Delivering for Nutrition in South Asia

Towards Impact at Scale

Crop Diversification with Nutrition Training Boosts Food Security, Income, Sustainability, and Agrifood Transformation in Rural Bangladesh

Pathways to Nutritious, Profitable, and Climate-Resilient Farming

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Rationale

🌾 The Triple Challenge: Productivity, Nutrition, and Sustainability

🥗 The Productivity–Nutrition Gap

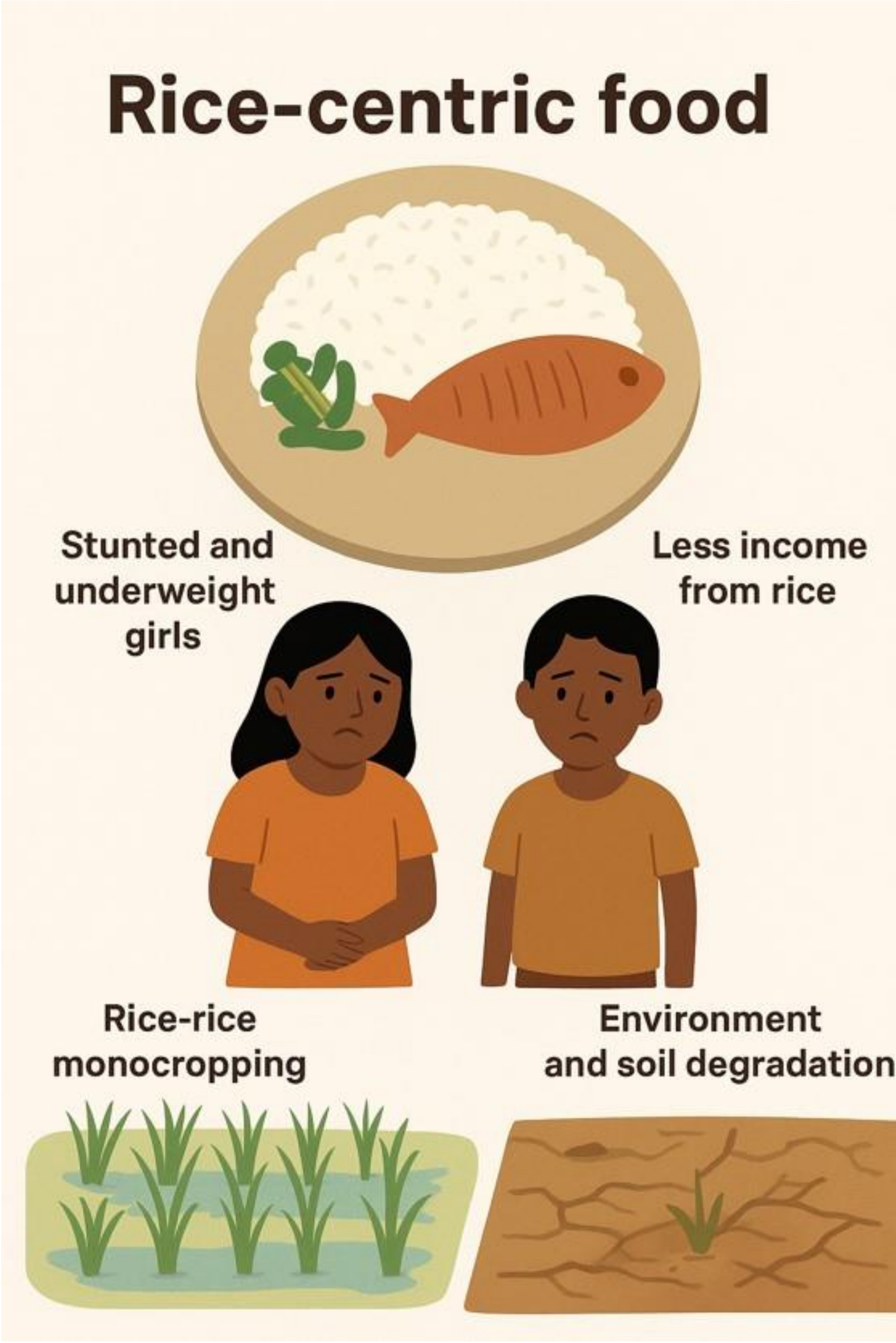
- Global food systems produce enough calories but leave **over 3 billion people** without a healthy diet.
- In South Asia, **rice monoculture** addresses hunger but not *hidden hunger*, leading to widespread micronutrient deficiencies.

🌍 The Environmental Cost of Monoculture

- Intensive **Rice–Rice systems**, especially flooded rice, are major sources of **methane (CH_4)**.
- The **environmental footprint** of food production is now as important as food quantity.

The Bangladesh Imperative

- Despite a **threefold increase in rice production**, the nation faces a **triple burden**: malnutrition, climate vulnerability, and economic risk for farmers.
- ➡️ We need a paradigm shift: **Agricultural systems must be evaluated not just on yield, but on their nutritional output and environmental footprint simultaneously.**



Research Objectives

🧪 Testing an Integrated Solution for a Sustainable Food System

Hypothesis: Can diversified farming systems, including biofortified crops, combined with nutrition training, provide a solution that boosts incomes, improves diets, and reduces the climate footprint of food production?

🎯 Study Objectives

This study assessed a diversified farming model compared to the traditional rice-rice system across three key dimensions: productivity, profitability, and planetary health.

📈 **Quantify the Agronomic & Economic Impact**

- Compare yields and net income of diversified systems (e.g., *Rice–Lentil–Sweet Corn*) vs. rice monoculture.

🥗 **Measure the Nutritional Output**

- Assess total output and availability of essential micronutrients such as **zinc** and **iron** from different cropping systems.

🔄 **Evaluate the Role of Behavior Change**

- Determine the impact of **nutrition-sensitive training** on household dietary diversity.

🌍 **Assess Environmental Efficiency**

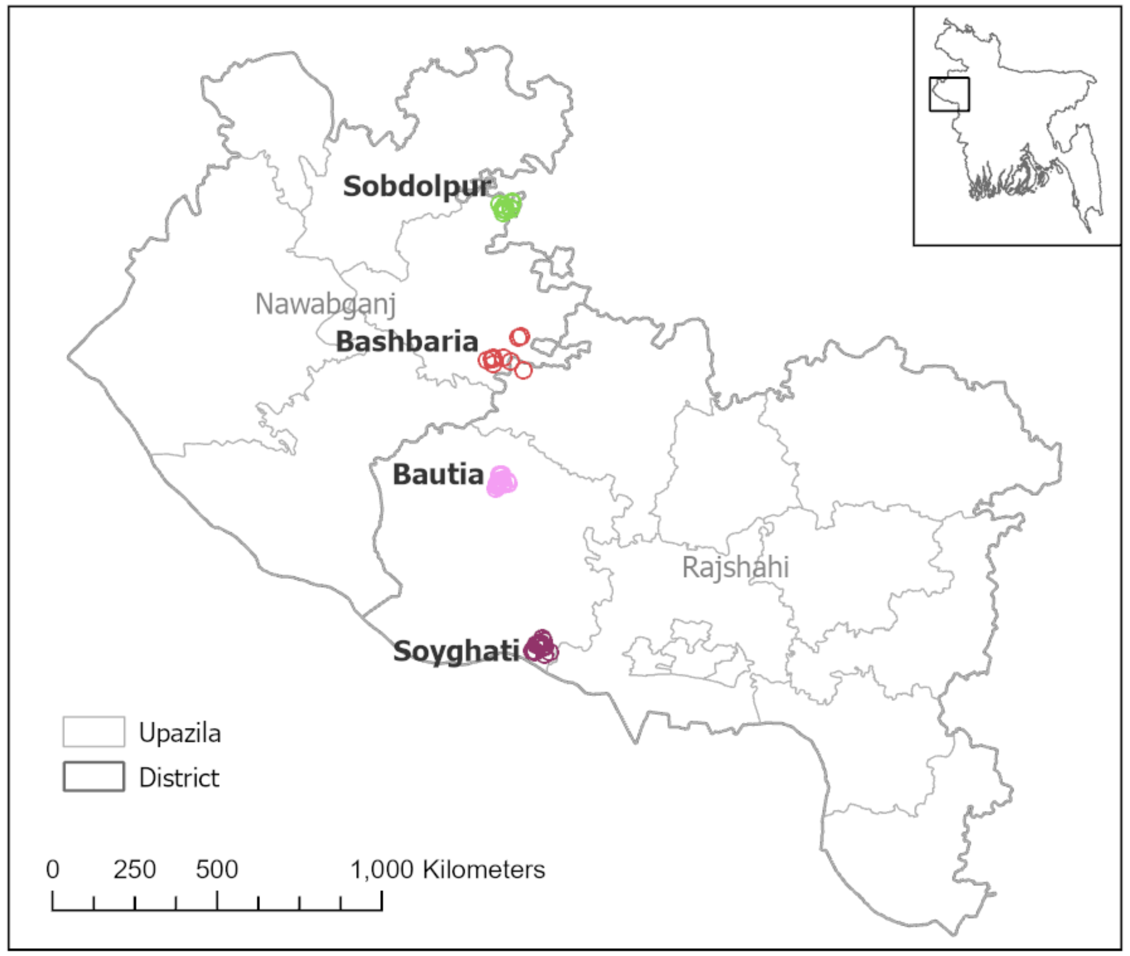
- Calculate and compare **Yield-Scaled Emission Intensity** (kg CO_2-eq per kg of food) for diversified systems vs. rice–rice cropping.

📘 **Develop a Scalable Model**

- **Synthesize results into a framework to guide policies that jointly improve agricultural productivity, human nutrition, and climate resilience.**

Methods

- **Study Area & Context:** Conducted in drought-prone High Barind Tract (AEZ 25–26), covering **Rajshahi and Chapainawabganj** districts.
- **Field Trials: 40 farmers' fields per district** involved in participatory research trials from **2022 to 2024**.



