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Spatial Characteristics of Long-term Changes in Indian Agricultural Production: District-Level Analysis, 1965-2007

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Spatial Characteristics of Long-term Changes in Indian Agricultural Production: District-Level Analysis, 1965-2007 [*]

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Takashi Kurosaki[†] and Kazuya Wada[‡]

Abstract: In this paper, we comprehensively describe spatial patterns of long-term changes in Indian agriculture at the district level. Variables of concern include the land use intensity, the ratio of rice and wheat in areas under foodgrains, the ratio of non-foodgrains in gross cultivated area, the fertilizer use intensity, and individual crop shares in gross cultivated areas. As a byproduct of the descriptive analysis, we propose a new regional classification of Indian districts based on their similarity in rainfall, the initial cropping and land-use patterns, and the initial condition and changes in irrigation. The proposed classification has a reasonable explanatory power in describing the spatial patterns of long-term changes at the district level.

1. Introduction

Sustaining agricultural growth is key to rural development and poverty reduction in India. As the room for extensive expansion has almost disappeared in Indian agriculture today, it is critically important to improve land productivity to sustain the growth. Among various factors that contribute to productivity improvement, the introduction of new technology has been investigated most intensively in literature. For example, in the standard literature on long-term growth in agricultural production in India, the contribution of Green Revolution since the late 1960s has been emphasized (e.g., Bhalla and Tyagi 1989, Bhalla and Singh 2001, Bhalla and Singh 2009, Bhalla and Singh 2012). The Green Revolution technology is characterized by high-yielding seeds, chemical fertilizer, and irrigation. Another area on which the existing literature has focused is institutional aspects including land tenancy, labor market institutions, and credit markets, as shown in articles published in previous issues of

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Besides these, there is another source of agricultural productivity growth, which is less investigated in the literature. Even with little improvement in per-acre yield of individual crops, the land productivity can increase through the reallocation of crops from low value-added to high value-added crops and from regions where productivity is low to regions where productivity is high. Using a longer-term horizon than adopted in the traditional literature, Kurosaki (2002, 2011, 2015) shows that sustained growth in agricultural production began in India during the 1950s, much earlier than the onset of Green Revolution, and shifts from low to high value crops (changes in cropping patterns) contributed to the agricultural growth during the earlier growth period. Similar findings were obtained for areas currently in Pakistan Punjab (Kurosaki 2003). Kurosaki (2003) also demonstrates that crop shifts from low productivity districts to high productivity districts contributed to the agricultural growth in West Punjab, especially during the colonial period. Nevertheless, there is a dearth of empirical studies on the contribution of spatial crop shifts to productivity improvement in post-independence Indian agriculture.

As a starting point for such studies, this paper describes spatial patterns of long-term changes in Indian agriculture at the district level for a period from 1965 to 2007. The analysis employs a district as the unit of investigation, defined by district boundaries prevalent in 1965. The purpose of the paper is descriptive in nature, without rigorously investigating the role of technology or policies or agrarian structure. Which districts produced which crops? How did such spatial patterns change over time? We address these questions in this paper by combining various quantitative methodologies to describe spatial changes.

A salient point of this paper is that such descriptive information is useful for addressing more fundamental questions such as what kind of market and technology development characterizes Indian agriculture. To understand the salience, microeconomic theory of spatial equilibrium (Takayama and Judge 1971) is useful. Agricultural production is linked with consumption demand in general. This linkage implies that when agricultural output markets are underdeveloped, farmers in a village produce what villagers want to consume. This is a situation where spatial equilibrium is closed within a village as a unit. The equilibrium is characterized by village-specific shadow prices,[1] which may diverge from market prices. Without technical innovation of producing individual crops, there is no room for productivity improvement under this situation. As agricultural output and factor markets develop, however, farmers and villages become more able to respond to the demand outside the village. By shifting to crops whose value-added is higher if calculated using market prices, production value can be improved even without innovation in individual crop production technology. If such market development is accompanied by irrigation development, the room for individual farmers to respond to market incentive becomes larger. The spatial pattern of agricultural production changes over time reflects such market and technology development (Takayama and Judge 1971, Timmer 1997).

With this theoretical background, Kurosaki (2003) provides district-level analysis for the case of West Punjab agriculture (now in Pakistan) for the period from 1903 to 1992. This paper shares research motivation with Kurosaki (2003) but extends the analysis to the whole of India. As all-India district-level analysis of agricultural production, Bhalla and Singh (2001) and Bhalla and Singh (2012) are notable research outcomes. These studies, however, do not interpret the observed spatial changes in the microeconomic framework of market development and spatial equilibrium. This focus distinguishes this paper from these studies.

The rest of the paper is organized as follows. Section 2 explains the data used and shows the heterogeneity observed across districts in terms of agricultural intensification. The heterogeneity evidence is the first descriptive exercise on spatial characteristics of changes in Indian agriculture. As the second descriptive exercise, Section 3 shows district-level GIS maps, which enables us eyeball perusal of changes in spatial production patterns that occurred between 1965 and 2007. In Section 4, we propose new agricultural zones derived from cluster analysis using the district-level data, which is another way to aggregate spatial changes in descriptive analysis. Section 5 adopts a more parametric

[1] See de Janvry et al. (1991) for how shadow prices are defined in mathematical models of farmers facing underdeveloped markets.

approach of describing the spatial changes, i.e., a regression analysis applied to district-level panel data. The regression analysis identifies correlates of changes in intensification measures. Section 6 concludes the paper.

2. Data

2.1 Dataset Used

We use the district-level study (DLS) database compiled by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). The original data sources include government statistics such as *Agricultural Statistics of India* and related publications at the state level. The compilation procedure is reported in the DLS manual (ICRISAT 1998). Although our dataset is based on the revised version up to 2007, the DLS manual has not been revised. The period of analysis is 42 years: from agricultural year[2] 1965/66 to agricultural year 2006/07. Smaller districts where agricultural production is negligible and statistics are reported only sporadically have been dropped from the analysis. Several observations with inconsistent data have also been dropped.

As a result, we employ a balanced panel dataset of 311 districts spread over 19 major states of India (Andhra Pradesh, Assam, Bihar, Chhattisgarh, Gujarat, Haryana, Himachal Pradesh, Jharkhand, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh, Uttarakhand, and West Bengal) over the 42 years. The 311 districts were based on district borders in 1965. According to the district borders in 2007, the 311 districts correspond to 498 districts. Regarding the state coverage, the analysis excludes 9 small states such as Jammu & Kashmir, Sikkim, Goa, etc. and 7 federal territories, which are all minor in analyzing Indian agriculture. Figure 1 shows the spatial coverage of these 311 districts.

<Insert Figure 1 around here>

From the DLS database, we compiled the following variables for the analysis in this paper. As production factors, we employ gross cultivated area (*gca*), net cultivated area (*nca*), irrigation ratio

[2] An agricultural year of India refers to a period from July 1 to June 30.

(“net cultivated area, irrigated” divided by *nca*), quantity of fertilizer (the sum of N, P, K fertilizers), the number of agricultural markets, the length of paved roads, and rainfall indicators. For individual crops, we employ area and output quantity of rice, wheat, maize, sorghum (*jowar*), pearl millet (*bajra*), finger millet (*ragi*), barley, chickpea (*gram*), pigeonpea (*toor/arhar*), and other pulses. The sum of areas under these crops cover 60 to 70% of the gross cultivate area.[3]

As demonstrated by Kurosaki (2011) and Kurosaki (2015), the twentieth century Indian agriculture can be characterized by sustained growth through improving land productivity and shifts to higher value-added crops. These papers have shown that the index of land use *intensity* (=*gca*/*nca*), the share of rice and wheat in the areas under foodgrain crops (*srw*), and the share of non-foodgrain crops in the gross cultivated area (*snfg*) gradually increased throughout the century.

2.2 Spatial Heterogeneity in Agricultural Intensification

Has the increase in these measures in agricultural intensification occurred homogeneously in all districts in India? As the first descriptive analysis of spatial characteristics, we plot in a histogram the district-level trends of *gca*, *intensity*, *snfg*, and *srw* (Figure 2).

<Insert Figure 2 around here>

Figure 2 clearly shows a substantial inter-district heterogeneity. Although the four indices were associated with positive trends at the all India level, the trend was negative for a non-negligible number of districts. The heterogeneity is more substantial for *snfg* and *srw* than for *gca* and *intensity*. This suggests that throughout India, gross cultivated area increased, mostly through the rising intensity of land use, while the list of crops that occupied the increased area under cultivation differs from districts to districts. Furthermore, the heterogeneity of trends in *snfg* and *srw* has been increasing in recent years.[4] In the next section, we examine which crops specifically were responsible for such heterogeneity.

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[3] The dataset includes crop information for oilseeds, sugarcane, cotton, potato, onion, and fodder crops. In this paper, we aggregate them as non-foodgrain crops. Crop-wise analysis of non-foodgrain crops is left for further analysis.

[4] Figure 2 was redrawn using the subsample of the period up to 1995. The re-drawn figure shows more compact distribution for *snfg* and *srw*. The redrawn figure is available on request from the authors.

3. Spatial Changes in Agricultural Production Described through GIS Maps

In this section, we describe spatial changes in agricultural production using GIS maps at the district level. In other words, this is an eyeball investigation of spatial patterns. Each of Appendix Maps shows four figures for each variable of interest. The upper left figure plots the initial distribution in five quantiles, where the initial period refers to the three year average from 1965/66 to 1967/68. The upper right figure (terminal, A) plots the terminal distribution in five quantiles, whose quantile thresholds are the same as those used for the initial quantiles. The terminal period refers to the three year average from 2004/06 to 2006/07. The lower left figure (terminal, B) plots the terminal distribution in five quantiles, whose quantiles are re-defined over the terminal values. The comparison of the initial and terminal A tells us about absolute changes in spatial patterns while the comparison of the initial and terminal B tells us about relative changes in spatial patterns. The lower right figure plots the distribution of growth rate. The growth rate was estimated for each district from 42 year data using OLS. We include in the appendix maps that show interesting spatial changes. Maps not shown in the appendix are available on request from the authors.

3.1 Cropped Area

Gross cultivate area (*gca*) increased in most of districts in India (Appendix Map 1). The positive trend has been more significant in northern districts such as those in Rajasthan, Punjab, Haryana, Madhya Pradesh, West Bengal, and Assam. On the other hand, several districts were associated with negative trends in *gca*, many of which are found in Himachal Pradesh, Bihar, and Tamil Nadu.

Looking at individual crops, rice-dominating districts in the initial years mostly remain as the same in the terminal years (Appendix Map 2). Districts with higher trends in rice area than other districts are concentrated in Punjab, Haryana, Chhattisgarh, and West Bengal. Except for those districts in West Bengal, all others are located inland. On the other hand, districts with negative trends in rice area are found in Tamil Nadu, Bihar, Jharkhand, and several districts in western India.

