till wheat. Predict changes in water productivity and sowing dates.
- Case 2: direct seeded rice is adopted without a herbicide program. Diagnose yield penalty and propose a corrective package.

1 Application of the APO Protocol: Pakistan Agriculture System

1.1 1. Anchoring (Baseline Context)

Pakistan's agriculture sector contributes about 22.9% to national GDP and employs nearly 37.4% of the labour force. It also provides essential raw materials to industry and contributes significantly to foreign exchange earnings. However, it is highly vulnerable to climate shocks—including floods, droughts, abnormal heatwaves, and glacial melt. For example, the 2022 floods affected 33 million people across 94 districts, damaged 4.4 million acres of crops, and caused agricultural losses estimated at US$12.9 billion (43% of total damages).

1.2 2. Projection (System Dynamics)

- **Crop Production**: The 2022–23 agriculture growth slowed to 1.55%. Important crops shrank by -3.20% overall, with rice down by -21.5% (7.32 Mt), cotton collapsing by -41% (4.9 million bales), but wheat increased 5.4% (27.63 Mt) and maize rose 6.9% (10.18 Mt).
- **Water Availability**: Surface water dropped sharply—Kharif 2022 water availability was 43.3 MAF compared to 65.1 MAF in 2021, a 29.8% fall. This shortage stressed rice and cotton, while timely Rabi water (29.4 MAF, +7% over 2021–22) stabilised wheat yields.
- **Livestock**: Contributes 62.7% of agriculture value-added and 14.4% of GDP, growing by 3.78% in 2022–23. Livestock recovery cushioned rural livelihoods post-flood.

1.3 3. Outcomes (Performance and Shocks)

- **Floods 2022**: Caused unprecedented destruction: 1 million livestock lost, Sindh and Balochistan worst affected, and 14.6 million people requiring emergency food and livelihood assistance.
- **Recovery Measures**: The government launched the Kissan Package (2022) including Rs 1.3 trillion in agri-credit disbursement (71.7% of target), waiver of Rs 3.07 billion mark-up on farmer loans, Rs 3.9 billion interest-free loans, DAP price subsidy (Rs 2,500 per bag reduction), and Rs 30 billion subsidy on imported urea.
- **Shift in Crop Balance**: Sugarcane (91.1 Mt, +2.8%) and maize provided resilience, while cotton and rice suffered from climate sensitivity, marking a transition in Pakistan's crop profile.

1.4 4. Systemic Risks

- Heavy reliance on **irrigated agriculture**—90% of cultivated land is irrigated, making Pakistan acutely water-dependent.

- **Fertilizer shocks**—2022–23 domestic fertilizer production dropped -8.3%, imports declined -26.2%, and offtake fell -15%, raising costs of production for farmers.
- Climate-induced **instability**: Pakistan contributes $< 1\%$ of global GHGs yet is among the top 10 most climate-affected nations, underscoring high vulnerability to external emissions.

1.5 5. Resilience Pathways

- **Wheat as stabiliser**: Government intervention (support price raised from Rs 2,200 to Rs 3,900 per 40kg) ensured a 27.63 Mt harvest, stabilising food supply.
- **Oilseed policy**: Rapeseed/mustard production jumped +98%, potato +4.8%, showing potential diversification for food security and import substitution.
- **Institutional support**: Inclusion of agro-SMEs in credit schemes, subsidy for tractors (CKD duty cut from 35% to 15%), and import facilitation show structural push towards mechanisation.

1.6 6. Eigen-Space Expansion (Analytical Axes)

From the Pakistan case, key independent axes emerge:

1. **Historical Baseline**: Agriculture as 22.9% of GDP, 37.4% employment.
2. **Climatic Anchor**: 2022 floods as a transformative systemic shock.
3. **Crop Duality**: Wheat as stabiliser, cotton/rice as climate-vulnerable.
4. **Livestock Cushion**: Livestock sector buffering growth and rural incomes.
5. **Policy Leverage**: Kissan Package, subsidies, MSP hikes.
6. **Water Constraint**: -29.8% water availability shock in 2022 Kharif.

1 Comparative Application of the APO Protocol: Pakistan and Bangladesh

Step 1. Anchoring (Baseline Context)

Pakistan	Bangladesh
Agriculture contributes about 22.9% of GDP and employs 37.4% of the labour force. Exports rice but imports wheat when deficits occur. Highly vulnerable to climate extremes (floods, droughts, heatwaves, glacial melt).	Agriculture contributes about 12.9% of GDP but supports over 40% of employment. Strong reliance on rice (staple calorie base, 75% of cropped area). Wheat is minor (about 1.0–1.3 Mt production vs demand over 7 Mt). Heavily import dependent.

Step 2. Projection (System Dynamics)

Pakistan	Bangladesh
2022–23 growth slowed to 1.55%. Rice output fell by –21.5% (7.32 Mt); cotton –41%; wheat +5.4% (27.63 Mt); maize +6.9% (10.18 Mt). Water shortage: –29.8% in Kharif 2022 vs 2021. Livestock grew 3.78%, stabilising GDP share.	Rice dominates with Aman, Aus, and Boro cycles. Boro is irrigation intensive, displacing wheat. Aman sets the seasonal anchor. Wheat is squeezed in the calendar and mostly imported. Production fluctuations tied to weather (floods, cyclones).