Treatments

Treat	Treat-code	Kharif-2	Rabi	Kharif-1
A. Rajshahi, two villages: 1. Bautia (AgP+NT) 2. Soyghati (AgP+)				
T1	**RLSc**	**Aman rice**	**Lentil**	**Sweet corn**
T2	**RMraS**	**Aman rice**	**Maize+red amaranth**	**Sole Sorghum**
T3	**RMuScp**	**Aman rice**	**Mustard (BARI14)**	**Sorghum+Cowpea**
T4	**RMuF**	**Aman rice**	**Mustard (BARI18)**	**Fallow**
T5	RR	Aman rice	Boro rice	
B. Chapainawabganj, two villages, 1. Bashbaria (AgP+NT), 2. Sobdolpur (AgP+)				
T1	**RLSc**	**Aman rice**	**Lentil**	**Sweet corn**
T2	**RMraS**	**Aman rice**	**Maize+red amaranth**	**Sole Sorghum**
T3	**RCScp**	**Aman rice**	**Chickpea**	**Sorghum+Cowpea**
T4	**RWF**	**Aman rice**	**Wheat**	**Fallow**
T5	RR	Aman rice	Boro rice	

BRRI Dhan 51 on the left and BINA dhan 20 on the right side, trial plot *kharif* 2, 2022-23 in Soyghati, Rajshahi

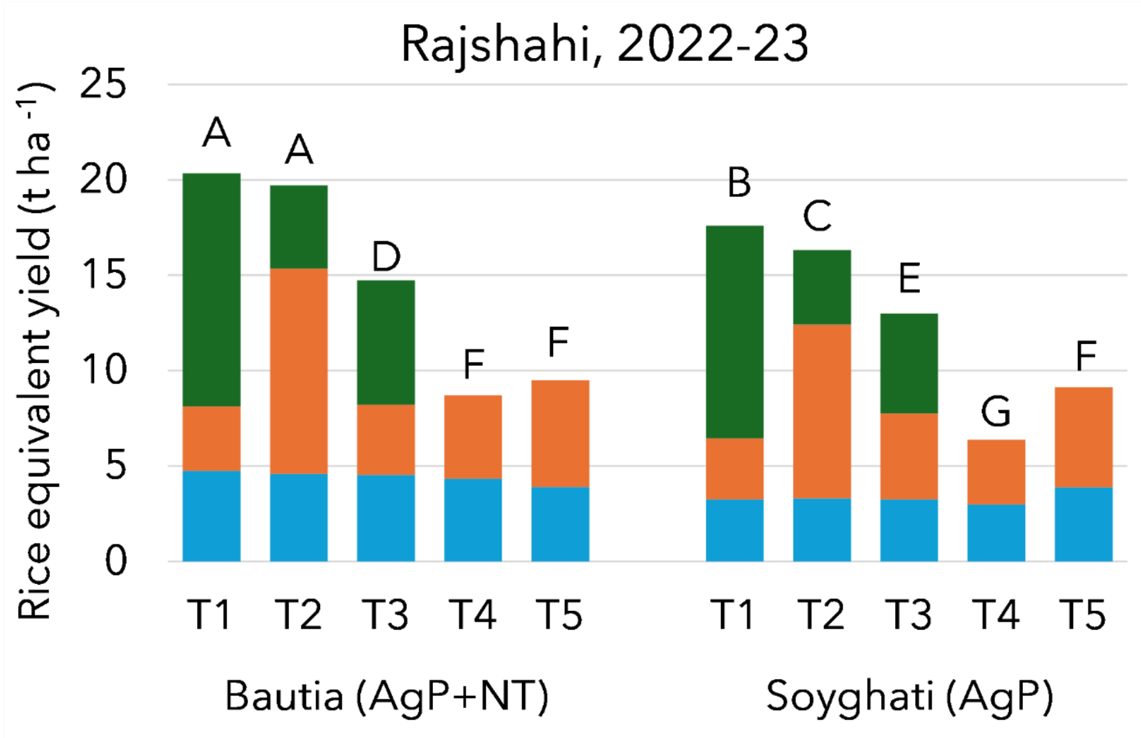
Data calculation

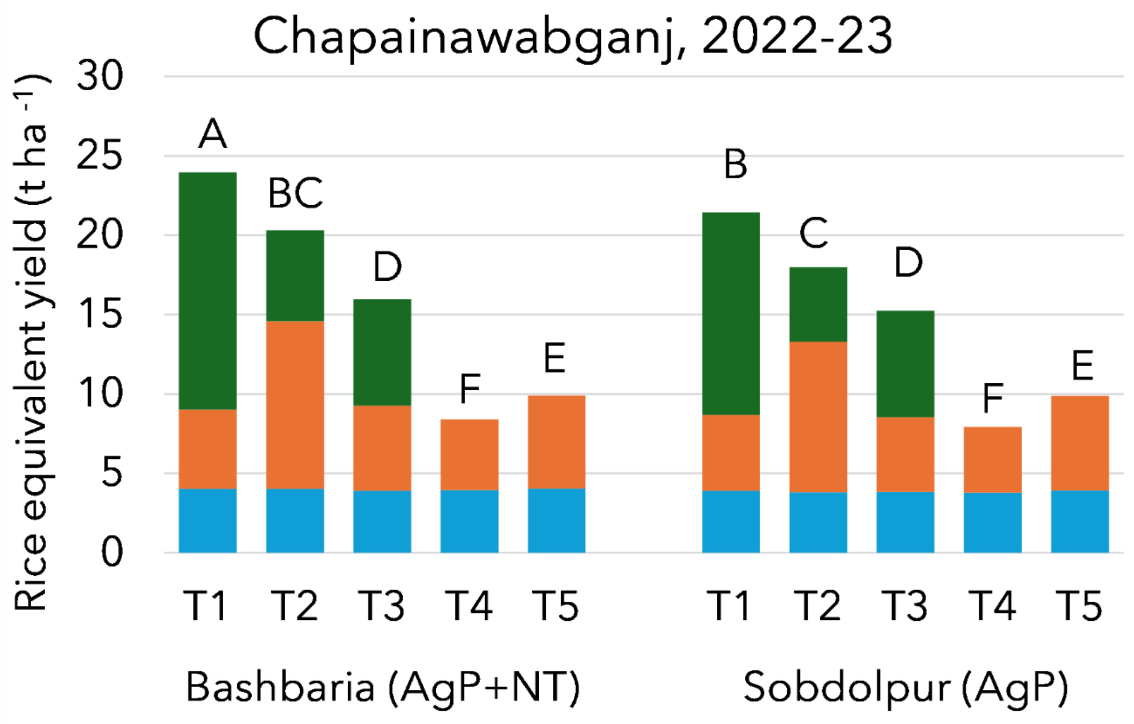
1. Productivity
2. Economic performance: TPC, GR, NR, BCR
3. **Nutrition Yield (DeFries et al., 2015)**
4. **Carbon footprint (using CCAF MOT)**
5. **Food Group Diversity Score (FGDS, 01-10)** Assessment
   - Five-round Dietary Quality Questionnaire (DDQ) surveys were conducted among four farmer groups: control (n=180), AgP (n=180), NT (n=180), and AgP+NT (n=180). These surveys were conducted three months after training and after the crop season.
   - The FGDS assessment was based on dietary intake, using 29 food groups to calculate the score **(Hereforth et al., 2024).**

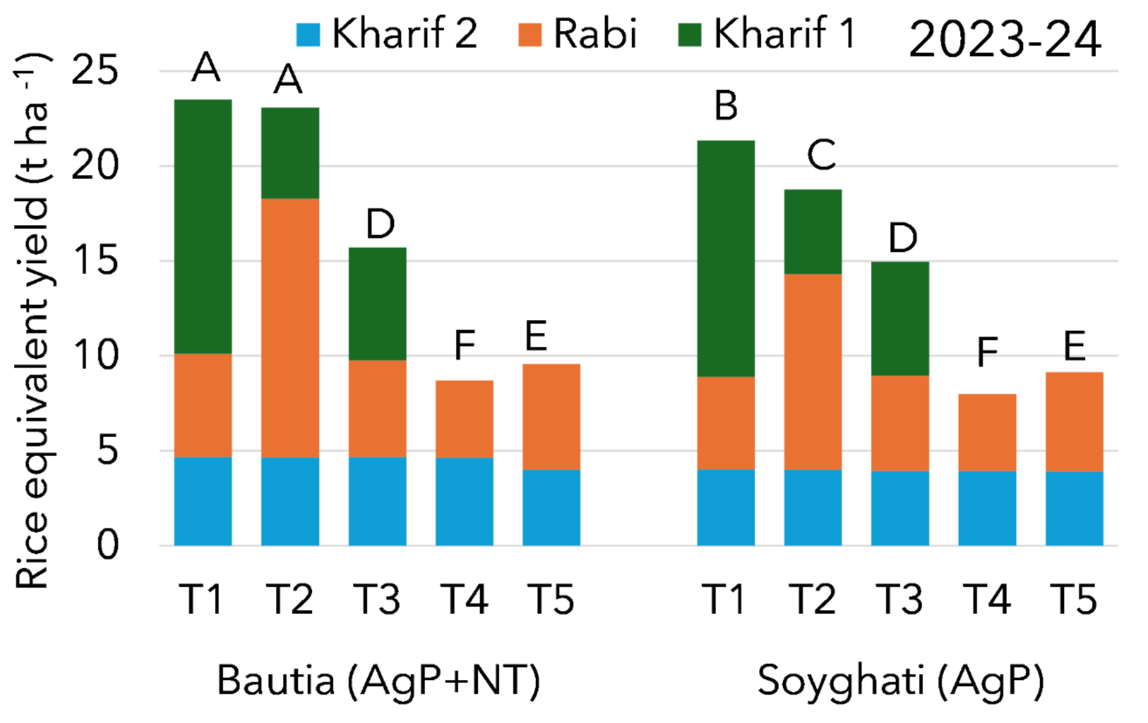
Statistical Analysis

Agronomic, economic, and nutritional yield analyses, Global Warming Potential, Emission intensity (as split-plot) and FGDS measured using LMM and TWFE models.