Wheat production is concentrated in north India (Appendix Map 3), spanning from districts in Punjab and Haryana (henceforth, called "Punjab region") to those in Uttar Pradesh, Bihar, Rajasthan, Madhya Pradesh, and Maharashtra. Districts with higher trends than the national average are also concentrated in the same states, except for Maharashtra. In Maharashtra, districts once cropped with large area with wheat were associated with negative trends in wheat area, as in districts in south India where wheat was not cultivated much in its traditional farming system.

A distinct spatial contrast is observed among coarse millets. In case of maize (Appendix Map 4), the initial production was concentrated in northern districts in Punjab, Haryana, Uttar Pradesh, Bihar, Jharkhand, and Rajasthan. In most of these districts, maize area decreased since the mid 1960s. New maize-producing centers have been emerging from interior Maharashtra, Madhya Pradesh, Karnataka, interior Andhra Pradesh, and interior Tamil Nadu. The production of sorghum (*jowar*) decreased in most districts throughout India, with no significant change in production centers in districts south of Maharashtra (Appendix Map 5). The production of pearl millet (*bajra*) also decreased in the majority of districts in India (Appendix Map 6). It is noteworthy of finding several exceptional districts in eastern Rajasthan where *bajra* area has been increasing. The overall decline is observed for *ragi* area as well, including those districts where *ragi* was once one of the most important crops, such as those districts in Tamil Nadu, Karnataka, Andhra Pradesh, and Orissa (Appendix Map 7). In contrast to the overall declining trend, districts in Uttarakhand show an increase in *ragi* area. Barley has becoming a minor crop in most of the districts, including those in Uttar Pradesh, where barley was once occupied a substantial share of area under crops.

A significant spatial shift of production center has been observed for chickpea (Appendix Map 8). The traditional production center in northern districts in Punjab, Haryana, Uttar Pradesh, and Bihar has witnessed a rapid decline of area under chickpea. To replace these districts, new chickpea production districts are appearing in Madhya Pradesh, Maharashtra, and northern Karnataka. In other words, the production center for chickpea has been going south. Regarding pigeonpea, traditional producing districts in Uttar Pradesh, Maharashtra, and Karnataka experienced a slight decrease in areas under the crop. No new center of significance is emerging, however. Production of other pulses is on the decline on average, except for several districts in Orissa.

3.2 Intensity of Land Use

As summary measures of cropping patterns focusing on the change in land use intensity, Appendix Maps 9-11 plot *intensity*, *srw*, and *snfg*, which were already discussed in Figure 2 regarding the heterogeneity among districts. By looking at maps, we can pin point where each of these measures increased or decreased.

The variable *intensity* was high in initial years (1960s) in districts located in Punjab, Uttar Pradesh, Orissa, and West Bengal (Appendix Map 9). This regional contrast remains the same in terminal years during the 2000s. Trends in *intensity* are positive in the majority of districts, especially in those districts whose initial level of *intensity* was high. Districts associated with a decline in *intensity* are concentrated in Tamil Nadu and Himachal Pradesh.

The importance of rice and wheat in foodgrain production (*srw*) was high in initial years in districts located in Punjab region, Uttar Pradesh, West Bengal, western Orissa, and coastal districts on the Arabian Sea (Appendix Map 10). The trends in *srw* were highly positive in Punjab region and Uttar Pradesh, while those were negative in Orissa. Changes in cropping patterns in favor of Green Revolution crops occurred more in Punjab region. Furthermore, many of arid districts in Rajasthan, where rice or wheat were not cultivated due to the lack of water, experienced a rapid increase in *srw*, thanks to recent irrigation development. In northern and western parts of India, irrigation in arid and semi-arid environments clearly favored these Green Revolution crops.

The tendency to grow pure cash crops is captured by variable *snfg* (Appendix Map11). In initial years, *snfg* was high in western half of India, coming down from Punjab in the north to Tamil Nadu and Kerala in the south. As trends in *snfg* were lower in Punjab while higher in western and southern parts of India, *snfg* became higher in western and southern parts of India but no longer so in northwestern India in the terminal years. In other words, the spatial change in cropping patterns was heterogeneous across regions, reflecting different comparative advantage of each district among crops. In some districts, the direction of change was towards Green Revolution crops, while in others, the direction was moving away from Green Revolution crops.

3.3 Interpretation

The descriptive analysis in this section implies the following. First, regarding the area under crops, the Indian agriculture already reached the limit of extensive expansion during the late 19th - early 20th century (Kurosaki 2015). To overcome the limit, the land use intensity increased especially in north India where irrigation was developed. Spread of chemical fertilizer was another factor that contributed to the intensification of land use, but the spread was also facilitated by irrigation. During the initial years of our analysis, irrigation was more developed in north India and coastal districts on the Bengal Bay including those in Tamil Nadu. Almost everywhere since then, water availability improved. The districts that experienced higher growth in land intensity were overlapping with the districts where irrigation was developed faster.

Throughout the period of our analysis, we observed shifts of crops such as more areas under rice and wheat in Punjab region and new production centers of coarse millets in the interior India. These changes suggest that production specialization has been going on in response to comparative advantages associated with heterogeneous climatic conditions and irrigation development. As Kurosaki (2003) suggested, rural infrastructure such as roads and markets could be responsible for these changes as well. According to the same study, there were two different phases of development of agricultural output markets: the first with local market integration linking nearby villages and cities, which occurred during the colonial period, and the second with national market integration after the independence in 1947. The spatial changes observed during the period of our study suggest that the process is still continuing during the post-colonial period. The next section examines the possibility of new typology as a descriptive tool, which reflects the long-term changes mentioned above.

4. New Typology of Indian Agriculture

4.1 Empirical Strategy: Cluster Analysis Using District-Level Data

In the previous section, spatial changes observed in GIS maps were discussed using state names as the main indicator for regional variation within India. However, in many cases, within-state heterogeneity is significant, while in other cases, some districts in a state showed patterns more similar to districts in the neighboring state than to the other districts in the same state. Using zones of regional typology is thus a convenient tool to aggregate spatial changes in descriptive analysis.

In the literature, several zones of regional typology regarding Indian agriculture have been proposed: state boundaries, as used in Section 3; fifteen agro-climatic zones designated by the Indian ministry of agriculture; agro-climatic regions from B1 to B8 of the ICRISAT, which were employed in ICRISAT (1998); a more recent attempt at the ICRISAT (Rao et al. 2004), discussed below; the twenty-one ecological & agrarian regions for the Indian Subcontinent prepared by Thorner (1996), etc. Given rich panel information included in our dataset, we attempt in this section to construct a new typology exploiting the district-level information. We examine the usefulness of the new typology in two ways: its ability to show coherent patterns (Subsection 4.2) and its explanatory power in parametric regressions (Section 5). Before the examination, we explain our methodology to group districts.

We adopt a quantitative methodology called "cluster analysis." It is a general term corresponding to the task of grouping a set of objects (in our case, districts) in such a way that districts in the same group (called a "cluster") are more similar to each other than to those in other clusters in terms of several observable characteristics. To solve the clustering task, various computer algorithms have been proposed and we have chosen a one that is popularly used in applied economics.[5] Similar cluster analysis has been adopted for India as well, for example by Rao et al. (2004).

[5] Specifically, we adopt a hierarchical clustering algorithm based on Ward method using similarity of Euclid and the same weight for observable variables (standardized) in calculating the similarities. See Everitt et al. (2001) for methodological details. Command *cluster* in the STATA 10 software was used to obtain clustering results.

Regarding the observable characteristics used for the classification, we use 15 variables that correspond to the initial conditions and one trend variable. The 16 variables are those described in the previous sections. They include the initial values (average of the first five years of the period of our study) of rainfall (annual, June, and July-August), irrigation ratio, land use intensity (*intensity* analyzed before), and shares of 10 crops in the gross cultivated area, and the annual trend of the irrigation ratio (obtained from time series regression for each district). Our strategy is thus to employ pre-determined variables of production choices and exogenous technology variables in order to describe the current production structure. In the classification exercise, we do not pay any attention to the geographic contiguity. The cluster analysis results may show zones with geographically compact areas; if the zoning predicts a zone comprising several districts that are not contiguous, such information could be useful so that we should report as they are. This is the approach we adopt.

Our approach is in sharp contrast to the one adopted by Rao et al. (2004), whose detail is described in ICRISAT (1999). They derived a regional typology with 15 zones (or 18 zones as two of the 15 zones are further divided into subzones) using cross-section DLS data of averages of three years from 1997/98. Their list of observable characteristics includes the shares of 15 crops and 5 livestock products in the agricultural gross output value. They also allowed for different classification depending on rainfed and irrigated regions and adjusted zone boundaries so that each zone is geographically contiguous. As their procedure classifies districts according to the production mix prevailing during the late 1990s, it provides us with a useful insight on the production structure corresponding to that specific period. However, the choice of variables is mechanical and does not reflect microeconomic reasoning of initial factors, endogeneity of crop choices, and market structure. If the interest is on describing the structure at a specific period, their approach is justifiable but the zoning procedure is better applied periodically with regular revisions. In other words, the procedure is not very useful in inferring underlying, fundamental factors that affect spatial patterns of the long-term dynamic changes. Our choice of the 16 observable variables is the result of our attempt to overcome these shortcomings.

The algorithm applied to our data clearly suggests a coarse typology with 5 zones and a medium-level typology with 10 zones, as shown in Figure 3. Unfortunately, more detailed typology with zones more than 10 resulted in unstable classifications, depending on specific algorithms. Therefore, we mainly adopt the medium-level typology with 10 zones in this paper.

<Insert Figure 3 around here>

4.2 Characteristics of New Typology Zones

What spatial patterns does each zone in our proposed typology show? If each zone does not show coherent patterns, our new typology is of little value. We thus prepare Table 1, showing characteristics of each zone derived from the cluster analysis. It specifically reports the spatial distribution of each zone and its average values of the sixteen variables on which our clustering was based. We describe the characteristics for each of the five large zones (L1 – L5), with explanations for medium-level zones (M1-M10) within each large zone.

<Insert Table 1 around here>

Zone L1 contains districts where rice cultivation dominated during the initial years. Therefore, we call it “rice zone.” The rice zone (L1) is subdivided into M1 districts in Orissa, West Bengal, Assam, etc., and M2 districts in Andhra Pradesh, Tamil Nadu, etc. The two sub-zones are distinguished by the amount of rainfall and the extent of irrigation development: M1 is thus called “high rainfall, rainfed rice zone” while M2 is called “low rainfall, irrigated rice zone.”

