Socioeconomic and Biophysical Drivers of Cropland Use Intensification in India: Analysis using satellite data and administrative surveys

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Introduction

1. Agriculture - primary source of food and livelihood in India. Multiple government policies support agriculture.
2. Cropping seasons: Kharif/Monsoon (Jul-Oct), Rabi/Winter (Nov-Mar), and Zaid/Summer (Apr-Jun).
3. Parcel-level cropping frequency: single (once in a given year) or multi (twice/thrice) cropped lands.
4. Amidst high population growth higher production is achievable through improved yields or acreage expansion.
5. We observe a shift of 286,540 km^2 from single to multi-cropped land during 2005-14.

Objectives

1. Model spatial-temporal dynamics of cropland intensification (single→double cropping) in India.
2. Combine high-resolution raster (56m pixel) data with the district-level administrative data.
3. Estimate first-order Markov land use transition probabilities using a logistic model conditional on social, economic and biophysical drivers.

Methodology

Bhuvan LULC Data + Administrative Data

Land Use Change Detection Matrix

Econometric Model

Markov Land Use Transition Probability

Model Robustness

Data

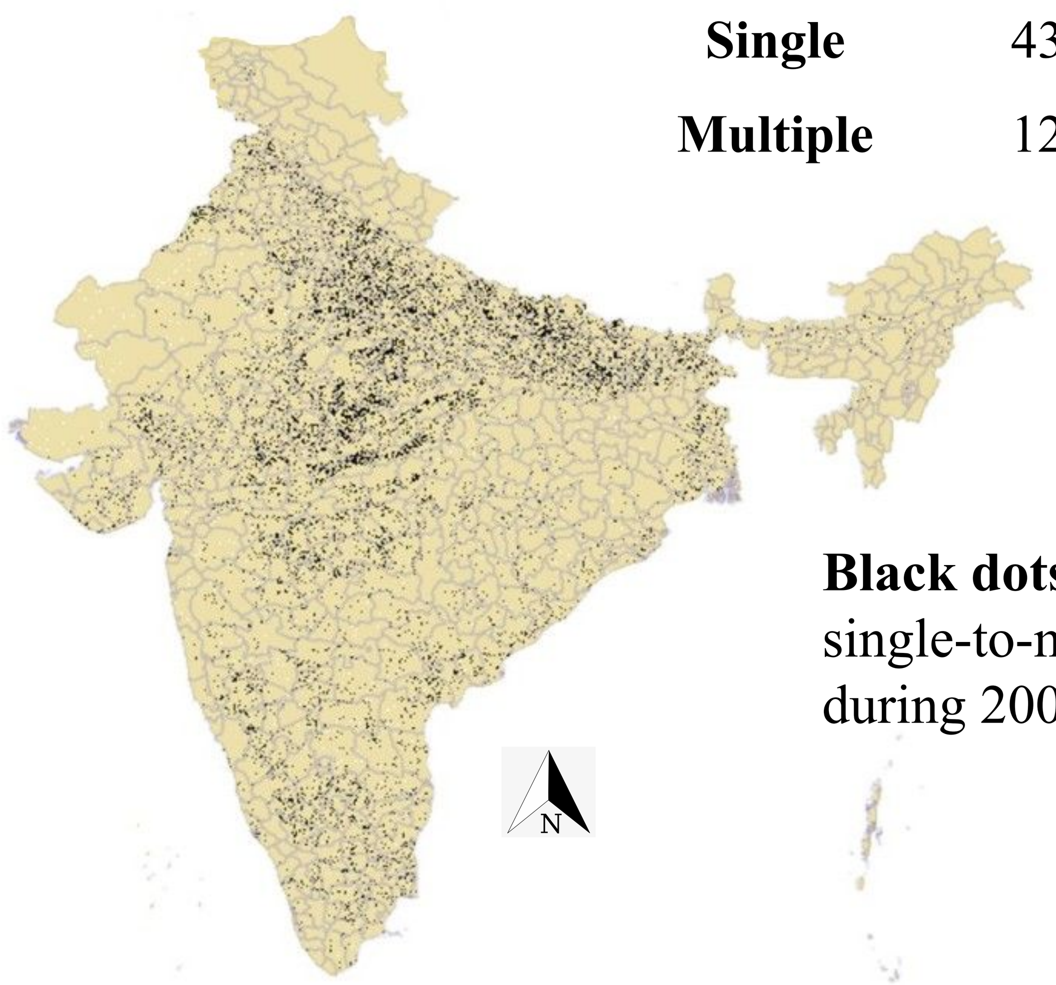
District-wise explanatory variables to model land use change:

Variable	Notation	Description
Rainfall	***Rain***	Annual rainfall (mm)
Irrigated Area	***Irrig***	Gross irrigated area (ha)
Elevation	***Elv***	*Elv* = 1 if hilly or 0 otherwise
Soil Nutrient Deficiency	***NDef***	% Nitrogen and Organic Carbon deficiency
Road Density	***Road***	Road length (km) ÷ district area (km^2)
Crop Yield		Output per unit area (kg/ha)
1. Rice	Y_R	
2. Wheat	Y_W	
Trend	***Tr***	*Tr* = 1 in 2005-06,..., =10 in 2014-15.
Dummy	D_{10}	D_{10}= 1 if Tr > 5, i.e., post-2010 to account for policy reforms#

MGNREGA (federal rural employment guarantee scheme); Central Govt. loan waiver scheme; Minimum Support Prices (safety net)

Land Use Change Detection (2005-14)

('000 km^2)	Single	Multiple
Single	433.40	286.54
Multiple	122.84	293.09



Black dots show field-level single-to-multiple crop transitions during 2005-06 to 2014-15

Econometric Model

First-order Markov land use transition matrix for each parcel i at time t

$$P_{it} = \begin{bmatrix} \phi_{it}^{S,S} & \phi_{it}^{D,S} \\ \phi_{it}^{S,D} & \phi_{it}^{D,D} \end{bmatrix}$$

where,

$$\phi_{it}^{S,S} + \phi_{it}^{D,S} = 1 \quad \text{and} \quad \phi_{it}^{S,D} + \phi_{it}^{D,D} = 1 \quad \forall i, t$$

Transition probabilities

$\phi_{it}^{D,S}$: single-crop in t - 1 to double-crop in t.

$\phi_{it}^{D,D}$: remains in double crop b/w t-1 and t.

Parcel-level probabilities were aggregated to the district-level to give us the dependent variable for the logit model:

$$y_{it} = \frac{\left(n_{D_t} - n_{D_{t-1}}\right)}{n_{S_{t-1}}}$$

where, n_{D_t} is the number of pixels in multiple crop category, n_{S_t} is the number of pixels in single crop in a district i at time t.