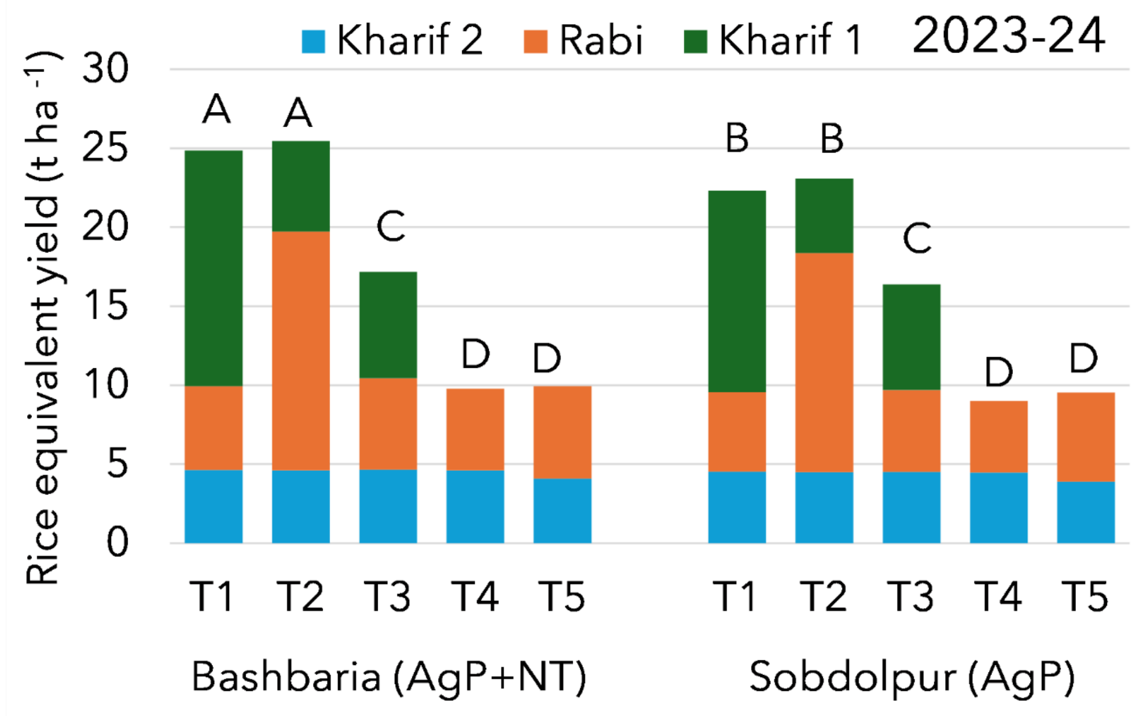
Diversified Cropping Systems Enhance Productivity







T1: Rice-Lentil-Sweet corn,
T2: Aman rice-Maize+red amaranth-Sorghum
T3: Aman rice-Mustard-Sorghum+Cowpea
T4: Aman rice-Mustard-Fallow
T5: Aman rice-Bor rice



T1: Rice-Lentil-Sweet corn,
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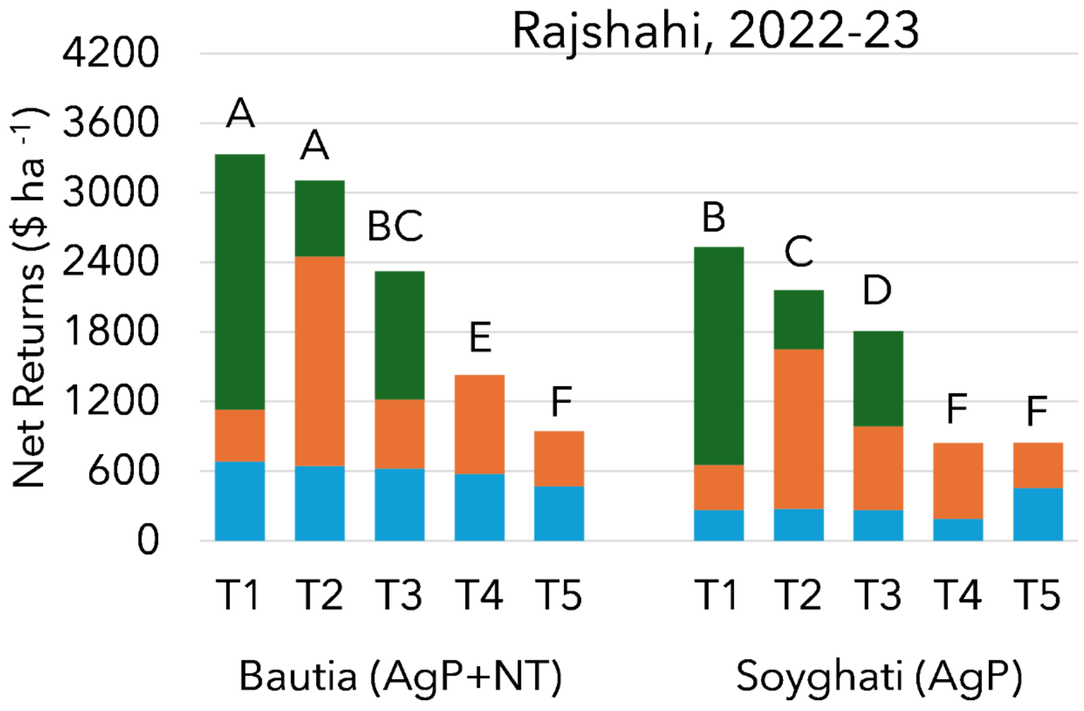
T3: Aman rice-Chickpea-Sorghum+Cowpea,
T4: Aman rice-Wheat-Fallow
T5: Aman rice-Bor rice