Zone L2 (= zone M3) spreads into districts in hilly and coastal areas in Kerala, Assam, coastal Andhra Pradesh, and coastal Karnataka. Due to extremely high rainfall, rice crops dominated during the initial years as in Zone L1. However, L2 is distinguished from other zones by the high extent of producing non-foodgrain crops. For this reason, we call L2 “extreme rainfall, rainfed, non-foodgrains zone.”

Zones L3-L5 are characterized by semi-arid agriculture, distinguished by the extent of land use intensity, irrigation ratio, and traditional crops. Using the most traditional crops in these districts, we call L3 “semi-arid, extensive, wheat-pulse zone,” L4 “semi-arid, intensive, maize zone,” and L5 “rainfed, extensive, millet zone.”

Zone L3 “semi-arid, extensive, wheat-pulse zone” is further subdivided into M4 (semi-arid, extensive, wheat-chickpea zone) that spreads over Madhya Pradesh, Uttar Pradesh, Haryana, and Rajasthan, and M5 (“semi-arid, extensive, pigeonpea-barley zone) that spreads over Uttar Pradesh and Madhya Pradesh. The key crop characterizing M4 is chickpea (*gram*) while the one characterizing M5 is pigeonpea (*toor/arhar*).

Zone L4 “semi-arid, intensive, maize zone” is similarly subdivided into M6 (semi-arid, intensive, maize-dominant zone) and M7 (irrigation-intensive, wheat-maize zone). In M6, the importance of maize in the traditional cropping patterns was more distinct than in L4. M7 may be alternatively called “Punjab-type zone.” It contains districts in Punjab, Haryana, and western Uttar Pradesh, where Green Revolution first spread during the late 1960s.

Zone L5 contains three sub-zones differentiated by the most important coarse millet crop. M8 districts are located in Maharashtra, Madhya Pradesh, Andhra Pradesh, and Rajasthan, where sorghum (*jowar*) dominated among the coarse crops during the initial years of our analysis. M9 districts are only found in Karnataka, where finger millet (*ragi*) was the dominant coarse millet. M10 districts are located in Rajasthan, Gujarat, and Maharashtra, characterized by the importance of pearl millet (*bajra*) among coarse millets.

<Insert Table 2 around here>

While Table 1 shows the initial characteristics of each zone, Table 2 summarizes the trends experienced in districts located in each zone and the terminal characteristics during the 2000s. It is worth noting that the high level of land use intensity among L4 districts was maintained and these districts are currently characterized by intensive use of land today. Especially, districts in M7 (Punjab-type zone) witnessed a growth rate of land use intensity and fertilizer use higher than other regions. Looking at the rice wheat ratio (*srw*) or the non-foodgrain ratio (*snfg*), the zone-wise difference is not very substantial. An exception is the rapid increase of *srw* in M10 (*bajra* zone), reflecting the replacement of *bajra* by wheat as irrigation is developed. In districts in M10, fertilizer use increased much faster than in other zones.

As shown above, the cluster analysis using 16 variables suggested a new spatial typology of Indian agriculture. Each zone (or sub-zone) derived by the cluster analysis was associated with its own initial conditions and changes thereafter. Therefore, we conclude that the new typology has an ability to show coherent patterns in district-level descriptive analysis. In the next section, we examine the usefulness of the new typology from a different angle as well.

5. Correlates of District-Level Changes in Land and Fertilizer Use

5.1 Empirical Model

So far in this paper, we found that four indicators of agricultural production intensity show different spatial dynamics across districts and zones. The four indicators are *intensity* (gross cultivated area divided by net cultivated area), *srw* (area share of rice and wheat in the total area under foodgrain crops), *snfg* (areas under non-foodgrain crops divided by gross cultivated area), and *fertilizer* (per-acre use of chemical fertilizer, total of N, P, and K). In this section, we estimate a parametric regression model to identify correlates of district-level changes in these variables. The objective of the regression exercise is again descriptive. We would like to quantify which districts experienced faster or slower growth in the four intensification measures. Candidates for the correlates include state boundaries, new zones suggested in the previous section, and more structural variables. As a byproduct of the regression analysis, we can evaluate how much explanatory power our new typology has in descriptive and parametric regression exercises. The regression model we estimate is specified as:

$$y_{it} = a_i + (b_0 + Z_i b_k)t + u_{it}, \qquad (1)$$

where y_{it} is one of the four indicators in district i in year t, a and b are parameters to be estimated, Z_i is a vector of variables that shift trends, and u_{it} is a zero-mean error.[6]

As each district is associated with different time-invariant characteristics such as weather, geography, history, etc., the level impact of such heterogeneity is perfectly controlled by district fixed effects, a_i. After controlling for such heterogeneity, which factor explains the diversity in district-level growth rate? This is the main motivation of estimating equation (1). In other words, parameters in *b* are of primary interest of this section. Equation (1) can be estimated by a standard one-way fixed effect panel method. As Z_i in the interaction term has no variation across time, we use district-clustered robust standard errors to evaluate the statistical significance of parameter *b*.

We attempt four variants with respect to the choice of Z_i. First, when Z_i is specified as an empty set, parameter b_0 identifies the Indian average growth rates of the four indicators (Model A). Then we include 18 state dummies in Z_i as Model B and 9 zone dummies as Model C. In Models B and C, we use the state (zone) where the largest number of districts are located as the reference, corresponding to parameter b_0. Then parameter b_k shows how much faster or slower growth state (zone) *k* experienced relative to the reference state (zone). In Model D, we include normalized variables of initial intensity measures and exogenous technology and infrastructure variables in Z_i. Then parameter b_0 shows the average growth rate corresponding to a hypothetical district that had the average values of all variables in Z_i while parameter b_k shows the marginal impact the variable has on the growth rate.

5.2 Regression Results

Regression results are shown in Table 3. As shown in Panel A, which correspond to Model A, all of the four indicators had a positive trend, statistically significant at the 1% level. The land use

[6] Equation (1) has its dependent variable in levels, not in their logs, and is estimated by weighted least squares (WLS). This is because our motivation of the regression analysis is descriptive, i.e., to obtain conditional means of district-level variables (*intensity*, *srw*, *snfg*, and *fertilizer*) that are aggregated consistently to the national average. By applying WLS to level variables with proper weights (*nca* for *intensity*, the total foodgrain area for *srw*, *gca* for *snfg*, and *gca* for *fertilizer*), we can achieve this consistent aggregation. Furthermore, the three of the four dependent variables are already in ratios (multiplied by 100), so that the coefficient estimates on the time trend have an intuitive meaning of average annual changes in percentage points. Regarding the fourth variable, *fertilizer*, it may be a good idea to take logs. However, the results are very similar when we use logs (full results are available on request from the authors).

intensity increased by 0.54 percentage points a year, *srw* by 0.33 percentage points, *snfg* by 0.25 percentage points, and *fertilizer* by 2.66 kg/ha per year.

<Insert Table 3 around here>

Panel B, Table 3 shows the regression results when each state is allowed to have a different growth rate. As the number of districts in Uttar Pradesh (UP) is the largest, we use UP as the reference state. The null hypothesis of homogeneous growth rates across states is rejected at the 1% level, as shown in the last row of Panel B. Land use intensity (*intensity*) grew faster than UP in districts in West Bengal, Punjab, and Haryana, while it grew slower by more than 0.5 percentage points in districts in Tamil Nadu, Bihar, Chhattisgarh, Uttarakhand, and Jharkhand. In Punjab and Haryana, where *intensity* grew faster, districts also witnessed faster growth in *fertilizer*. The importance of non-foodgrain crops (*snfg*) increased faster than UP in districts in Maharashtra, Rajasthan, West Bengal, and Andhra Pradesh. Using estimates for b_0 and b_k in Panel B, we examine which state shows a dynamic change that was most similar to the one found at the national level (Panel A). Interestingly, all of the 19 states had one or more variables out of the four that was associated with statistically-significant difference from the national average. In this sense, no state in India represents the Indian average. In the relative sense, however, we found that the dynamic changes observed in Gujarat were the most similar to the national pattern, followed by Karnataka and Maharashtra.

Panel C, Table 3 shows the regression result when each zone in Table 1 is allowed to have a different growth rate. As the number of districts in M8 (rainfed, extensive, *jowar* zone) is the largest, we use the *jowar* zone as the reference zone. Again the null hypothesis of homogeneous growth rates across zones is rejected at the 1% level. The variable *intensity* grew at the fastest rate in districts belonging to M7 (Punjab-type zone), followed by districts belonging to M4 (semi-arid, extensive, wheat-chickpea zone). In contrast, *density* grew at significantly lower rates in M9 (*ragi* zone) and M10 (*bajra* zone). Similar contrast is found for *srw*, *snfg*, and *fertilizer*. Although using a much smaller number of explanatory variables, Model C explains the variation in data as good as Model B does, as shown in adjusted R^2 reported in Table 3. Therefore, we judge the ten-zone typology shown in Figure

3 as fairly useful. This does not imply that there will be other typology that has higher R^2 than model C and a fewer number of zones. The point here is that our typology, which was derived using the criterion of utilizing the information on initial conditions and trends in irrigation only, has reasonable explanatory power in parametric models for spatial changes, when we compare it with other existing typologies.[7]

Finally, Model D employs structural factors as shifters of heterogeneous growth rates. In other words, this is an attempt to open the black box represented by state- or zone-specific growth rates by borrowing insights from microeconomic theory explained in the introduction. As structural shifters, we utilize information contained in 8 variables: *intensity* (initial[8] value), irrigation ratio noted as *iratio* (initial and trend), *srw* (initial), *snfg* (initial), *fertilizer* (initial), *rainfall* (42 year average), *road density* (initial), and *market density* (initial and dummy for missing information).[9] The null hypothesis of homogeneous growth rates across zones is rejected at the 1% level. The regression results (Panel D, Table 3) clearly show that both the initial level and trend of *iratio* are the most important determinant of heterogeneous growth rates in *intensity*, *srw*, *snfg*, and *fertilizer*. The initial level of road density is associated with a higher growth rate of *fertilizer* while the initial level of market density is associated with a higher growth rate of *intensity*. Therefore, the disparity in infrastructure development during the 1960s resulted in the disparity in agricultural intensification since then. Furthermore, the spatial dynamics of *srw* and *snfg*, which show different aspects of commercialization of agriculture, are diverse across districts, reflecting the difference in the initial conditions of cropping patterns and in rainfall patterns. Many of the coefficients on these variables have opposite signs between *srw* and *snfg*. The adjusted R^2 for Model D is similar to the one for Model C, implying that the ten-zone typology has an explanatory power as high as a structural model.

[7] In this paper, we compare our new typology (Panel C) and state boundaries (Panel B). We also estimated a similar model using the 18-zone typology of Rao et al. (2004). Adjusted R^2 was 0.850 (*intensity*), 0.957 (*srw*), 0.810 (*snfg*), and 0.847 (*fertilizer*) (full results are available from the authors on request). These numbers are comparable to those reported in Panel C, Table 3. In this comparison as well, our new typology shows reasonable explanatory power in describing the spatial patterns.

