Supplementary information

Supplementary Information for: Quantifying environmental co-benefits of nitrogen based crop restructuring and its implication on trade network system

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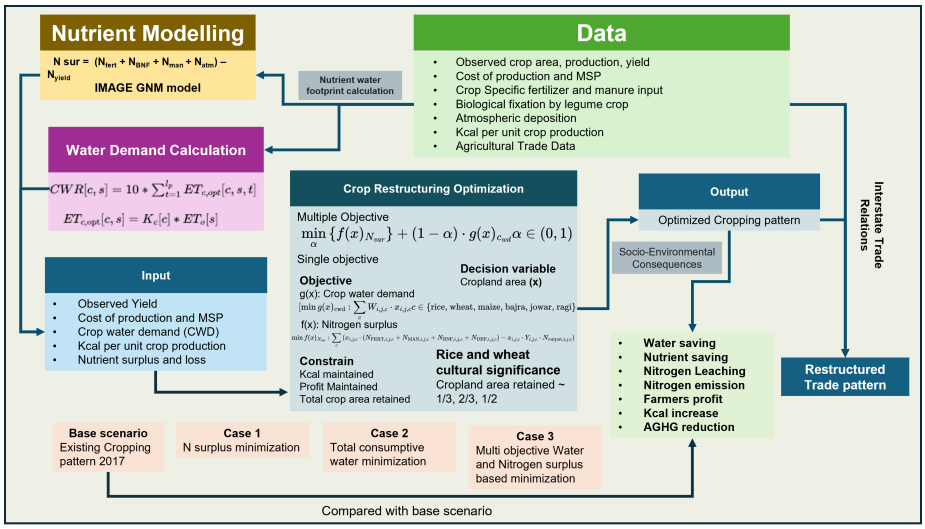
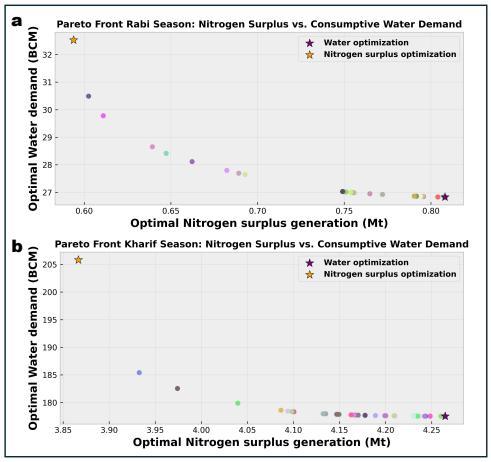
Supplementary Figures S1 to S7