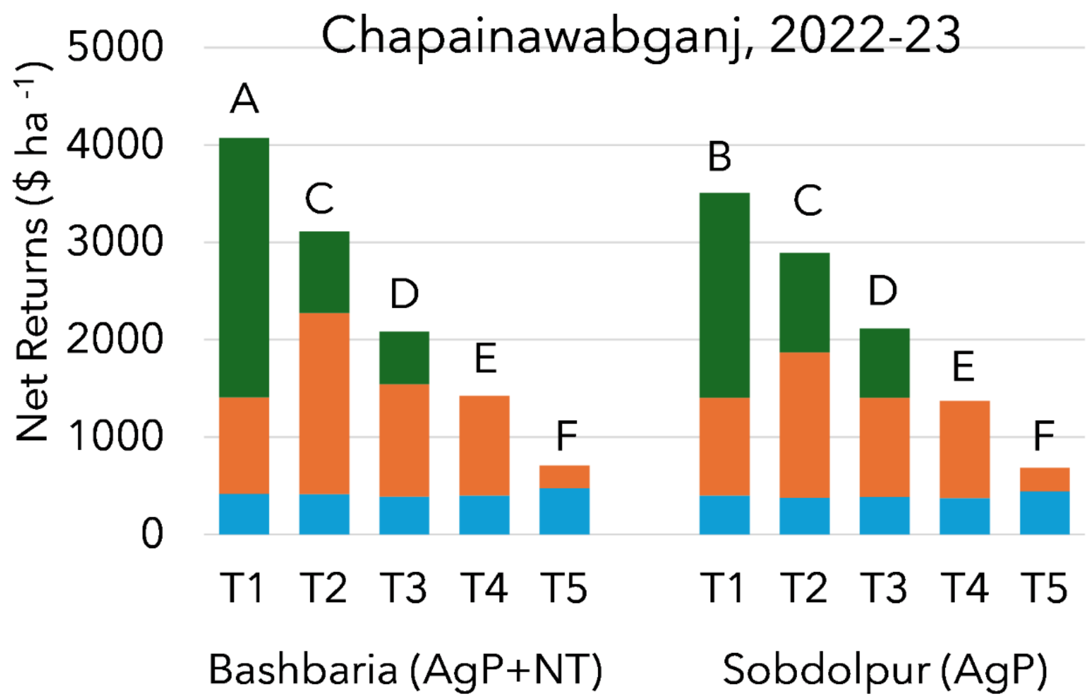
Key Findings on Productivity

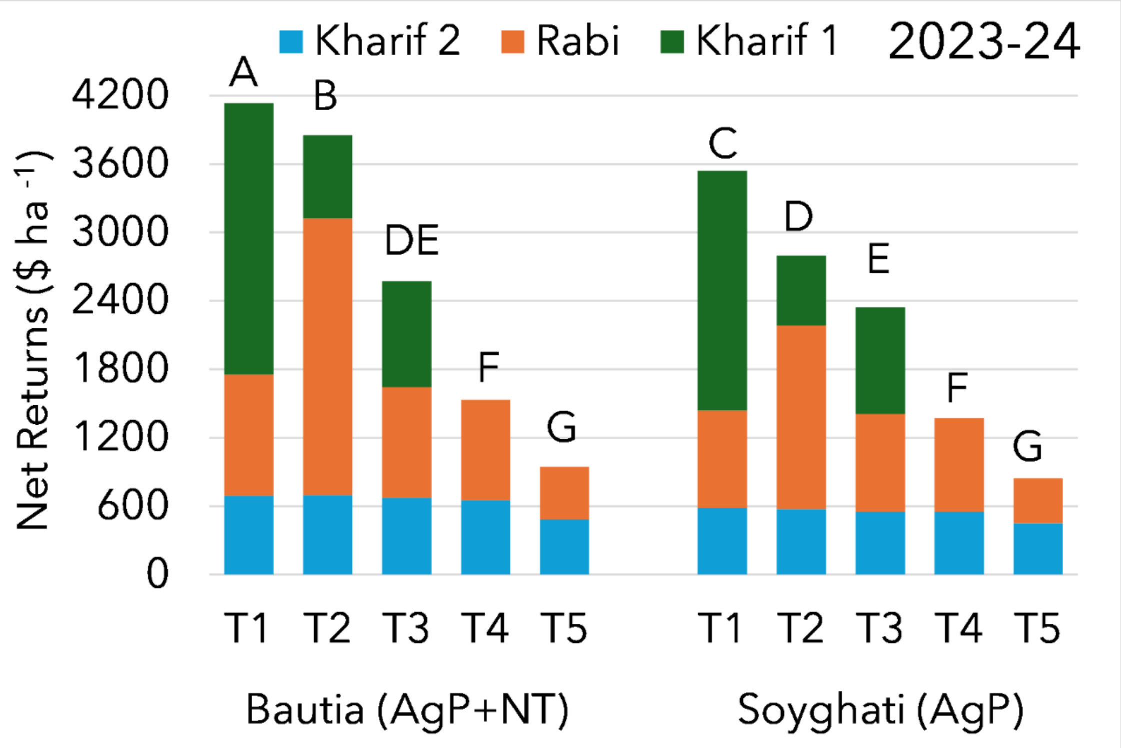
- The villages received combined intervention , like Bautia, Bashabria (AgP+NT) performed significantly better than Soyghati (AgP+), and Sobdolpurr (Agp) in all diversified cropping systems (T1-T3).
- **All diversified cropping systems almost doubled productivity (104-152%) over farmers' practices (T4 and T5).**
- Among the cropping systems, **Rice-Lentil-Sweet Corn & Rice-Maize+red amaranth-Sorghum yielded the highest REY, 23.0-24.9 & 19.5-24.3 t ha^{-1}, respectively.**

Mustard (BARI 18) on the left and mustard (BARI 14) on the right, trial plot rabi 2022-23 in Soyghati, Rajshahi, Photo credit: Maruf Hossain Shanto

Diversified Cropping Systems Improve Profitability







T1: Rice-Lentil-Sweet corn
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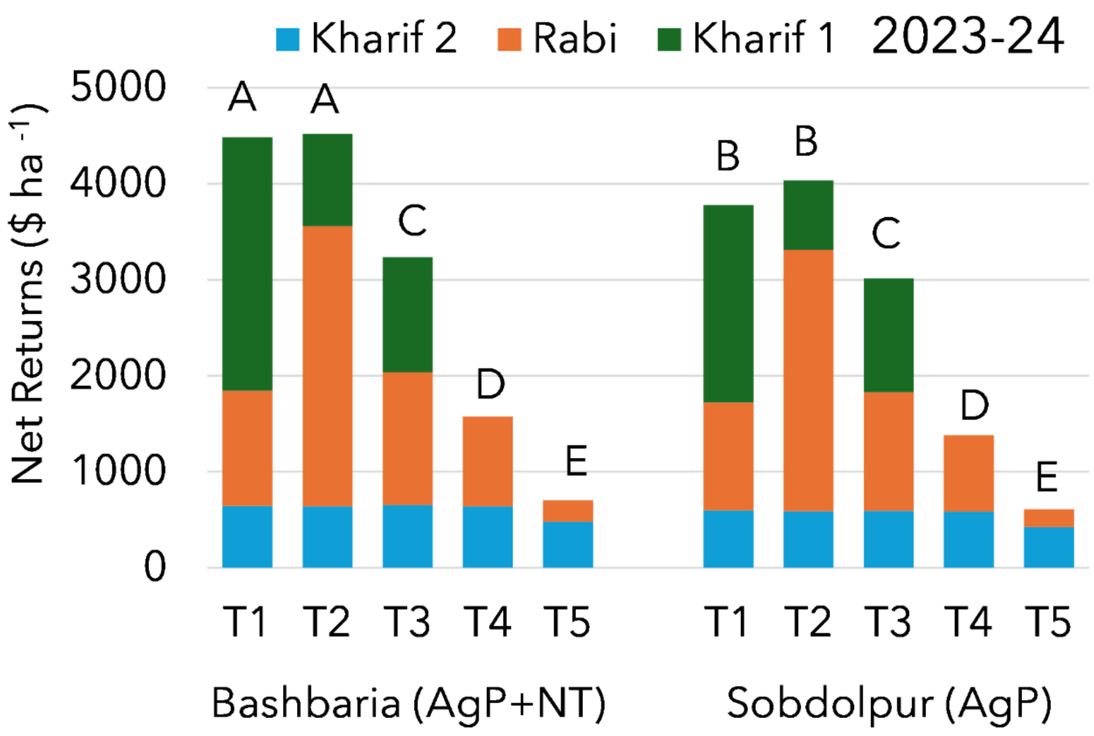
T4: Aman rice-Mustard-Fallow
T5: Aman rice-Bor rice



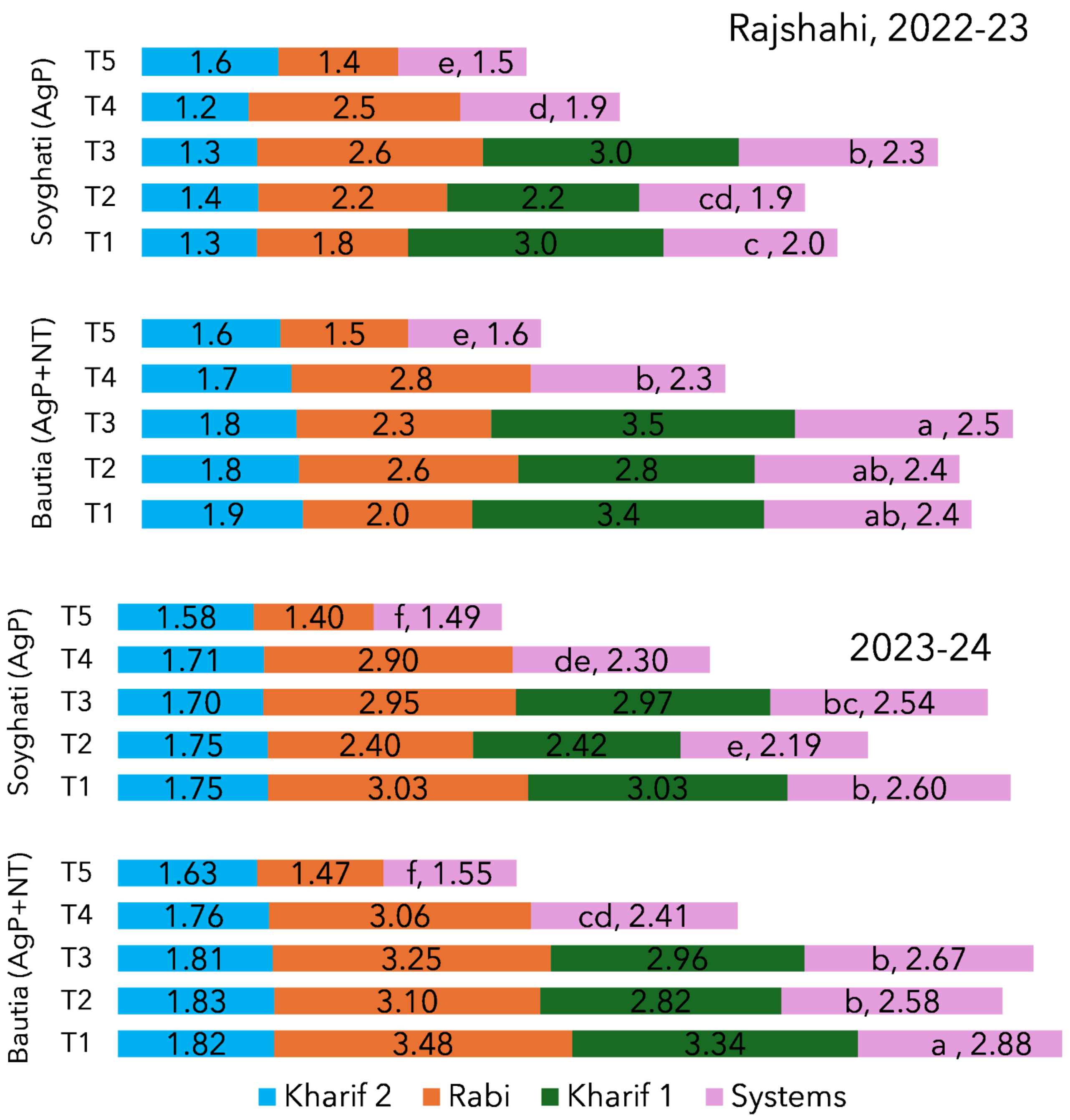
T1: Rice-Lentil-Sweet corn
T2: Aman rice-Maize+red amaranth-Sorghum
T3: Aman rice-Chickpea-Sorghum+Cowpea
T4: Aman rice-Wheat-Fallow
T5: Aman rice-Bor rice