[8] "Initial" values in this regression are the averages of the first five years of the panel data.

[9] We use the per-acre density of principal and sub markets in a district. As this information was missing for many districts in early years in Orissa, Bihar, and West Bengal, we included a dummy for the data missing as a shifter of growth rates.

6. Conclusion

In this paper, we described spatial patterns of long-term changes in Indian agriculture at the district level using a balanced panel dataset from 1965/66 to 2006/07 (42 years). Comprehensively investigating the land use intensity, the ratio of rice and wheat in areas under foodgrains, the ratio of non-foodgrains in gross cultivated area, the fertilizer use intensity, and individual crop shares in gross cultivated areas, we found the following.

First, there existed huge heterogeneity across districts in the speed of agricultural intensifications in the last 42 years. Second, the eyeball perusal of GIS maps identified a shift of rice production into the interior districts of north India, shift of wheat production to the east in north India, new appearance of maize production centers in the interior districts of the Deccan, southward shift of chickpea production, etc. The spatial shift appeared consistent with comparative advantages of each district. Third, we attempted aggregating districts into similar zones using cluster analysis based on their similarity in rainfall, the initial cropping and land-use patterns, and the initial condition and changes in irrigation. The proposed classification has reasonable explanatory power in describing the spatial patterns of long-term changes at the district level. Fourth, we estimated a parametric regression model to identify correlates that were associated with heterogeneous growth rates of the land use intensity, the ratio of rice and wheat in foodgrains, the ratio of non-foodgrains in gross cultivated area, and the fertilizer use intensity across districts. The results confirmed the critical role of irrigation, market, and road development in facilitating intensification of agricultural production. The regression results also clarified the different aspects of agricultural commercialization represented by the rice wheat share and the foodgrain share, respectively. These findings have enriched our knowledge on spatial aspects of agricultural development in India.

The analysis in this paper is descriptive and preliminary in nature, however. Quantifying the contribution of spatial changes to aggregate productivity improvement is left for further study. More fundamental determinants of infrastructure and market development need to be examined in the historical, institutional, and spatial context, which is also left for further research. In the current paper, infrastructure and market development, including the key input of irrigation, were regarded as exogenous to farmers' decision making. This is unsatisfactory considering the political economy context in which the development occurs. Another area of future work is more disaggregated analysis combining household and village level changes in cropping pattern with changes at the district or state (zone) levels. It is possible that the same change at the district level is observed in two districts despite within-district, inter-village changes are substantially different in the two districts. Such cases will shed further light to our understanding of the interaction between market development and agricultural production. Extending the analysis to include more recent years is also left for further research.

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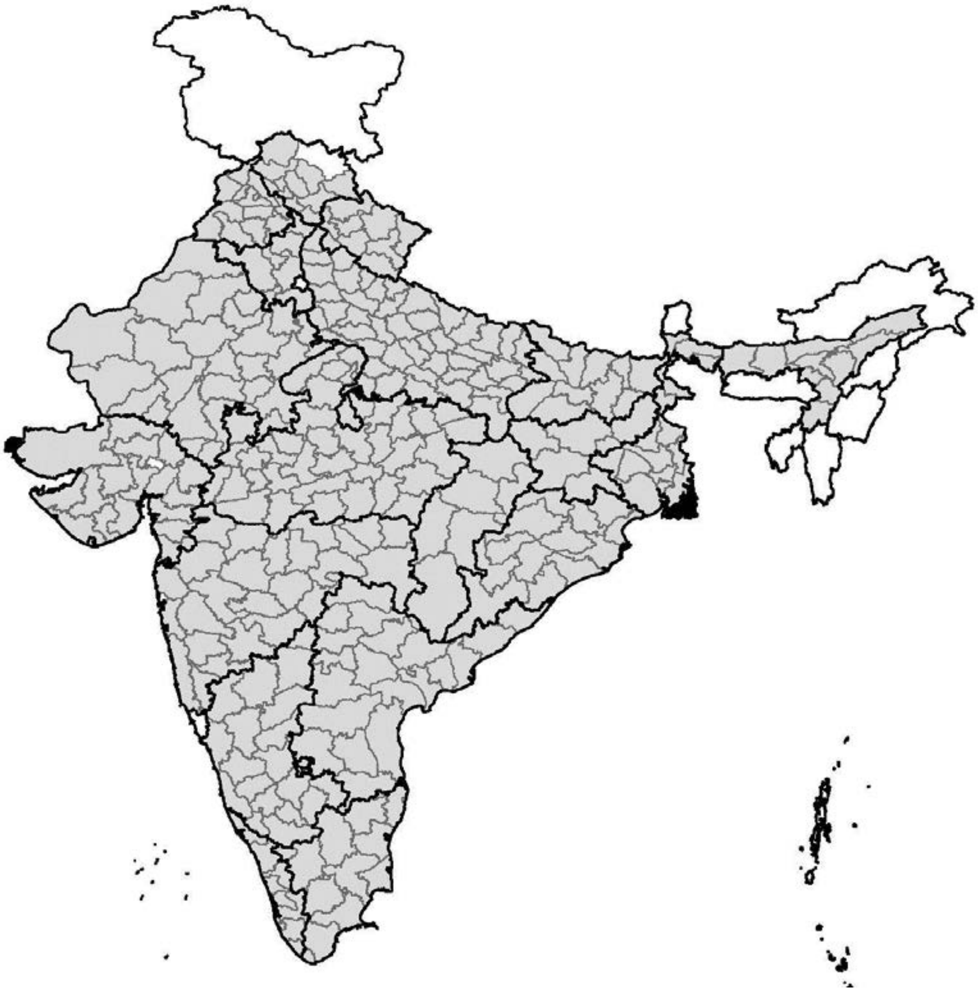
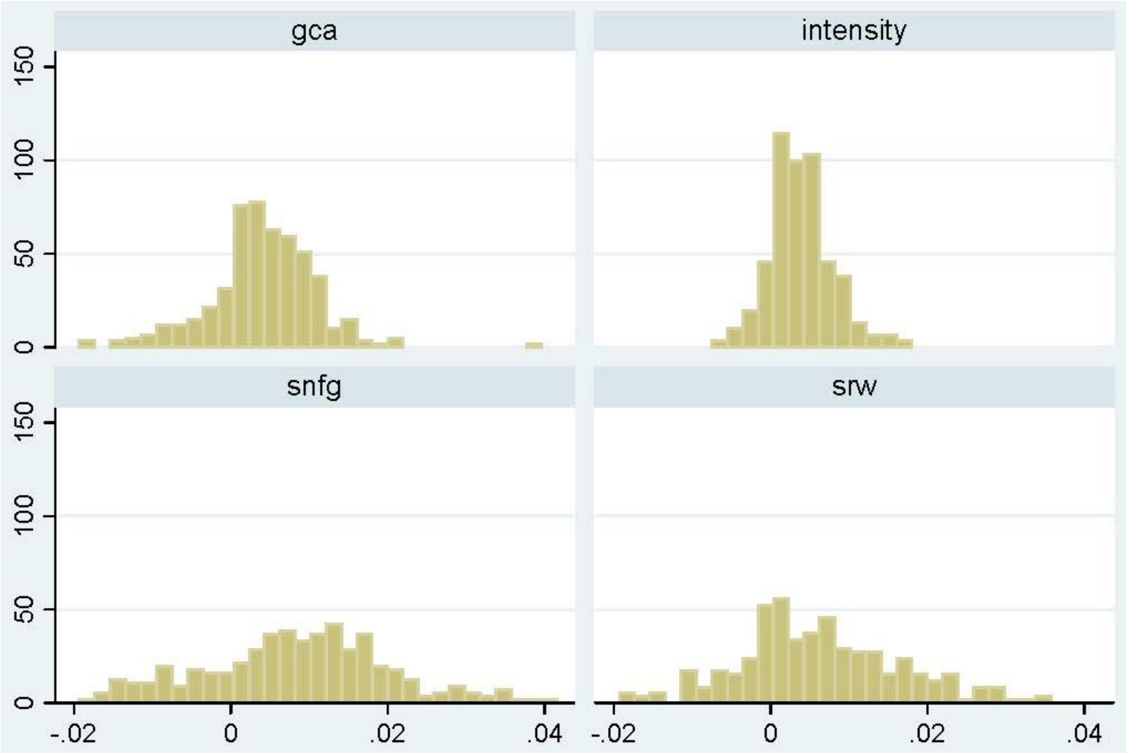
Figure 1. Spatial Distribution of the 311Districts Analyzed



Source: Drawn by the authors using the DLS database (the same for following tables and figures).
Note: The shaded area within thin lines corresponds to a district (boundaries in 1965) included in this study. Bolder lines show state boundaries in 2014.

Figure 2. Distribution of Average Annual Growth Rates at the District Level, 1965/66 - 2006/07



Notes: We first regress a time series model for each of the 311 districts, using the natural logarithm of *gca*, *intensity*, *snfg*, or *srw* as the dependent variable and the annual trend as the explanatory variable (*gca* = gross cultivated area; *intensity* = *gca* / net cultivated area; *snfg* = the share of non-foodgrain crops in *gca*; *srw* = the share of rice and wheat in the areas under foodgrain crops). We then plot the distribution of the 311 parameter estimates in a histogram. To make histograms easy to compare, we trim the range between -.02 (annual average decline at 2%) and .04 (annual average increases at 4%). The number of outliers outside the range is 2 for *gca*, 0 for *intensity*, 22 for *snfg*, and 10 for *srw*.