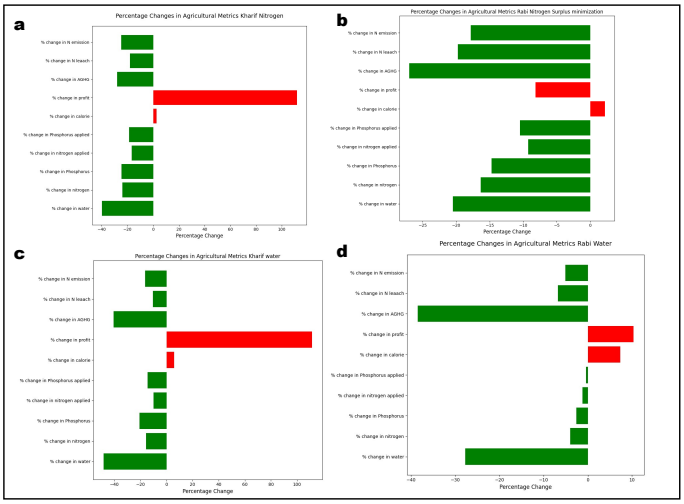
Supplementary Table 1 to 5



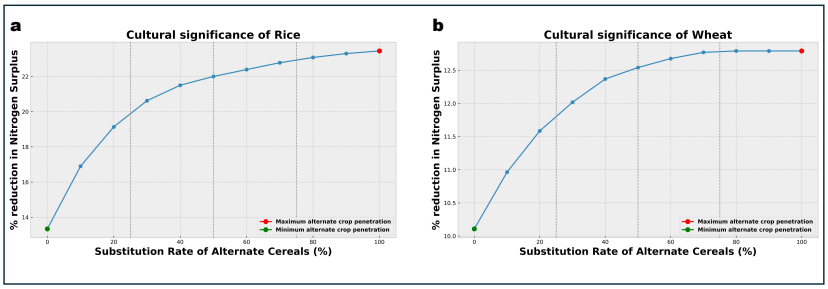
Supplementary Figure 1 – Methodological framework



Supplementary Figure 2 – Comparing Water and Nitrogen Perito Curves in Rabi and Kharif Seasons:(a) Rabi Season (b) Kharif Season



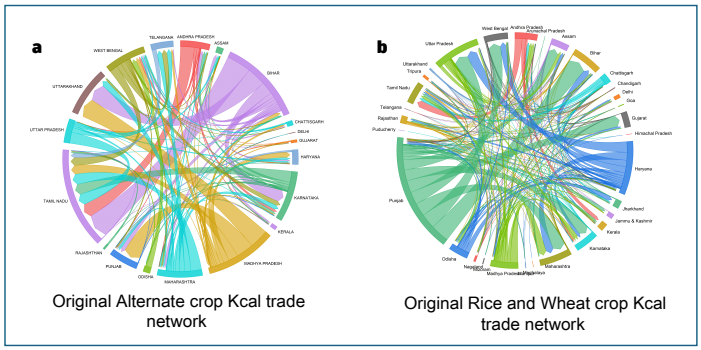
Supplementary Figure 3 – Analyzing Percentage Change Metrics for Socio-Environmental Tradeoffs: (a) and (c) depict strategies for nitrogen surplus reduction and water minimization in the Kharif season, while (b) and (d) showcase similar strategies tailored for the Rabi season.



Supplementary Figure 4 – Exploring the Cultural Significance of Staple Crops in Karif and Rabi Seasons on Nitrogen Surplus Reduction Potential: (a) highlights the dominance of rice cultivation in the Kharif season, while (b) illustrates the prevalence of wheat cultivation during the Rabi season.

Supplementary Table 1 – Datasets used in this study

Data type	Source	Resolution	Ref
Yield and harvested area	Ministry of agriculture and farmers welfare DESAGRI[5]	District-level	[5]
Cost of cultivation	Agricultural Statistics at a Glance	State-level	[4]
MSP	Government of India farmers portal	India-level	[7]
Calorie and nutritional content	National Institute of Nutrition [2]	India-level	[2]
Fertilizer and Manure production	DESAGRI[6]	Plot-level	[6]
N atmospheric deposition	input4MIPS	Gridded	[1]
Biological Fixation	FAOSTAT	District-level	[10]
N and P Content	FAOSTAT	Global	[10]
Agriculture Greenhouse Gas emission	Carlson et al.[3]	Global	[3]
Crop water demand	Kampman et al.[8]	State-level	[8]
Agricultural Trade	Ministry of Commerce and Industry DGCIS[9]	State-level	[9]