Net Returns

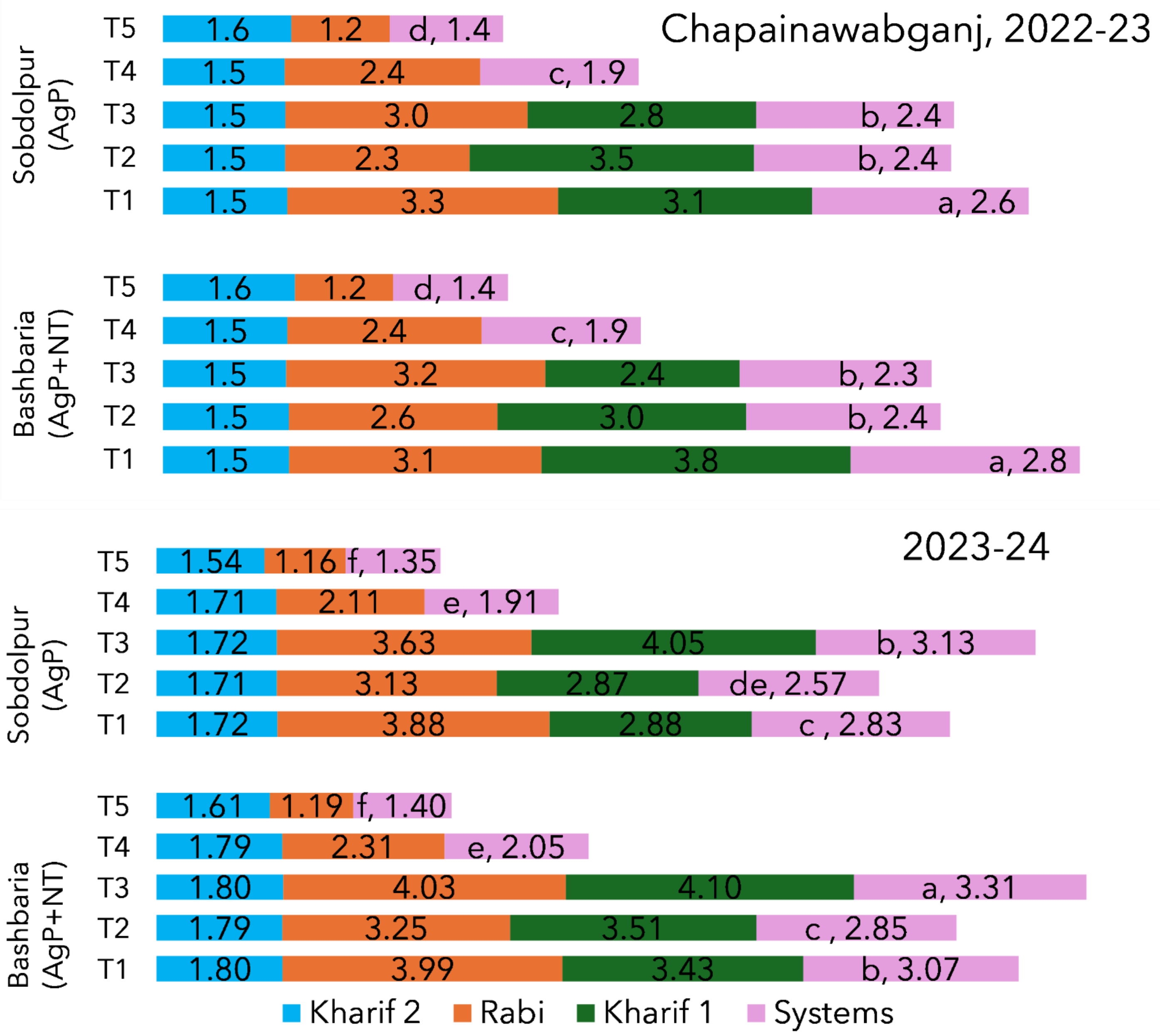
- **AgP+NT boosted net returns by 18–36%** over AgP alone.
- **Cropping system choice** was the strongest profitability driver.
- **Top performers:**
  - **RLSc:** Rajshahi **4136 US$ ha^{-1}**, & in Chapainawabganj **4483 US$ ha^{-1}**
  - **RMraS:** also generated high returns.
- **Traditional systems (RR, RMuF, RWF): <700 US$ ha^{-1}**.
- **Diversified systems achieved 3–6× higher returns** than rice monoculture.

Wheat and chickpea trial plot in rabi 2022-23 in Soyghati, Rajshahi

Diversified Cropping Systems Enhance Economic Efficiency



T1: Rice-Lentil-Sweet corn
T2: Aman rice-Maize+red amaranth-Sorghum
T3: Aman rice-Mustard-Sorghum+Cowpea
T4: Aman rice-Mustard-Fallow
T5: Aman rice-Bor rice



T1: Rice-Lentil-Sweet corn
T2: Aman rice-Maize+red amaranth-Sorghum
T3: Aman rice-Cheakpea-Sorghum+Cowpea,
T4: Aman rice-Wheat-Fallow,
T5: Aman rice-Bor rice

Benefit–Cost Ratio (BCR)

- The combination of AgP and NT resulted in higher Benefit-Cost Ratios (BCRs) compared to AgP alone.
- Diversified systems demonstrated the strongest BCRs.
- **For the RLSc, Rajshahi had a BCR of 2.88, while Chapainawabganj had the highest at 3.31.**
- RMraS also provided strong BCRs across different locations.
- Traditional systems, such as RR, RMuF, and RWF, achieved BCRs between **1.3 and 1.4**, which is near break-even.
- In summary, the combination of AgP, NT, and diversification yielded the highest and most efficient BCRs in both districts.

Diversified Cropping Systems Increase Nutrition Yield

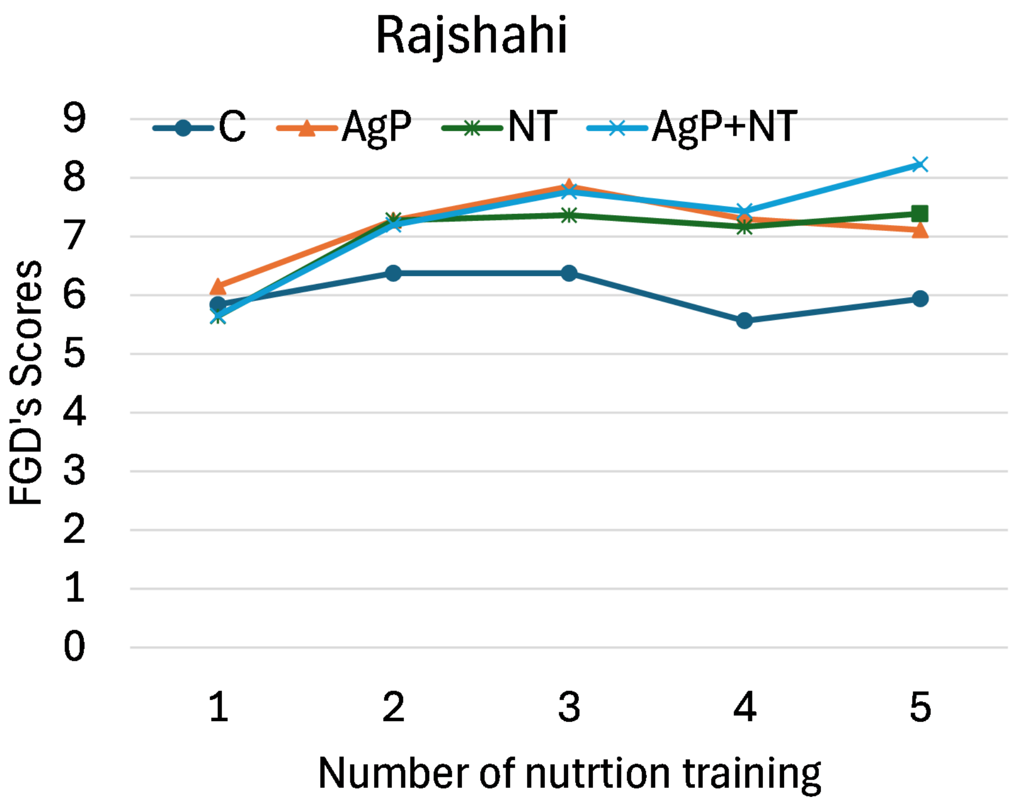
Source of Variations	Rajshahi, 2022-23							Rajshahi, 2023-24						
	Carbo	Protein	Fat	Zinc	Iron	Vit-C	Vit-A	Carbo	Protein	Fat	Zinc	Iron	Vit-C	Vit-A
Location (L)	Nutrition yields (adults ha $^{-1}$ yr $^{-1}$)													
Bautia (AgP+NT)	37.6a	39.4a	8.9a	55.1a	62.6a	12.0a	23.7a	41.1a	45.8a	10.4a	62.6a	72.2a	14.4	28.3
Soyghati (AgP)	30.4b	33.6b	8.3b	45.3b	53.1b	11.4a	22.5a	35.3b	39.7b	9.6b	53.6b	61.5b	11.4	21.8
Cropping systems (CS)														
RLSc	29.3c	34.5b	2.2d	41.1c	42.0c	7.3b	0.7b	34.4c	46.0b	2.7d	50.6b	53.0c	9.1b	0.92b
RMraS	**54.9a**	**62.3a**	9.1c	**96.3a**	**128.7a**	**51.4a**	**114.6a**	**65.0a**	**73.9a**	11.2c	**114.2a**	**148.1a**	**55.4a**	**124.2a**
RMuScp	20.8d	28.8c	**15.7a**	44.0b	53.2b	0	0.06b	23.2d	34.0c	**19.3a**	51.3b	62.9b	0.0c	0.07b
RMuF	19.6d	27.2d	14.9b	41.5c	50.3b	0	0.06b	22.7d	29.9d	15.6b	46.2c	55.2c	0.0c	0.06b
RR	45.4b	29.6c	1.1e	28.1d	14.9d	0	0	45.6b	29.8d	1.1e	28.2d	15.0d	0.0c	0.0b
F ratio														
L	145***	142***	16***	148***	117***	NS	NS	135***	134***	21***	142***	13***	13**	13**
CS	1536***	1391**	1998***	1995***	2906***	1914***	2146***	1520***	1178***	1407***	1818***	23264***	679***	789***