Figure 3. New Typology Zones Derived from Cluster Analysis

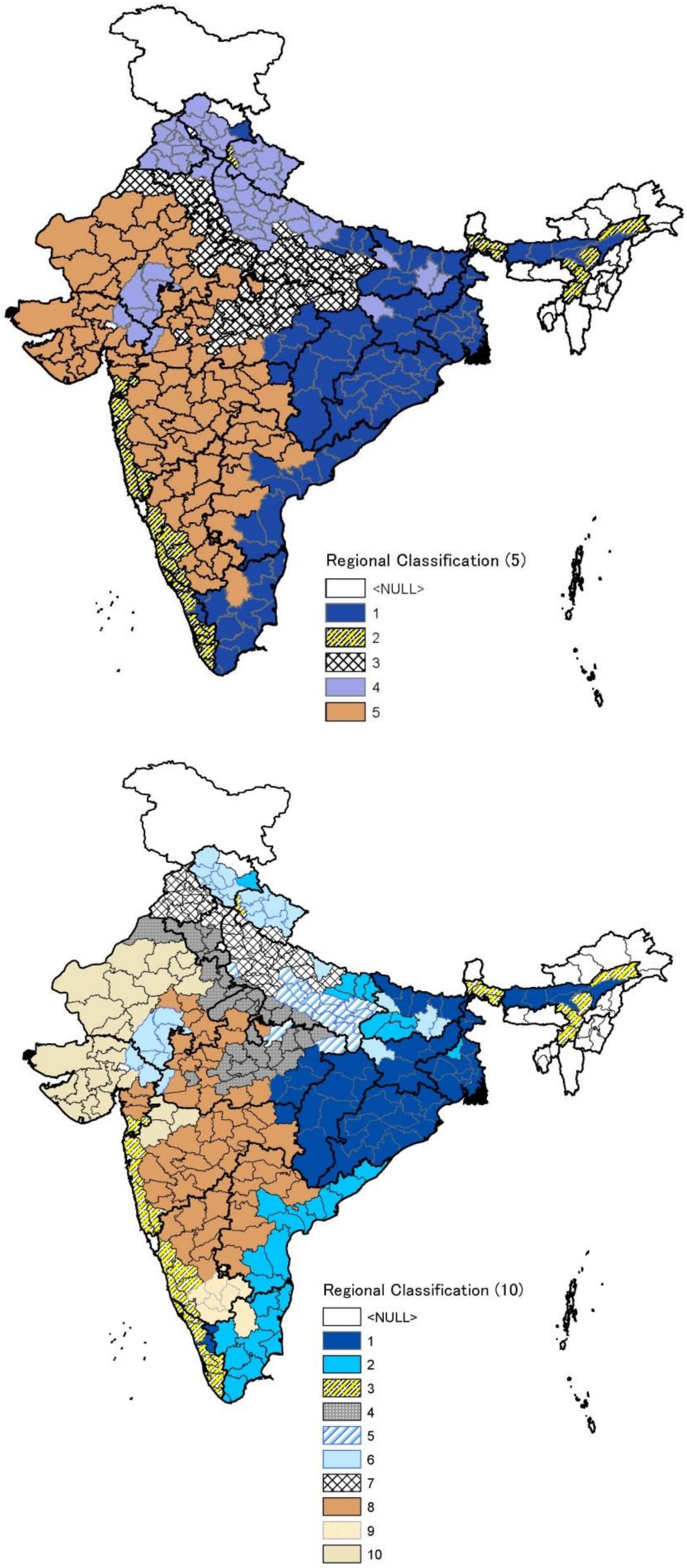


Table 1. Charactersitics of New Typology Zones for Indian Agriculture Derived from Cluster Analysis

Large (5 zones)	Medium (10 zones)	Number of districts	States included*	Rainfall: Annual	Rainfall: June	Rainfall: July-August	Intensity, initial value	Irrigation ratio, initial value	Irrigation ratio, trend	Area under individual crop in gross cultivated area, initial value: rice	wheat	maize	sorghum	pearl millet	finger millet	barley	chick pea	pigeon pea	other pulses	Name (preliminary)
L1	**(=M1,2)**	**83**	**OR, WB, TN, AP, BH, CG, AS, JK, MP, UP, HP, MH**	**0.20**	**0.19**	**-0.11**	**0.14**	**0.30**	**-0.41**	**1.02**	**-0.47**	**-0.28**	**-0.42**	**-0.31**	**-0.04**	**-0.19**	**-0.43**	**-0.41**	**0.12**	**Rice zone**
	M1	53	OR, WB, CG, AS, BH, JK, MP, MH	0.42	0.51	0.25	0.04	-0.26	-0.31	1.18	-0.47	-0.17	-0.53	-0.38	-0.11	-0.23	-0.36	-0.38	0.18	High rainfall, rainfed rice zone
	M2	30	AP, TN, BH, UP	-0.18	-0.37	-0.73	0.30	1.28	-0.59	0.72	-0.48	-0.48	-0.22	-0.18	0.08	-0.12	-0.55	-0.46	-0.01	Low rainfall, irrigated rice zone
L2	**M3**	**29**	**KL, AS, MH, KN, WB**	**2.43**	**2.22**	**2.14**	**0.02**	**-0.18**	**-0.96**	**0.77**	**-0.80**	**-0.38**	**-0.64**	**-0.51**	**0.32**	**-0.50**	**-0.69**	**-0.58**	**-0.59**	**Extreme rainfall, rainfed, non-foodgrains zone**
L3	**(=M4,5)**	**48**	**UP, MP, HY, RS**	**-0.32**	**-0.49**	**0.03**	**-0.10**	**0.01**	**0.96**	**-0.43**	**0.86**	**-0.33**	**-0.11**	**0.11**	**-0.26**	**1.17**	**1.65**	**1.06**	**-0.20**	**Semi-arid, extensive, wheat-pulse zone**
	M4	30	MP, UP, HY, RS	-0.35	-0.53	0.06	-0.37	-0.33	1.07	-0.68	1.14	-0.51	0.03	0.29	-0.28	0.15	2.23	0.66	-0.26	Semi-arid, extensive, wheat-chickpea zone
	M5	18	UP, MP	-0.28	-0.43	-0.03	0.36	0.57	0.78	0.00	0.38	-0.03	-0.36	-0.18	-0.23	2.86	0.67	1.73	-0.11	Semi-arid, extensive, pigeonpea-barley zone
L4	**(=M6,7)**	**61**	**UP, PJ, UK, RS, HP, BH, GJ, HY**	**-0.33**	**-0.28**	**-0.14**	**1.11**	**0.54**	**0.11**	**-0.40**	**0.93**	**1.29**	**-0.61**	**-0.26**	**-0.24**	**0.14**	**0.10**	**-0.32**	**-0.53**	**Semi-arid, intensive, maize zone**
	M6	27	HP, RS, BH, GJ, UK	-0.19	-0.07	-0.11	1.34	-0.29	-0.56	-0.49	-0.01	1.91	-0.58	-0.42	-0.20	0.20	-0.29	-0.39	-0.56	Semi-arid, intensive, maize-dominant zone
	M7	34	UP, PJ, HY	-0.44	-0.45	-0.17	0.92	1.19	0.64	-0.33	1.68	0.79	-0.63	-0.12	-0.28	0.10	0.42	-0.27	-0.51	Irrigation-intensive, wheat-maize zone
L5	**(=M8,9, 10)**	**90**	**MH, RS, MP, KN, GJ, AP**	**-0.57**	**-0.44**	**-0.51**	**-0.83**	**-0.58**	**0.10**	**-0.68**	**-0.40**	**-0.31**	**1.07**	**0.56**	**0.24**	**-0.38**	**-0.33**	**0.22**	**0.55**	**Rainfed, extensive, millet zone**
	M8	57	MH, MP, AP, RS, KN, GJ	-0.42	-0.31	-0.34	-0.83	-0.62	0.17	-0.65	-0.30	-0.21	1.73	-0.14	-0.18	-0.40	-0.18	0.66	0.40	Rainfed, extensive, jowar zone
	M9	7	KN	-0.50	-0.71	-1.20	-0.70	-0.11	-0.50	-0.31	-0.89	-0.52	-0.22	-0.39	5.35	-0.54	-0.66	-0.06	1.02	Rainfed, extensive, ragi zone
	M10	26	RS, GJ, MH	-0.93	-0.64	-0.70	-0.85	-0.63	0.10	-0.85	-0.48	-0.49	-0.04	2.36	-0.23	-0.28	-0.56	-0.67	0.77	Rainfed, extensive, bajra zone

* Name of states: AP=Andhra Pradesh, AS=Assam, BH=Bihar, CG=Chhattisgarh, GJ=Gujarat, HP=Himachal Pradesh, HY=Haryana, JK=Jharkhand, KN=Karnataka, KL=Kerala, MP=Madhya Pradesh, MH=Maharashtra, OR=Orissa, PJ=Punjab, RS=Rajasthan, TN=Tamil Nadu, UP=Uttar Pradesh, UK=Uttarakhand, WB=West Bengal.

This table reports the normalized cluster-wise average. Therefore, under the normal distribution, the threshold for the top 5% (bottom 5%) is +1.64 (-1.64), while the threshold for the top 10% (bottom 10%) is +1.28 (-1.28).

Table 2. Changes That Occurred in Each Typology Zone Regarding Intensity of Agricultural Production and Cropping Patterns

Large (5 zones)	Medium (10 zones)	Name (preliminary)	States included	Indices for intensity of agric. production#				Area under individual crop in gross cultivated area#									
				intensity	srw	snfg	fertlizer	rice	wheat	maize	sorghum	pearl millet	finger millet	barley	chick pea	pigeon pea	other pulses
L1		**Rice zone**	**OR, WB, TN, AP, BH, CG, AS, JK, MP, UP, HP, MH**	**(, ,)**	**(+, ,)**	**(, ,)**	**(, ,)**	**(+, , +)**	**(, ,)**	**(, ,)**	**(, ,)**	**(, ,)**	**(, ,)**	**(, ,)**	**(, ,)**	**(, ,)**	**(, ,)**
	M1	High rainfall, rainfed rice zone	OR, WB, CG, AS, BH, JK, MP, MH	(, ,)	(+, ,)	(, ,)	(, ,)	(+, , +)	(, ,)	(, ,)	(, ,)	(, ,)	(, ,)	(, ,)	(, ,)	(, ,)	(, ,)
	M2	Low rainfall, irrigated rice zone	AP, TN, BH, UP	(, - ,)	(, ,)	(, ,)	(+, ,)	(, ,)	(, ,)	(, ,)	(, ,)	(, ,)	(, ,)	(, ,)	(, + ,)	(, ,)	(, ,)
L2	**M3**	**Extreme rainfall, rainfed, non-foodgrains zone**	**KL, AS, MH, KN, WB**	**(, ,)**	**(+, , +)**	**(+, , +)**	**(, ,)**	**(, ,)**	**(, , -)**	**(, ,)**	**(, ,)**	**(, ,)**	**(, ,)**	**(, ,)**	**(, ,)**	**(, ,)**	**(, ,)**
L3		**Semi-arid, extensive, wheat-pulse zone**	**UP, MP, HY, RS**	**(, ,)**	**(, ,)**	**(, ,)**	**(, ,)**	**(, ,)**	**(+, , +)**	**(, ,)**	**(, ,)**	**(, ,)**	**(, ,)**	**(+, ,)**	**(+, , +)**	**(+, ,)**	**(, ,)**
	M4	Semi-arid, extensive, wheat-chickpea zone	MP, UP, HY, RS	(, ,)	(, ,)	(, ,)	(, ,)	(, ,)	(+, ,)	(, ,)	(, ,)	(, ,)	(, ,)	(, ,)	(+, , +)	(, ,)	(, ,)
	M5	Semi-arid, extensive, pigeonpea-barley zone	UP, MP	(, ,)	(, ,)	(, ,)	(, ,)	(, ,)	(, , +)	(, ,)	(, ,)	(, ,)	(, ,)	(+, ,)	(, ,)	(+, ,)	(, ,)
L4		**Semi-arid, intensive, maize zone**	**UP, PJ, UK, RS, HP, BH, GJ, HY**	**(+, , +)**	**(, ,)**	**(, ,)**	**(, ,)**	**(, ,)**	**(+, , +)**	**(+, , +)**	**(, ,)**	**(, ,)**	**(, ,)**	**(, ,)**	**(, ,)**	**(, ,)**	**(, ,)**
	M6	Semi-arid, intensive, maize-dominant zone	HP, RS, BH, GJ, UK	(+, - ,)	(, ,)	(+, ,)	(, ,)	(, ,)	(, ,)	(+, , +)	(, ,)	(, ,)	(, ,)	(, , +)	(, ,)	(, ,)	(, ,)
	M7	Irrigation-intensive, wheat-maize zone	UP, PJ, HY	(+, + , +)	(, , +)	(, ,)	(+, , +)	(, + ,)	(+, , +)	(, ,)	(, ,)	(, ,)	(, ,)	(, ,)	(, ,)	(, ,)	(, ,)
L5		**Rainfed, extensive, millet zone**	**MH, RS, MP, KN, GJ, AP**	**(, ,)**	**(-, , -)**	**(, ,)**	**(, ,)**	**(, ,)**	**(, ,)**	**(, ,)**	**(+, ,)**	**(, ,)**	**(, ,)**	**(, ,)**	**(, ,)**	**(, ,)**	**(, ,)**
	M8	Rainfed, extensive, jowar zone	MH, MP, AP, RS, KN, GJ	(, ,)	(-, , -)	(, ,)	(, ,)	(, ,)	(, ,)	(, ,)	(+, , +)	(, ,)	(, ,)	(, ,)	(, ,)	(, , +)	(, ,)
	M9	Rainfed, extensive, ragi zone	KN	(, - , -)	(-, , -)	(, ,)	(+, ,)	(, ,)	(-, , -)	(, ,)	(, ,)	(, ,)	(+, + , +)	(, ,)	(, ,)	(, ,)	(+, ,)
	M10	Rainfed, extensive, bajra zone	RS, GJ, MH	(-, ,)	(-, + , -)	(, ,)	(, + ,)	(-, , -)	(, + ,)	(, ,)	(, ,)	(+, , +)	(, ,)	(, + ,)	(, ,)	(, ,)	(, + ,)