Step 3. Outcomes (Performance and Shocks)

Pakistan	Bangladesh
2022 floods: 33 million affected, 4.4 million acres damaged, US$12.9 bn losses. Recovery: Kissan Package worth Rs 1.3 trillion (credit, urea, DAP subsidies). Shift in crop balance: wheat and sugarcane resilient, cotton and rice vulnerable.	Wheat imports buffer shocks. 2022–23 imports reached 19.1 lakh MT. Domestic wheat remains marginal. Boro rice stabilises annual rice supply, offsetting Aman/Aus variability. Bangladesh avoided catastrophic collapse by relying on imports and irrigation.

Step 4. Systemic Risks

Pakistan	Bangladesh
Heavy irrigation reliance (90% cultivated land irrigated). Fertiliser supply shocks: –8.3% domestic production, –26.2% imports. Climate instability despite <1% of global GHGs.	Import dependence for wheat (85–90% of requirement). Cropping intensity (190%) creates stress on soil and water. Irrigation for Boro overexploits groundwater. Vulnerable to salinity in coastal districts and climate shocks (cyclones).

Step 5. Resilience Pathways

Pakistan	Bangladesh
Wheat stabiliser (MSP Rs 2,200 to 3,900 per 40kg). Oilseed diversification (rapeseed +98%). Institutional support: agri-SMEs credit, mechanisation subsidies, duty cuts on tractors.	Boro rice as stabiliser. Import agreements (e.g. Russia 100k t at $267/t). Release of resistant wheat varieties (BARI Gom 33). Subsidies on fertiliser and credit for irrigation pumps. Expansion of safety nets (VGD, VGF) to offset food price shocks.

Step 6. Eigen-Space Expansion (Analytical Axes)

Pakistan	Bangladesh
1. Historical baseline: 22.9% GDP, 37.4% employment. 2. Climatic anchor: 2022 floods. 3. Crop duality: wheat stabiliser vs rice/cotton vulnerable. 4. Livestock cushion. 5. Policy leverage: Kissan Package. 6. Water constraint: –29.8% surface water.	1. Historical baseline: rice dominance, wheat marginal. 2. Seasonal anchor: Aman rice. 3. Early season constraint: Aus overlap. 4. Boro water squeeze. 5. Import dependence as structural axis. 6. Policy leverage: import deals, varietal innovation, safety nets.

1 Comparative Application of the APO Protocol: Pakistan and Bangladesh

Step 1. Anchoring (Baseline Context)

Pakistan	Bangladesh	Synthesis (Commonalities / Contrasts)
Agriculture contributes 22.9% of GDP and 37.4% employment. Climate vulnerable: floods, droughts, glacial melt.	Agriculture contributes 12.9% of GDP, but employs 40%+. Rice staple; wheat minor and import dependent.	Both agrarian economies, but Pakistan higher GDP share, Bangladesh higher labour share. Pakistan export-oriented (cotton, rice); Bangladesh food-security driven (rice imports wheat).

Step 2. Projection (System Dynamics)

Pakistan	Bangladesh	Synthesis
2022–23: Growth 1.55%; rice –21.5%; cotton –41%; wheat +5.4%; maize +6.9%. Water shortage –29.8% in Kharif. Livestock grew +3.78%.	Rice cycles (Aman, Aus, Boro) dominate. Boro (Jan–May) irrigated, displacing wheat. Imports fill wheat gap. Production fluctuates with floods/cyclones.	Both face climate-linked volatility. Pakistan diversified (maize, livestock); Bangladesh intensification (triple rice system). Wheat stabiliser in Pakistan; marginal in Bangladesh.

Step 3. Outcomes (Performance and Shocks)

Pakistan	Bangladesh	Synthesis
2022 floods: 33m people affected, US$12.9 bn agri losses. Recovery: Rs 1.3 trillion Kissan Package. Wheat and sugarcane resilient; cotton and rice vulnerable.	Wheat imports 19.1 lakh MT in 2022–23. Boro rice stabilises supply despite Aman/Aus shocks. Imports and irrigation prevented food collapse.	Pakistan shock = production losses, recovery via policy. Bangladesh shock = import dependence, recovery via trade. Both rely on state intervention but through different levers.

Step 4. Systemic Risks

Pakistan	Bangladesh	Synthesis
90% cultivated land irrigated = high water dependence. Fertiliser shocks: –26.2% imports. Climate risk despite <1% global GHGs.	Wheat import dependence (85–90%). Cropping intensity (190%) stresses land/water. Boro overuses groundwater. Coastal salinity and cyclone vulnerability.	Both dependent systems: Pakistan on water and fertiliser, Bangladesh on imports and irrigation. Both highly exposed to climate risk despite small GHG footprints.