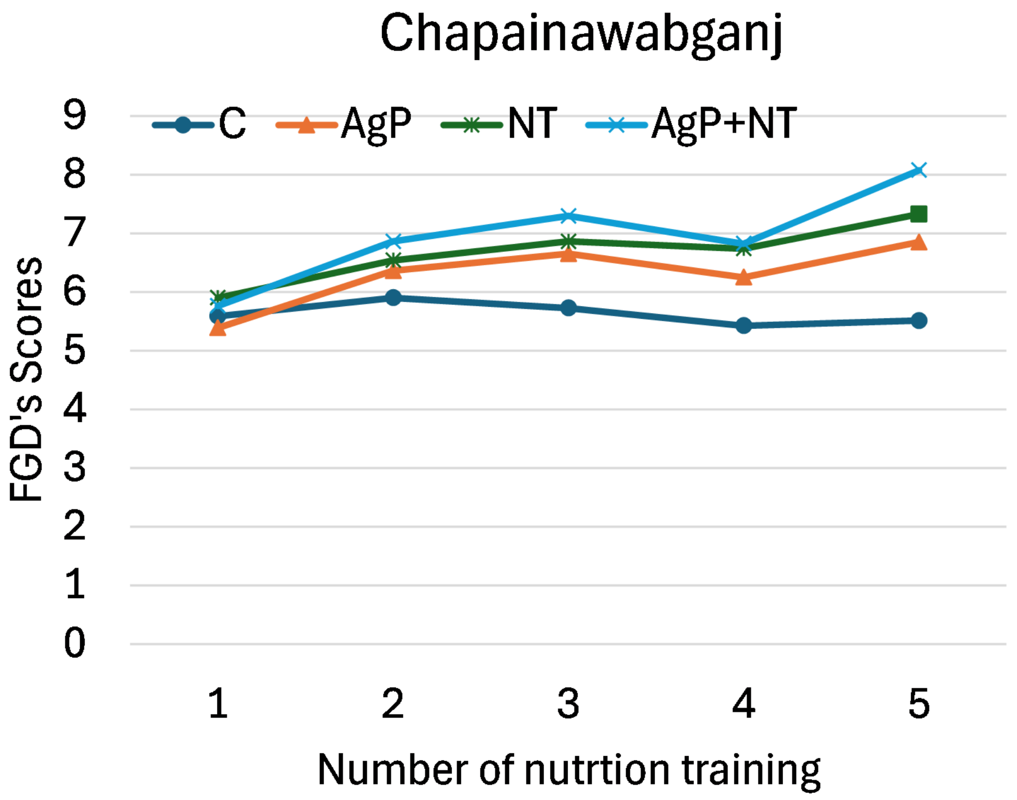
Source of Variations	Chapainawabganj, 2022-23							Chapainawabganj, 2023-24						
	Carbo	Protein	Fat	Zinc	Iron	Vit-C	Vit-A	Carbo	Protein	Fat	Zinc	Iron	Vit-C	Vit-A
Location (L)	Nutrition yields (adults ha $^{-1}$ yr $^{-1}$)													
Bashbaria (AgP+NT)	39.8	42.2a	4.2a	53.6	68.2	14.7a	29.0a	46.5a	49.7a	5.3a	64.7a	81.6a	17.3a	34.8a
Sobdolpur (AgP)	37.9	39.5b	3.9b	50.4	62.4	12.1b	23.8b	44.3b	46.8b	5.0b	61.4b	75.7b	14.8b	29.8b
Cropping systems (CS)														
RLSc	31.8c	44.4b	2.5c	47.7b	50.5d	8.3b	0.86b	35.4d	48.2b	2.7c	52.7b	55.5d	8.7b	0.9b
RMraS	**57.0a**	**66.0a**	**9.7a**	**101.3a**	**139.2a**	**58.8a**	**130.9a**	**78.1a**	**91.2a**	**14.1a**	**139.8a**	**184.7a**	**72.3a**	**161.9a**
RCScp	23.9d	30.0d	3.5b	34.3c	57.7c	0	0.21b	27.8e	33.9d	3.8b	39.5c	65.1c	0.0c	0.23b
RWF	33.3b	32.4c	3.5b	46.8b	63.1b	0	0.0b	38.5c	37.2c	4.0b	53.9b	72.4b	0.0c	0.0b
RR	48.2	31.5cd	1.1d	29.8d	15.8e	0	0.0b	47.3b	30.9e	1.1d	29.3d	15.5e	0.0c	0.0b
F ratio														
L	10**	24***	20***	16***	25***	10**	10**	33***	29***	17***	24***	21***	6*	4*
CS	1056***	1012***	1826***	1975***	1676***	842***	943***	2085***	2617***	2923***	3380***	1918***	820***	936***

Nutrition Yield – Key Findings (6 bullets)

- **Diversified systems sharply increased macro- & micro-nutrient yields**, far outperforming rice–rice (RR).
- **RMraS led overall**, supplying up to **78–91 adults' carbs/protein** and **14 adults' fat** per hectare.
- **RR remained the weakest**, providing <50 adults' needs and almost no fat.
- **Micronutrients rose dramatically under RMraS**, reaching **140 adults' zinc**, **191 iron**, and **173 vitamin A** per hectare.
- **Mustard-inclusive rotations** improved fat supply, peaking at **≈19 adults' needs**.
- Diversification in cropping ensures nutritional security.

Effects of Nutrition Training on Food Group Diversity Score (FGDS)





Key findings

- **Nutrition training was the strongest driver** of dietary improvement across households.
- **Combined AgP+NT households achieved the highest (8.23, Rajshahi, & 8.03 in Chapainawabganj), and most sustained gains**, with dietary diversity increasing by **up to 2.4 points (P < 0.001)**.
- **Diversified systems + nutrition training** delivered the **measurable nutritional improvements** at the household level.

Main effects of diversified cropping system treatments and covariates across multiple model specifications.

Predictor	LMM (CR2)- Season	LMM (CR2) - Round	GEE exchangeable	GEE AR (1) (robust)
Intercept	5.796 (5.463, 6.130) ***	4.572 (4.240, 4.903) ***	5.796 (5.464, 6.128) ***	4.628 (4.294, 4.962)
Treatment				
AgP	0.887 (0.676, 1.098) ***	0.888 (0.676, 1.099) ***	0.887 (0.677, 1.097) ***	0.849 (0.642, 1.056)
NT	0.993 (0.780, 1.205) ***	0.993 (0.780, 1.206) ***	0.993 (0.781, 1.204) ***	0.968 (0.761, 1.175)
AgP + NT	1.298 (1.101, 1.494) ***	1.297 (1.100, 1.493) ***	1.298 (1.102, 1.493) ***	1.284 (1.093, 1.475)
Season				
Kharif2	-0.399 (-0.537, -0.260)	-0.399 (-0.537, -0.260)	-0.399 (-0.537, -0.260)	–
Rabi	-0.484 (-0.593, -0.374)	-0.484 (-0.593, -0.374)	-0.484 (-0.593, -0.375)	–
Locations (Rajshahi)	0.443 (0.308, 0.579) ***	0.444 (0.308, 0.580) ***	0.443 (0.308, 0.578) ***	0.402 (0.269, 0.534)
Gender (Female)	-0.206 (-0.351, -0.060) **	-0.216 (-0.361, -0.071)	-0.205 (-0.350, -0.061) **	-0.230 (-0.375, -0.085)
Age (years)	0.006 (0.001, 0.012) *	0.006 (-0.000, 0.012)	0.006 (0.001, 0.012) *	0.006 (-0.000, 0.012)
Round				
Round 2	–	0.981 (0.836, 1.126) ***	–	0.980 (0.835, 1.124)
Round 3	–	1.247 (1.111, 1.382) ***	–	1.246 (1.110, 1.381)
Round 4	–	0.847 (0.697, 0.997) ***	–	0.846 (0.696, 0.996)
Round 5	–	1.313 (1.166, 1.460) ***	–	1.313 (1.166, 1.459)

Coefficients are shown with 95% confidence intervals in parentheses. Significance is indicated by stars (P *< 0.05, **P < 0.01, ***P < 0.001). **Linear mixed models (LMM)** use cluster-robust CR2 covariance, specified by season or round. **Generalized estimating equations (GEE)** report robust standard errors with exchangeable or AR(1) correlation structures. Predictors include treatment (AgP = Agronomic practices, NT = Nutrition training, AgP+NT = combined), seasonal effects, district, female gender, age, and survey round (Rounds 2–5 relative to Round 1).

Treatment effects

- Diversified systems improved dietary quality.
- NT and AgP ↑ ~1.0 point each.
- AgP + NT ↑ ~1.3 points (**strongest effect**).

Seasonal & Location

- Drops in **Kharif-2** and **Rabi**.
- **Rajshahi** is consistently higher.

Sociodemographic

- Females lower (~–0.22).
- Age effect is small (+0.006).

Trends

- Big gains in Rounds **2, 3, 5**.
- Slight dip in Round **4**.