Note: # (x, y, z) shows the relative positions of each cluster in the Indian average, where x indicates the initial value, y the trend, and z the terminal value. If the relative position is high (low) at the 20% significance level, + (-) is shown. A black implies statistical insignificance. For instance, (+, -,) indicates that the cluster had its initial value higher than the Indian average but the trend was more negative than the Indian average, resulting in insignificant difference in the terminal value.

Table 3. Regression Results for District-Level Changes in Agricultural Production Intensity

	intensity (x100)		srw (x100)		snfg (x100)		fertilizer	
Summary Statistics								
No. of observations#	12,620		12,936		12,680		12,680	
Mean (Std.Dev.) of the dep. var.	126.43	(21.95)	52.01	(31.21)	32.27	(18.45)	55.39	(56.14)
Regression Results	coeff.	std.err	coeff.	std.err	coeff.	std.err	coeff.	std.err
A. Homogeneous Trends across All Districts								
District fixed effects to the intercept	(Yes.$)		(Yes.$)		(Yes.$)		(Yes.$)	
Common trend: b_0	0.544 ***	0.034	0.328 ***	0.030	0.254 **	0.027	2.764 ***	0.104
R^2	0.829		0.952		0.799		0.810	
R^2 adjusted	0.825		0.951		0.794		0.806	
B. State-Specific Trends								
District fixed effects to the intercept	(Yes.$)		(Yes.$)		(Yes.$)		(Yes.$)	
Base trend: b_0 (reference=UP)	0.646 ***	0.054	0.738 ***	0.048	0.208 ***	0.040	3.592 ***	0.207
State-specific deviation of trends: b_k (k = state dummy)								
Andhra Pradesh	-0.336 ***	0.096	-0.391 ***	0.112	0.223 **	0.087	1.028 *	0.522
Assam	0.019	0.153	-0.731 ***	0.049	-0.044	0.049	-2.369 ***	0.296
Bihar	-0.648 ***	0.132	-0.316 ***	0.082	-0.504 ***	0.185	-0.403	0.327
Chhattisgarh	-0.620 ***	0.077	-0.435 ***	0.058	-0.328 ***	0.065	-1.935 ***	0.395
Gujarat	-0.402 ***	0.078	-0.362 ***	0.097	0.132	0.131	-1.003 ***	0.309
Himachal Pradesh	-0.322 ***	0.109	-0.590 ***	0.052	-0.546 ***	0.139	-2.281 ***	0.247
Haryana	0.509 ***	0.190	0.534 ***	0.152	0.143	0.136	1.102 *	0.612
Jharkhand	-0.582 ***	0.088	-0.575 ***	0.071	0.142 **	0.069	-1.934 ***	0.328
Karnataka	-0.210 **	0.098	-0.678 ***	0.087	-0.070	0.096	-0.719 *	0.399
Kerala	-0.499 ***	0.187	-0.708 ***	0.060	0.415 ***	0.085	-1.843 ***	0.300
Maharashtra	-0.038	0.110	-0.663 ***	0.065	0.190 ***	0.064	-1.258 ***	0.258
Madhya Pradesh	0.100	0.099	-0.546 ***	0.086	0.203 **	0.098	-2.113 ***	0.241
Orissa	0.106	0.093	-1.030 ***	0.069	-0.127 *	0.065	-2.318 ***	0.289
Punjab	0.809 ***	0.142	0.088	0.112	-0.538 ***	0.066	1.020 ***	0.244
Rajasthan	-0.115	0.091	-0.474 ***	0.088	0.245 **	0.095	-2.411 ***	0.287
Tamil Nadu	-0.779 ***	0.087	-0.723 ***	0.096	0.068	0.103	0.399	0.406
Uttarakhand	-0.626 ***	0.154	-0.818 ***	0.088	-1.596 ***	0.523	-0.733	1.850
West Bengal	0.881 ***	0.173	-0.510 ***	0.074	0.225 ***	0.051	0.082	0.313
R^2	0.871		0.969		0.827		0.873	
R^2 adjusted	0.867		0.968		0.822		0.870	
F (18, 310) stat for b_k=0 for all k.	20.08 ***		28.66 ***		17.47 ***		37.48 ***	
C. Typology-Zone-Specific Trends (10 zones)								
District fixed effects to the intercept	(Yes.$)		(Yes.$)		(Yes.$)		(Yes.$)	
Base trend: b_0 (reference=8.Jowar	0.584 ***	0.057	0.188 ***	0.045	0.407 ***	0.059	2.526 ***	0.177
Zone-specific deviation of trends: b_k (k = cluster dummy)								
1. High rainfall, rainfed rice zone	-0.003	0.121	-0.075	0.065	-0.300 ***	0.077	-0.372	0.254
2. Low rainfall, irrigated rice zone	-0.451 ***	0.103	0.087	0.084	-0.300 **	0.118	1.972 ***	0.318
3. Ext. rainfall, rainfed, non-fg zone	-0.163	0.169	-0.099	0.063	0.047	0.078	-0.228	0.329
4. Semi-arid, ext., wheat-chickpea zo	0.224 *	0.117	0.327 **	0.156	0.049	0.086	-0.247	0.314
5. Semi-arid, ext., pigeonpea-barley z	0.121	0.085	0.779 ***	0.075	-0.411 ***	0.079	0.523	0.356
6. Semi-arid, intensive, maize zone	-0.366 ***	0.093	0.068	0.095	-0.722 ***	0.124	-0.426	0.337
7. Punjab type zone	0.373 ***	0.128	0.578 ***	0.065	-0.330 ***	0.092	2.037 ***	0.276
9. Rainfed, extensive, ragi zone	-0.357 ***	0.081	-0.114	0.094	0.142	0.088	0.650	0.498
10. Rainfed, extensive, bajra zone	-0.194 **	0.086	0.009	0.070	0.039	0.089	-0.979 ***	0.307
R^2	0.845		0.962		0.818		0.855	
R^2 adjusted	0.841		0.961		0.813		0.851	
F (9, 310) stat for b_k=0 for all k.	10.53 ***		31.06 ***		14.52 ***		20.08 ***	

Table 3. Regression Results for District-Level Changes in Agricultural Production Intensity (cont'd)

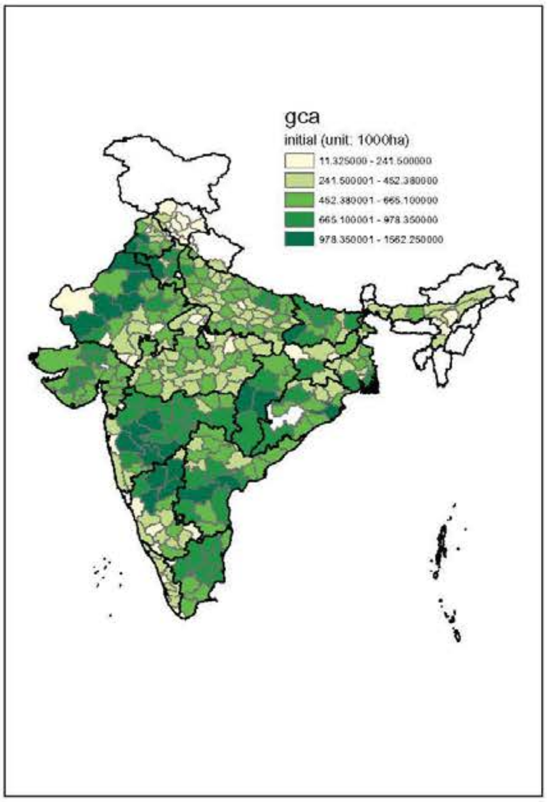
	intensity (x100)		srw (x100)		snfg (x100)		fertilizer	
	coeff.	std.err	coeff.	std.err	coeff.	std.err	coeff.	std.err
D. Initial-Factor-Dependent Trends								
District fixed effects to the intercept	(Yes.$)		(Yes.$)		(Yes.$)		(Yes.$)	
Base trend: b_0	0.530 ***	0.048	0.339 ***	0.030	0.257 ***	0.032	2.658 ***	0.102
Deviation for the following variables: b_k (*k* = structural factors)								
intensity, initial (normalized)	-0.109	0.072	0.113 ***	0.031	-0.207 ***	0.051	-0.017	0.091
iratio, initial (normalized)	0.181 **	0.078	0.251 ***	0.043	0.102 **	0.046	0.485 ***	0.114
iratio, trend (normalized)	0.224 ***	0.043	0.220 ***	0.025	0.101 ***	0.029	0.478 ***	0.073
srw, initial (normalized)	0.085	0.056	-0.113 ***	0.036	-0.178 ***	0.038	-0.130	0.103
snfg, initial (normalized)	-0.005	0.048	-0.001	0.035	-0.053	0.039	-0.174 **	0.084
fertilizer, initial (normalized)	-0.136 **	0.052	-0.102 ***	0.035	0.019	0.030	0.946 ***	0.119
rainfall, 42 year average (norm.)	-0.030	0.065	-0.017	0.039	0.227 ***	0.038	-0.001	0.145
road density, initial (norm.)	-0.078	0.148	0.074	0.075	-0.076	0.075	0.714 **	0.319
market density, initial (norm.)	0.169 ***	0.063	0.041	0.033	-0.014	0.035	0.031	0.169
dummy for missing market info	0.008	0.064	-0.079 *	0.042	-0.081	0.056	0.273 *	0.142
R^2	0.844		0.966		0.818		0.877	
R^2 adjusted	0.840		0.965		0.813		0.874	
F(10, 310) stat for b_k=0 for all *k*.	6.43 ***		20.73 ***		6.64 ***		27.62 ***	