Step 5. Resilience Pathways

Pakistan	Bangladesh	Synthesis
Wheat MSP raised to Rs 3,900/40kg, stabilising 27.63 Mt harvest. Oilseed diversification (rapeseed +98%). Agro-SME credit and mechanisation subsidies.	Boro rice stabiliser. Import deals (100k t from Russia at $267/t). BARI Gom 33 wheat variety. Subsidised fertiliser, irrigation pumps, and safety nets.	Both deploy subsidies and varietal innovation. Pakistan leans on domestic wheat policy; Bangladesh leans on trade and irrigation. Convergence: both use diversification (oilseeds in PK, pulses in BD).

Step 6. Eigen-Space Expansion (Analytical Axes)

Pakistan	Bangladesh	Synthesis
1. Historical baseline (22.9% GDP, 37.4% employment). 2. Climatic anchor: 2022 floods. 3. Crop duality: wheat stabiliser vs rice/cotton vulnerable. 4. Livestock cushion. 5. Policy leverage (Kissan Package). 6. Water constraint (surface water –29.8%).	1. Historical baseline: rice dominance, wheat marginal. 2. Seasonal anchor: Aman rice. 3. Aus overlap = early-season constraint. 4. Boro irrigation squeeze. 5. Import dependence axis. 6. Policy leverage: import deals, varietal innovation.	Both define eigenvectors from shocks + anchors. Pakistan's axes highlight floods and water; Bangladesh's axes highlight rice system and imports. Shared axis = policy leverage. Divergence = wheat central vs marginal.

1 Comparative Analysis: Wheat vs Rice Systems

Step 1. Anchoring (Baseline Context)

Wheat System	Rice System	Synthesis
Staple winter crop; sown Nov–Dec, harvested March–April. Contributes 35–40% of daily calorie intake in Pakistan; minor in Bangladesh (10–15%).	Dominant staple in South Asia. Triple cropping in Bangladesh (Aman, Aus, Boro). Provides 70–80% of calories. Seasonal anchor of agrarian cycle.	Wheat = caloric stabiliser in arid climates. Rice = caloric anchor in monsoon climates. Contrasts reflect water availability and dietary dependency.

Step 2. Projection (System Dynamics)

Wheat	Rice	Synthesis
Relies on winter irrigation (canal + tubewell). Vulnerable to late sowing due to cotton/paddy delays. Increasing heat stress (>35°C at grain filling).	Requires standing water 3–5 cm. Aman relies on monsoon rainfall, Boro depends on intensive irrigation. High fertiliser and energy demand for pumping.	Wheat water use = 4000 L/kg; rice = 2500–5000 L/kg depending on system. Both heavily water-dependent but rice demands higher continuous irrigation.

Step 3. Outcomes (Performance and Shocks)

Wheat	Rice	Synthesis
Pakistan 2023 harvest: 27.63 Mt. Yield gaps persist: Punjab leads; Sindh water shortage affects output. Bangladesh: 1.0–1.3 Mt (imports cover rest).	Bangladesh: 38 Mt rice (2022). Aman flood-vulnerable; Aus declining; Boro stable but groundwater stressed. Pakistan: 9.3 Mt rice in 2022–23, but floods cut –21.5%.	Wheat = stabiliser (Pakistan) but marginal (Bangladesh). Rice = structural anchor (Bangladesh) but export crop (Pakistan). Shocks reshape balance: wheat policy price vs rice water stress.

Step 4. Systemic Risks

Wheat	Rice	Synthesis
• Heat stress (terminal heat reduces yields by 15–20%). • Late sowing due to cotton/paddy delays. • Dependence on government procurement (MSP, imports).	• Groundwater depletion (Boro). • Flood/cyclone damage (Aman). • Methane emissions ∼10% of GHGs in Bangladesh.	Wheat's main risk = abiotic stress + policy dependence. Rice's main risk = ecological stress + climate disasters. System interaction: paddy harvest delays wheat sowing; wheat policies crowd out rice diversification.

Step 5. Resilience Pathways

Wheat	Rice	Synthesis
BARI Gom 33 blast-resistant, HD-3086 heat-tolerant varieties. MSP support prices. Import diversification (Russia, Black Sea).	Hybrid rice (BRRI dhan hybrids). Mechanised transplanting. Alternate Wetting and Drying (AWD) for water saving. Crop insurance schemes.	Both depend on varietal innovation + state policy. Wheat: trade cushion. Rice: water-tech cushion. Together, innovations shape resilience pathways of South Asian food security.

Step 6. Eigen-Space Expansion (Analytical Axes)

Wheat	Rice	Synthesis
1. Import dependence. 2. Heat/abiotic stress. 3. Policy procurement. 4. Cotton/paddy conflict (sowing delays).	1. Seasonal anchor (Aman). 2. Aus overlap constraint. 3. Boro irrigation squeeze. 4. Climate disaster axis (floods, cyclones).	Shared: water dependence, policy leverage, varietal innovation. Divergent: wheat as stabiliser vs rice as anchor. Theoretical debate: rice–wheat system shows asymmetry — should they be de-hyphenated for policy clarity?