Conclusion

- **Combined AgP + NT works best, shaped by season, gender, and location**

Treatment × Round interaction effects across multiple model specifications on dietary quality scores

Treatment × Round	LMM (CR2)	OLS FE (cl id)	TWFE (ID FE + District × Round FE)
AgP × Round 2	0.630 (0.239, 1.021) **	1.015 (0.729, 1.301) ***	1.015 (0.729, 1.301) ***
AgP × Round 3	1.144 (0.753, 1.535) ***	1.446 (1.199, 1.693) ***	1.446 (1.199, 1.693) ***
AgP × Round 4	1.230 (0.839, 1.621) ***	0.971 (0.704, 1.238) ***	0.971 (0.704, 1.238) ***
AgP × Round 5	1.208 (0.817, 1.599) ***	1.180 (0.956, 1.404) ***	1.180 (0.956, 1.404) ***
NT × Round 2	0.718 (0.327, 1.109)***	1.108 (0.831, 1.385) ***	1.108 (0.831, 1.385) ***
NT × Round 3	1.006 (0.615, 1.397) ***	1.315 (1.067, 1.563) ***	1.315 (1.067, 1.563) ***
NT × Round 4	1.405 (1.014, 1.796) ***	1.152 (0.886, 1.418) ***	1.152 (0.886, 1.418) ***
NT × Round 5	1.580 (1.189, 1.971) ***	1.558 (1.313, 1.803) ***	1.558 (1.313, 1.803) ***
AgP+NT × Round 2	0.897 (0.508, 1.286) ***	1.246 (0.981, 1.511) ***	1.246 (0.981, 1.511) ***
AgP+NT × Round 3	1.486 (1.095, 1.877) ***	1.747 (1.512, 1.982) ***	1.747 (1.512, 1.982) ***
AgP+NT × Round 4	1.650 (1.259, 2.041) ***	1.345 (1.127, 1.563) ***	1.345 (1.127, 1.563) ***
AgP+NT × Round 5	2.435 (2.044, 2.826) ***	2.366 (2.171, 2.561) ***	2.366 (2.171, 2.561) ***

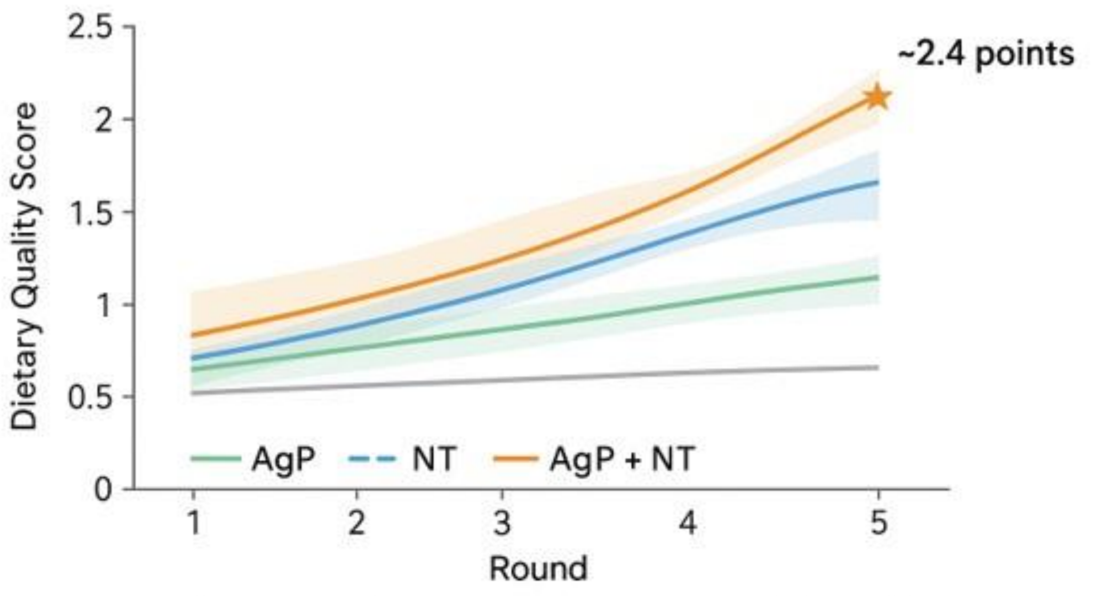
Reported coefficients with 95% confidence intervals in parentheses. Stars indicate statistical significance (P < 0.05, *P < 0.01, **P < 0.001). Estimates are from **linear mixed models** with cluster-robust covariance (LMM, CR2), **ordinary least squares with individual-level clustered fixed effects** (OLS FE, cl id), and **two-way fixed effects controlling for both individual and district × round heterogeneity (TWFE)**. Interaction terms reflect treatment differences relative to the baseline round. Predictors include treatment (AgP = Agronomic practices, NT = Nutrition training, AgP+NT = combined), and survey round (Rounds 2–5 relative to Round 1).Full model specification is provided in the Methods.

Key Findings

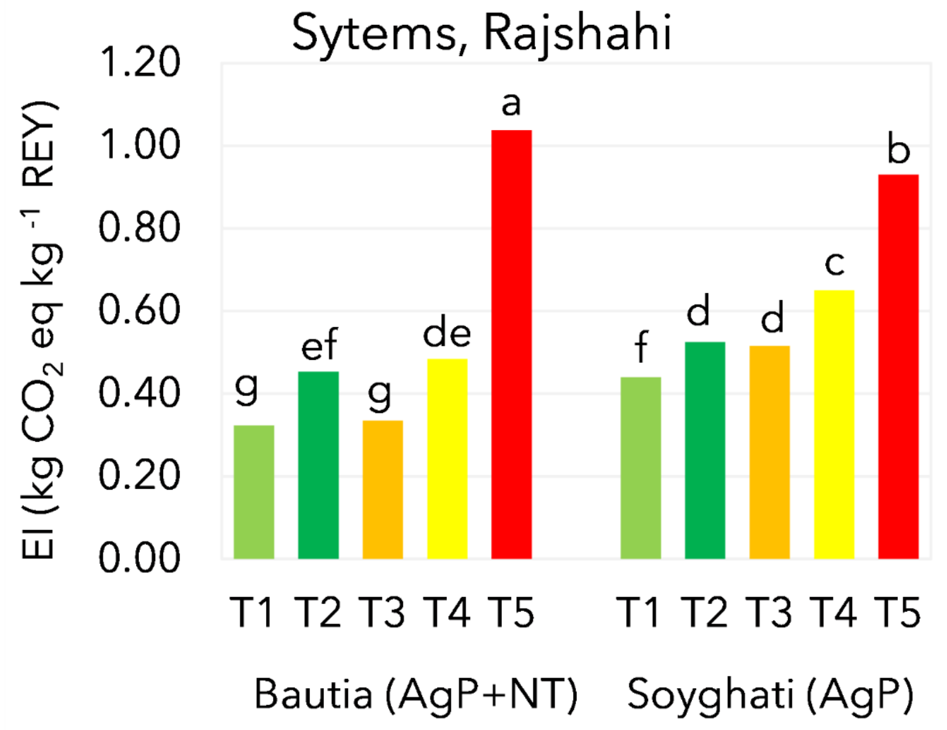
Dietary quality improved steadily across all intervention rounds.

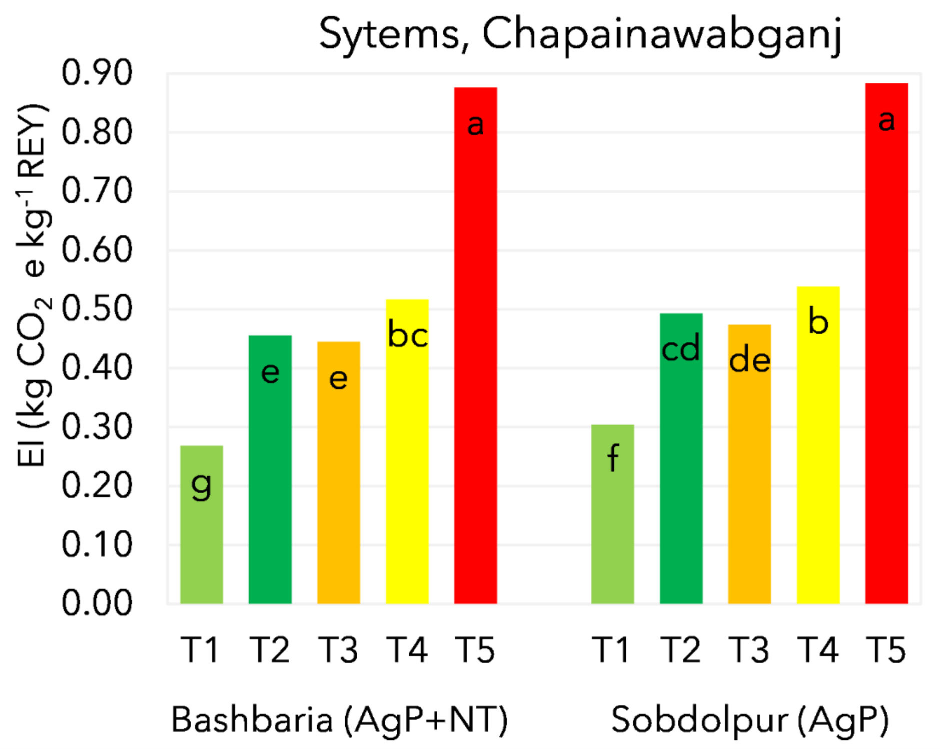
- AgP showed clear gains from Round 2, peaking in Round 3.
- NT produced greater cumulative improvements by Round 5.
- **AgP + NT delivered the largest and most sustained gains, reaching ~2.4 points**.
- Results remained strong across LMM, TWFE, and OLS models.
- **Overall: Effects strengthened over time, with the combined (AgP+NT) intervention performing best.**

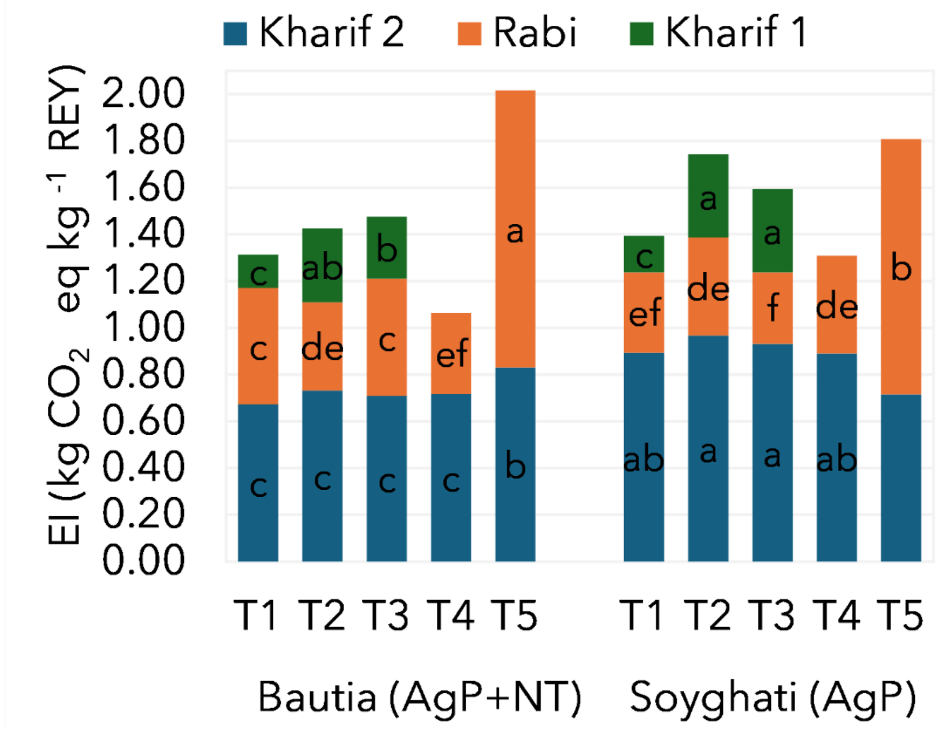
Treatment × Round Effects on Dietary Quality