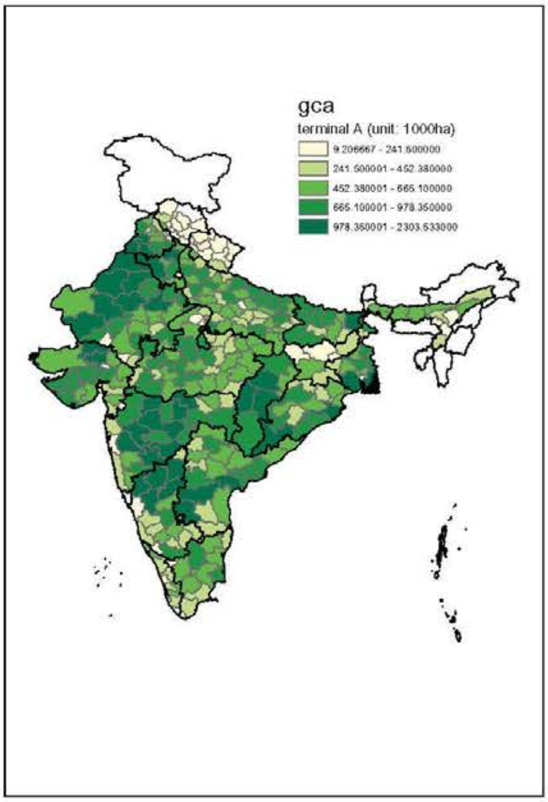
Notes: Estimated by weighed least squares with district-clustered robust standard errors. The weights are *nca* for *intensity*, the total foodgrain area for *srw*, *gca* for *snfg*, and *gca* for *fertilizer*). Statistically significant at 1% ***, 5% **, 10% *. See Table 1 for the distribution of districts across 10 zones used in Panel C. The summary statistics for original variables used to calculate shifters in Panel D are available on request from the authors.

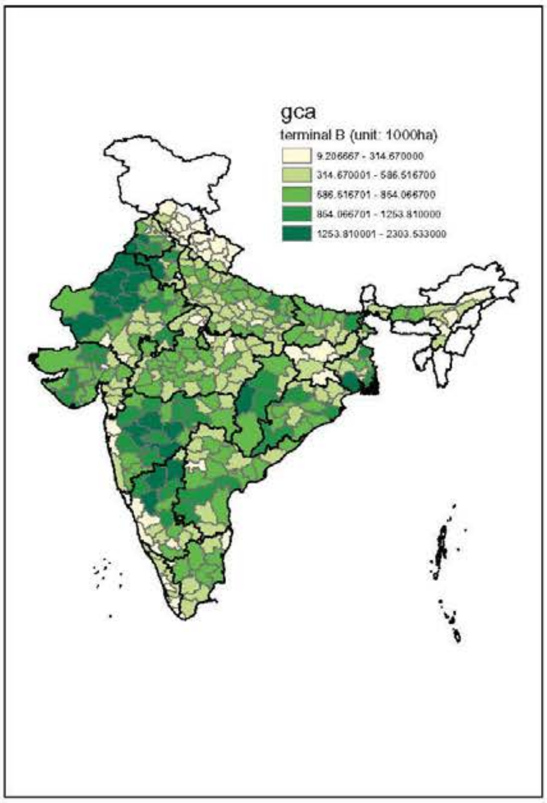
$ For brevity, district fixed effects on intercepts are not reported. They are jointly significant at the 0.1% level in all specifications.

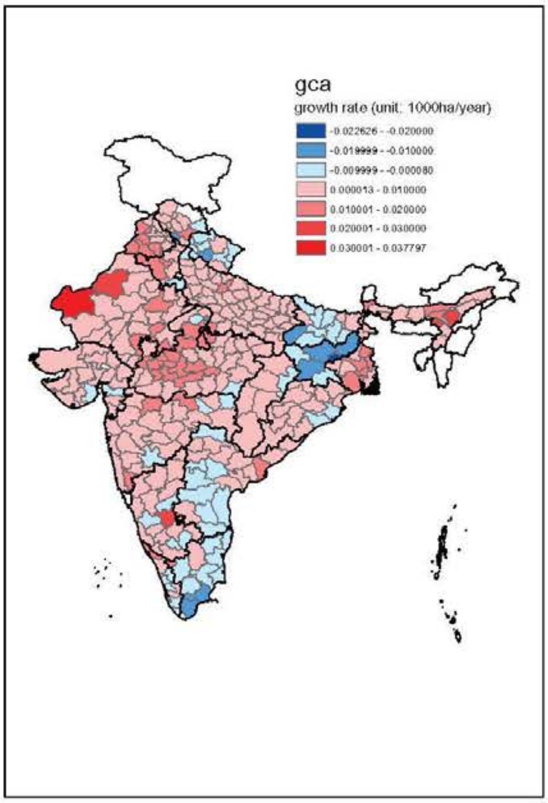
Although we potentially use 13,062 observations (=311 districts * 42 years), the actual number of observations used in regressions was less than this due to missing observations.

Appendix Map 1. District-level changes, gross cultivated area (1965-2007)

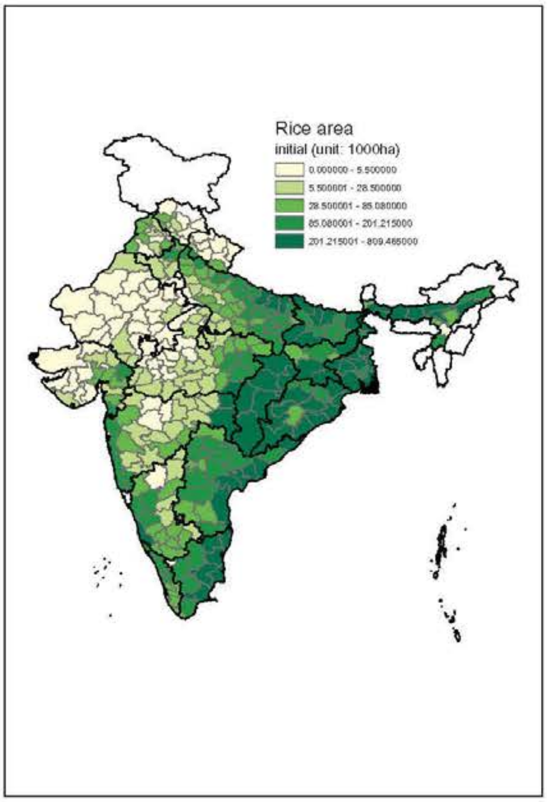


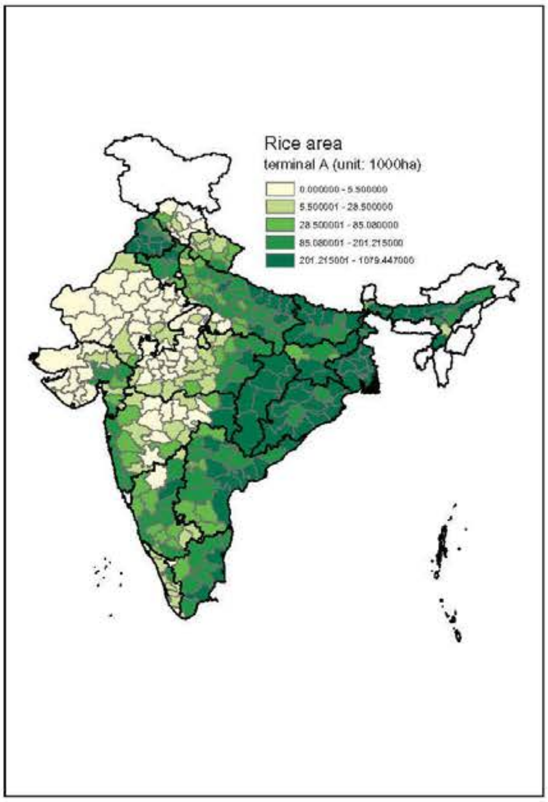


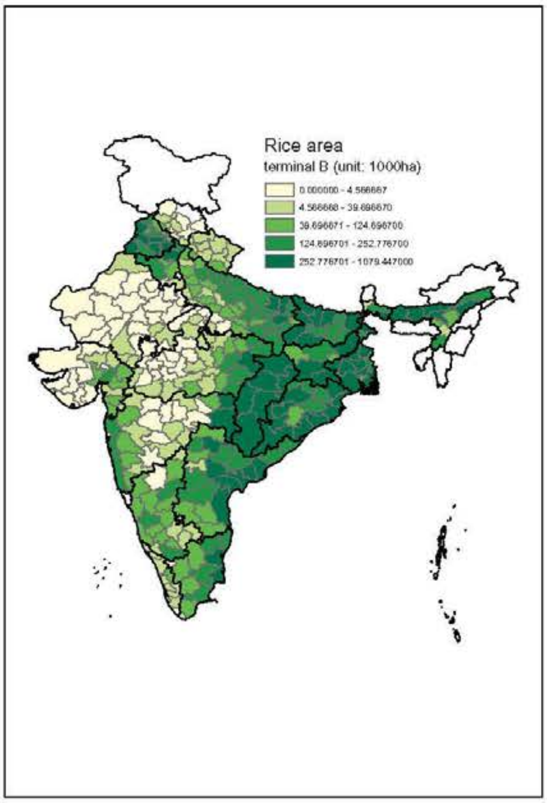


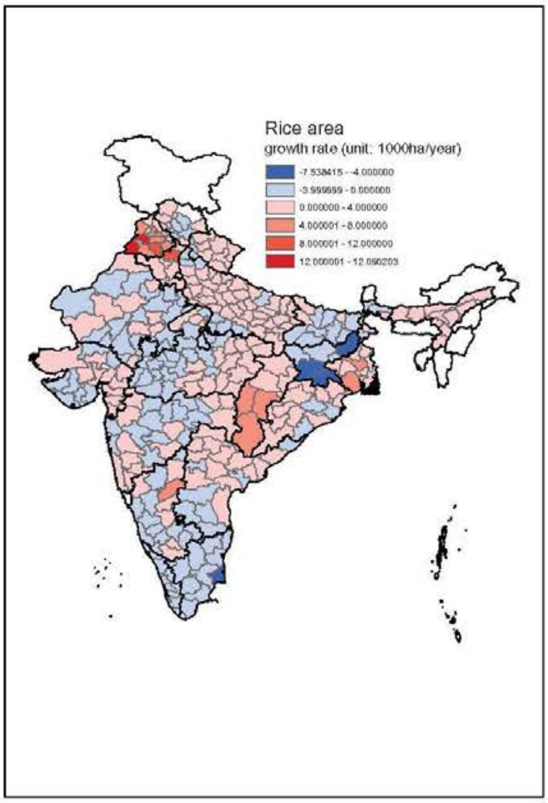


Appendix Map 2. District-level changes, rice area (1965-2007)