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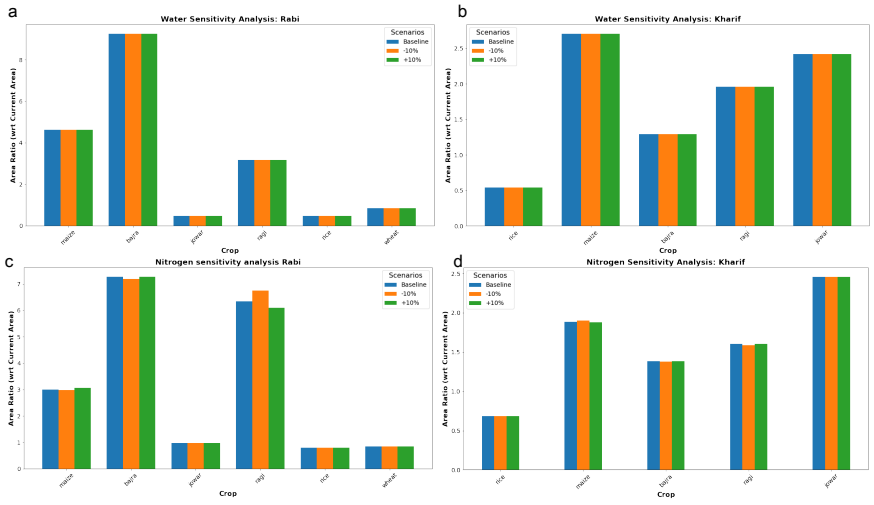
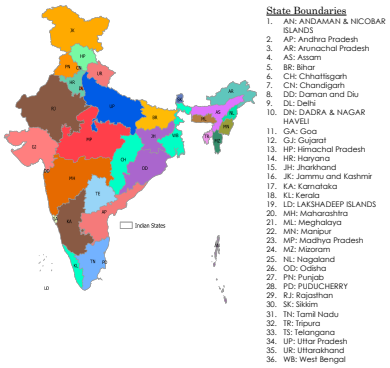
Supplementary Figure 5 – Visualizing the Original Trade Network in Kcal Average Across Three Years (2016-2018): (a) Chord diagram showing the cumulative average trade volume for maize, ragi, jowar, and bajra from 2016 to 2018. The diagram depicts trade flows with arrows directed towards importing states, where the color of each link corresponds to the exporting state. The width of each link represents the strength of trade. (b) Chord diagram illustrating the combined average trade network for rice and wheat. In this diagram, the link colors indicate the source state, and the link width reflects the strength of trade between states. The diagram provides a comprehensive view of the trade dynamics for these staple crops.



Supplementary Figure 6 – Post optimization sensitivity analysis: (a) Optimum Crop area fractions with respect to original cropping area with ±10% change in water demand data as input to the optimization model for rabi season, (b) Optimum Crop area fractions with respect to original cropping area with ±10% change in water demand data as input to the optimization model for kharif season, (c) Optimum Crop area fractions with respect to original cropping area with ±10% change in nitrogen input rate as input to the optimization model for rabi season and (b) Optimum Crop area fractions with respect to original cropping area with ±10% change in nitrogen input rate as input to the optimization model for kharif season



Supplementary Figure 7 – Map represents the state boundaries of India.

Supplementary Table 2 – Nitrogen and Phosphorous Content of Various Crops

Crop	**Nitrogen Content**	**Phosphorous Content**
Rice	0.0129	0.0028
Sorghum (Jowar)	0.0146	0.0045
Bajra	0.0204	0.0042
Maize	0.0124	0.0034
Ragi	0.0204	0.0042

Supplementary Table 3 – Minimum Support Price (MSP) for Food Grains (Fair Average Quality) in India (2017)

Crop	**MSP (Rs. per Quintal)**
Wheat	1735
Paddy (Rice)	1570
Jowar	1712.5
Bajra	1425
Maize	1425
Ragi	1900

Supplementary Table 4 – Calorie Content per 100g of Various Crops

Crop	**Calorie Content (per 100g)**
Ragi	321
Bajra	348
Rice	356
Sorghum (Jowar)	334
Wheat	322
Maize	342

Supplementary Table 5 – Summary of Reactive Nitrogen Emissions in India for 2015 (USD kg^{-1} N) adapted from Sutton, M. A., et al.2017[11]

Year	Health	Ecosystem	Climate
Nr to water	0.3	3.6	0.0
NH_3 to air	3.6	0.6	0.0
NO_x to air	5.4	0.6	0.0
N_2O to air	0.6	0.0	2.7

Supplementary References

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