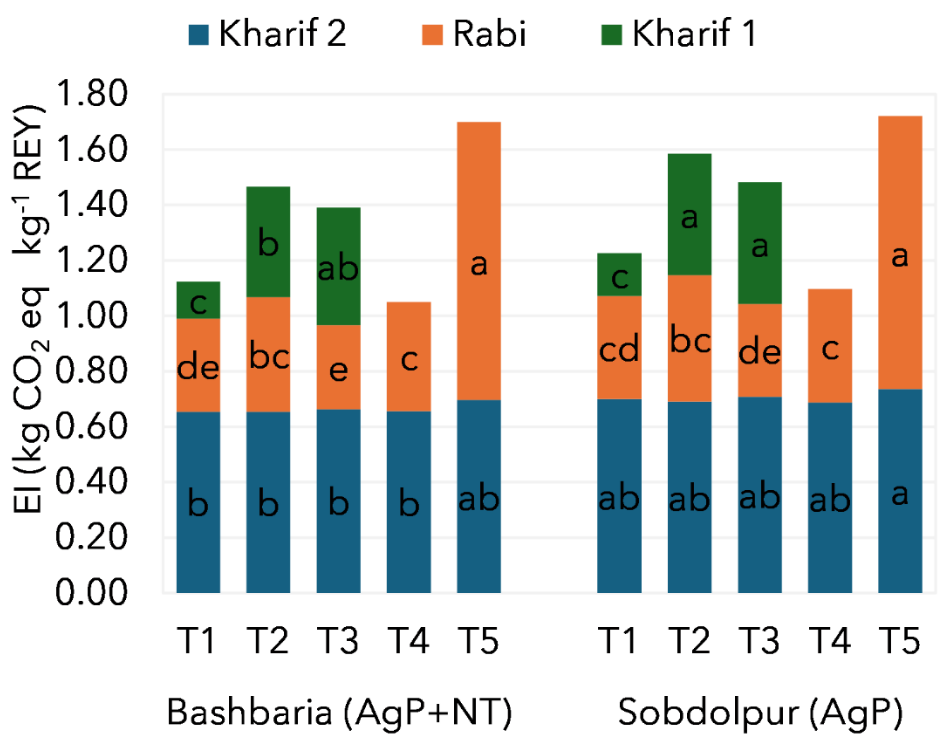


Combined intervention shows largest & most sustained dietary improvements









T1: Rice-Lentil-Sweet corn
T2: Aman rice-Maize+red amaranth-Sorghum
T3: Aman rice-Mustard-Sorghum+Cowpea
T4: Aman rice-Mustard-Fallow
T5: Aman rice-Bor rice

T1: Rice-Lentil-Sweet corn
T2: Aman rice-Maize+red amaranth-Sorghum
T3: Aman rice-Cheakpea-Sorghum+Cowpea
T4: Aman rice-Wheat-Fallow
T5: Aman rice-Bor rice

Crop Diversification Increases Environmental Sustainability

Significantly Lower Emission Intensity

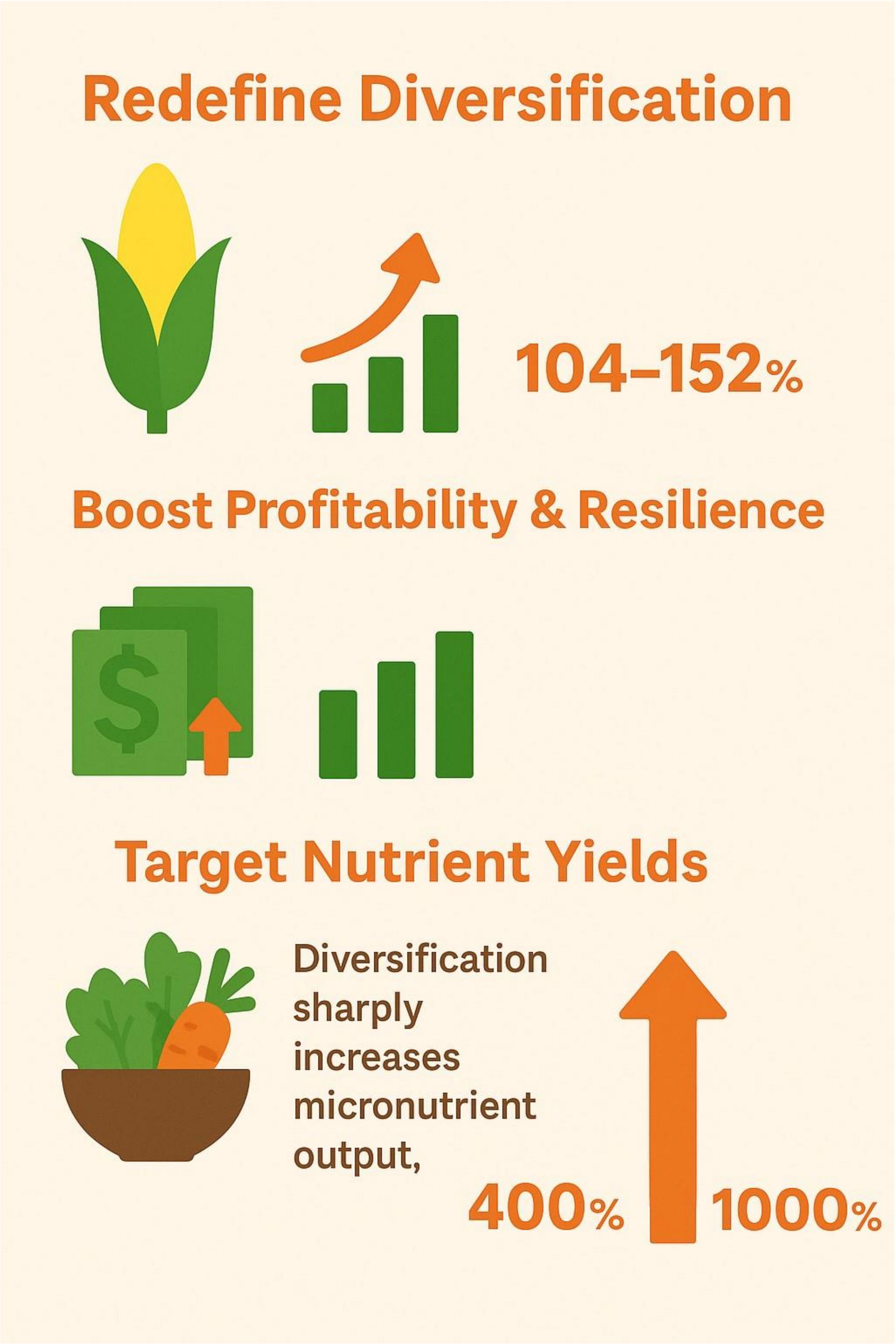
- Diversified systems (T1-T3) consistently showed **lower GHG emissions per kilogram of food produced (EI)** compared to traditional Rice-Rice (T5) and Rice-Mustard-Fallow, & Rice-Wheat-Fallow (T4) systems.

Highest Impact in Rice-Rice Systems

- The conventional Rice-Rice system (T5) had the **highest emission intensity**, making it the least climate-efficient.

Conclusions: A New Model for South Asian Diversified Cropping Systems

- **Redefine Diversification:** Strategic **diversification**, rather than cereal monoculture, is the **most effective path to food and nutrition security**, increasing productivity by 104–152%.
- **Boost Profitability & Resilience:** Diversified farming systems can **triple net income** for farms, enhancing long-term economic viability and encouraging more farmers to adopt these practices.
- **Target Nutrient Yields:** Diversification significantly **boosts micronutrient output,** increasing zinc by 400% and iron by 1000%, effectively addressing hidden hunger.
- **Environmental Sustainability:** Diversification significantly **reduces the carbon footprint of farming**.



The Way Forward: Implications for Scaling Impact

Immediate Actions to Scale Impact

- **Scale Proven Systems: Promote high-yield, profitable rotations (e.g., Rice-Maize+red amaranth-Sorghum, Rice-Lentil-Sweet Corn) combined with nutrition training.**
- **Secure Markets & Profitability:** Develop value chains for diversified crops to ensure economic incentives for farmers.
- **Target Seasonal Hunger:** Deploy interventions specifically designed to address nutritional gaps during lean periods (e.g., *kharif* season).

Foundational Strategies for Success

- **Mainstream Supportive Policies: Advocate for national policies that incentivize nutrition-sensitive agriculture and sustainable intensification.**
- **Invest in Adaptive Research & Capacity Building:** Foster collaboration to optimize systems for different regions and empower farmers through nutritional training as key agents of change.

Our Goal

Transform cereal systems into engines of food security, improved livelihoods, and environmental health for South Asia's smallholders.

Thank you for your attention and collaboration:

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CGIAR Transforming Agrifood Systems in South Asia