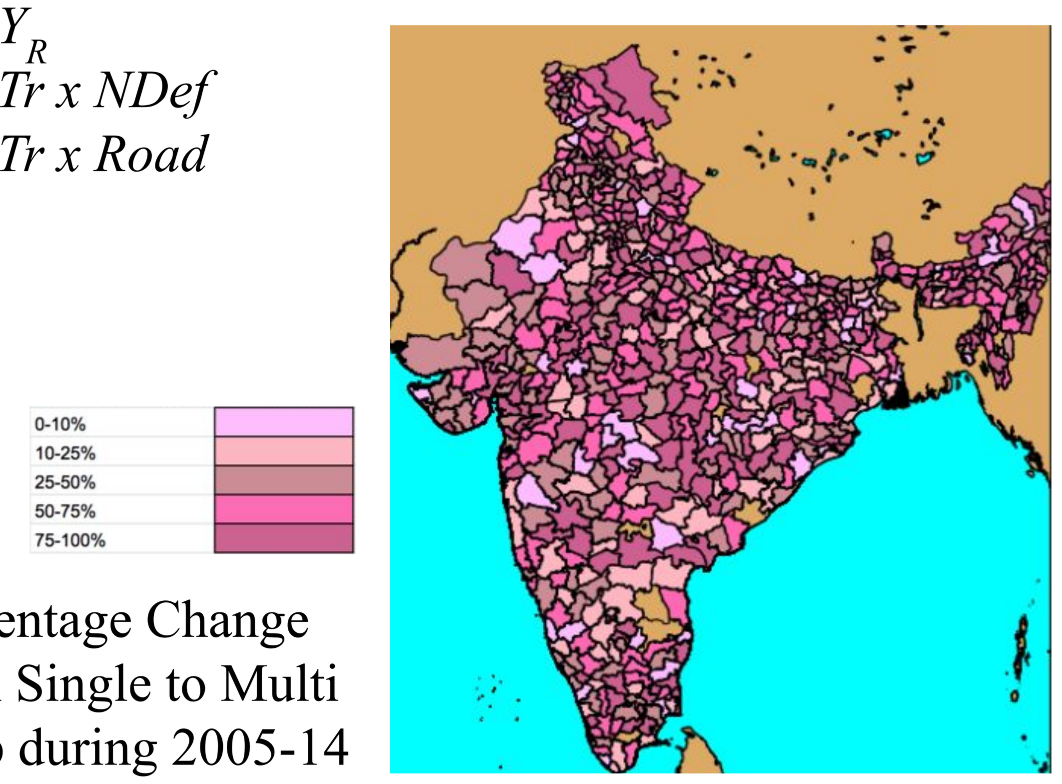
Logistic Regression

$$\ln\left(\frac{y_{it}}{1 - y_{it}}\right) = X'\beta$$

where the vector X comprises of the data variables (as seen in the Results section)

Robustness (Example)

- Removed outliers based on percentage shift from single to double cropping. Threshold=10%.
- Most coefficient estimates were robust to removing outliers, except that of
  - Y_R
  - *Tr x NDef*
  - *Tr x Road*



Percentage Change from Single to Multi Crop during 2005-14

Results

Marginal Effects (ME): Change in land use transition prob. given unit change in the respective explanatory variable, keeping all else constant.

$$\frac{\partial y}{\partial x_i} = \frac{\beta_i \cdot e^{X'\beta}}{\left(1+e^{X'\beta}\right)^2} \quad \text{where, } \frac{e^{X'\beta}}{1+e^{X'\beta}} \text{ is the logit function.}$$

	Model 1	SE	Model 2	SE
Rain	0.095***	0.021	0.095***	0.021
Rain^2	-0.038*	0.021	-0.039*	0.021
Irrig	-0.037	0.028	-0.037	0.028
Elv	-0.036	0.036	-0.034	0.031
NDef	-0.099***	0.030	-0.036	0.036
Road	0.093***	0.031	0.099***	0.030
Y_W	-0.036***	0.014	0.106***	0.041
Y_W^2			-0.051	0.041
Y_R	-0.035**	0.014	-0.035	0.293
Y_R^2			0.092	0.293
Tr	-0.035	0.048	-0.036	0.048
Tr x Irrig	0.096***	0.030	0.096***	0.030
Tr x Elv	-0.044	0.037	-0.044	0.037
Tr x NDef	-0.040	0.044	-0.039	0.044
Tr x Road	-0.034	0.037	-0.035	0.037
Tr x D_{10}	0.102***	0.035	0.102***	0.035
RMSE	**0.31**		**0.34**	

***p<0.01, **p<0.05, *p<0.1

Conclusion

- Over time, multiple cropping moves to nutrient deficient soils. *Cropping becomes riskier and costlier*.
- Average ***Irrig*** impact is insignificant, but it drives land use intensification over time (***Tr x Irrig***).
- ***Rain*** induces higher cropland intensification but excessive rainfall (***Rain***^{2}) is inhibitory.
- Higher ***Road*** density supports crop intensification.
- Post-2010 policy interventions aided crop intensification (***Tr x*** D_{10}).
- High Y_W is critical for transitioning to multi-cropping.

# - Equal Contribution
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