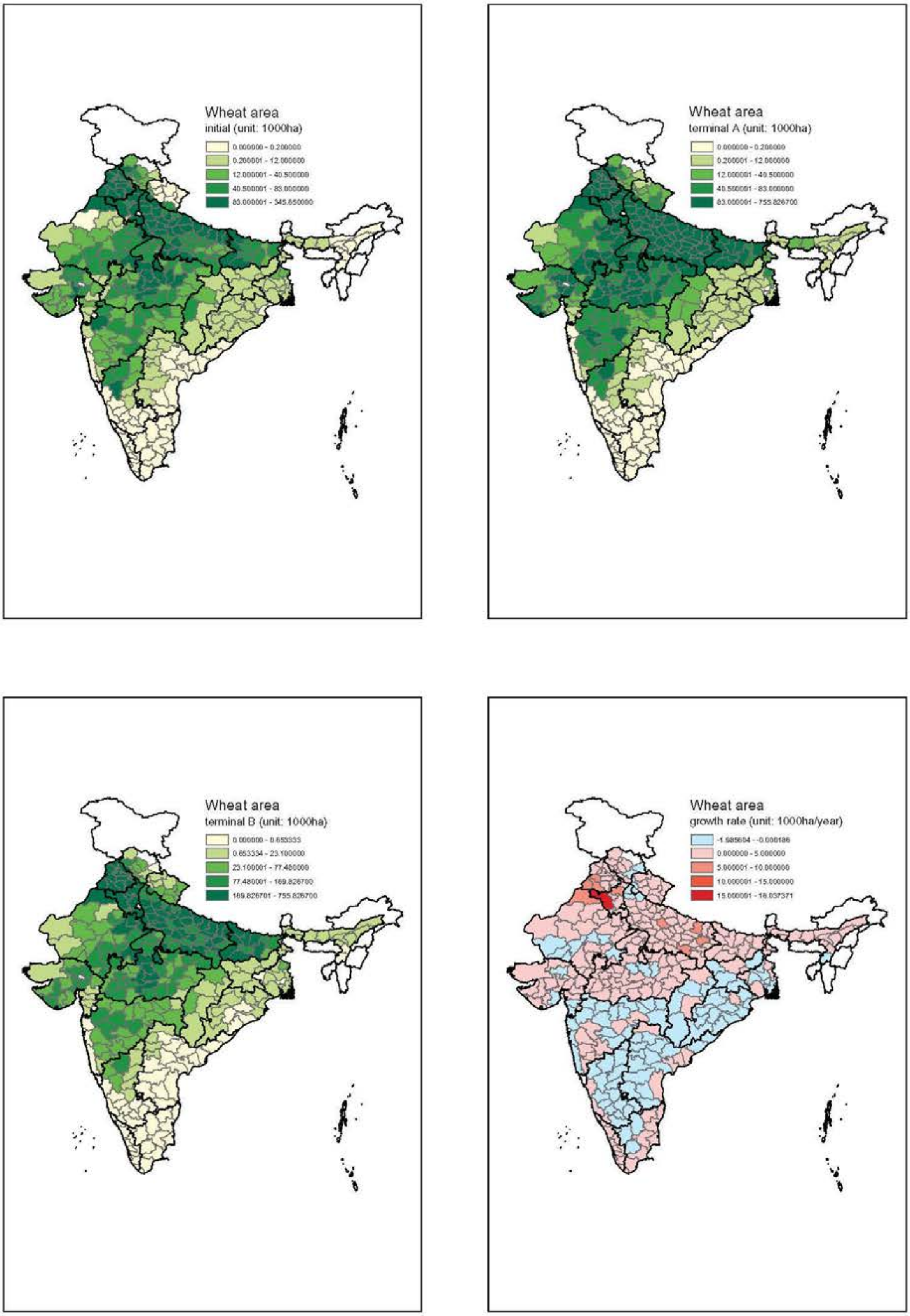




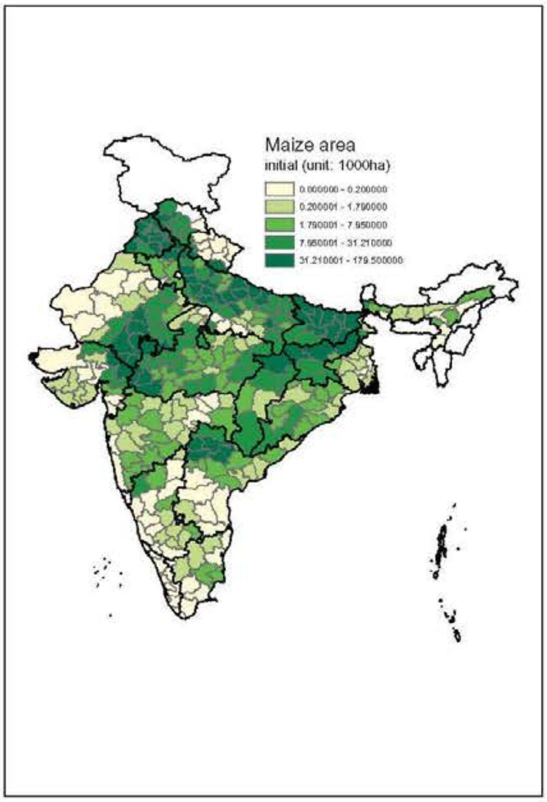


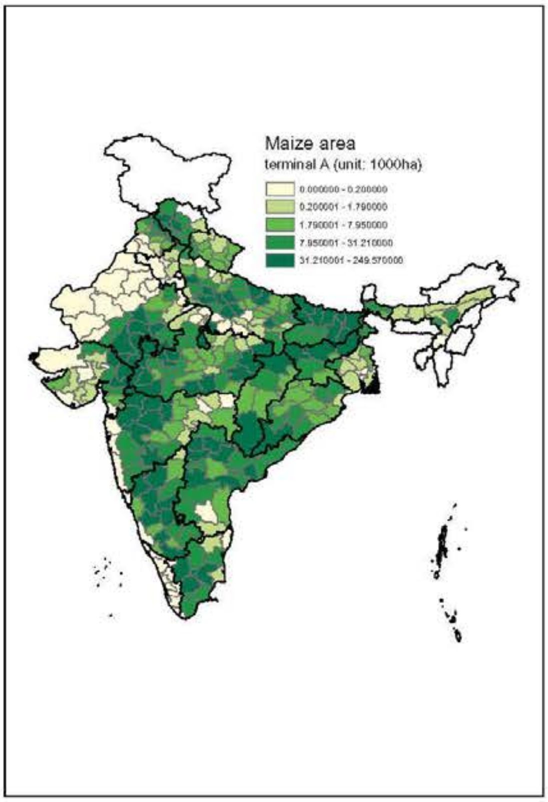


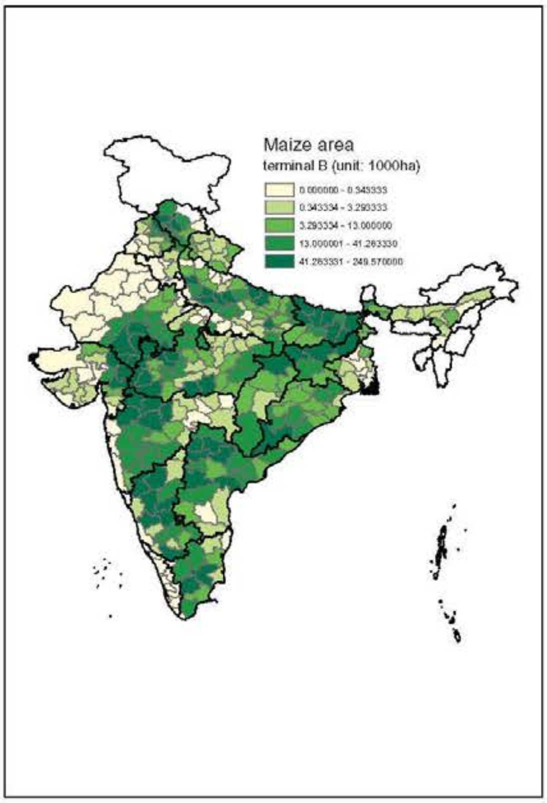
Appendix Map 3. District-level changes, wheat area (1965-2007)

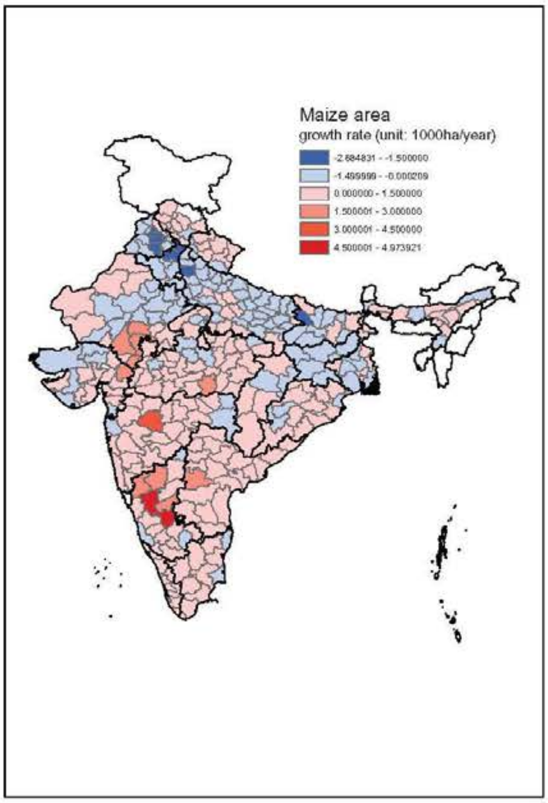


Appendix Map 4. District-level changes, maize area (1965-2007)

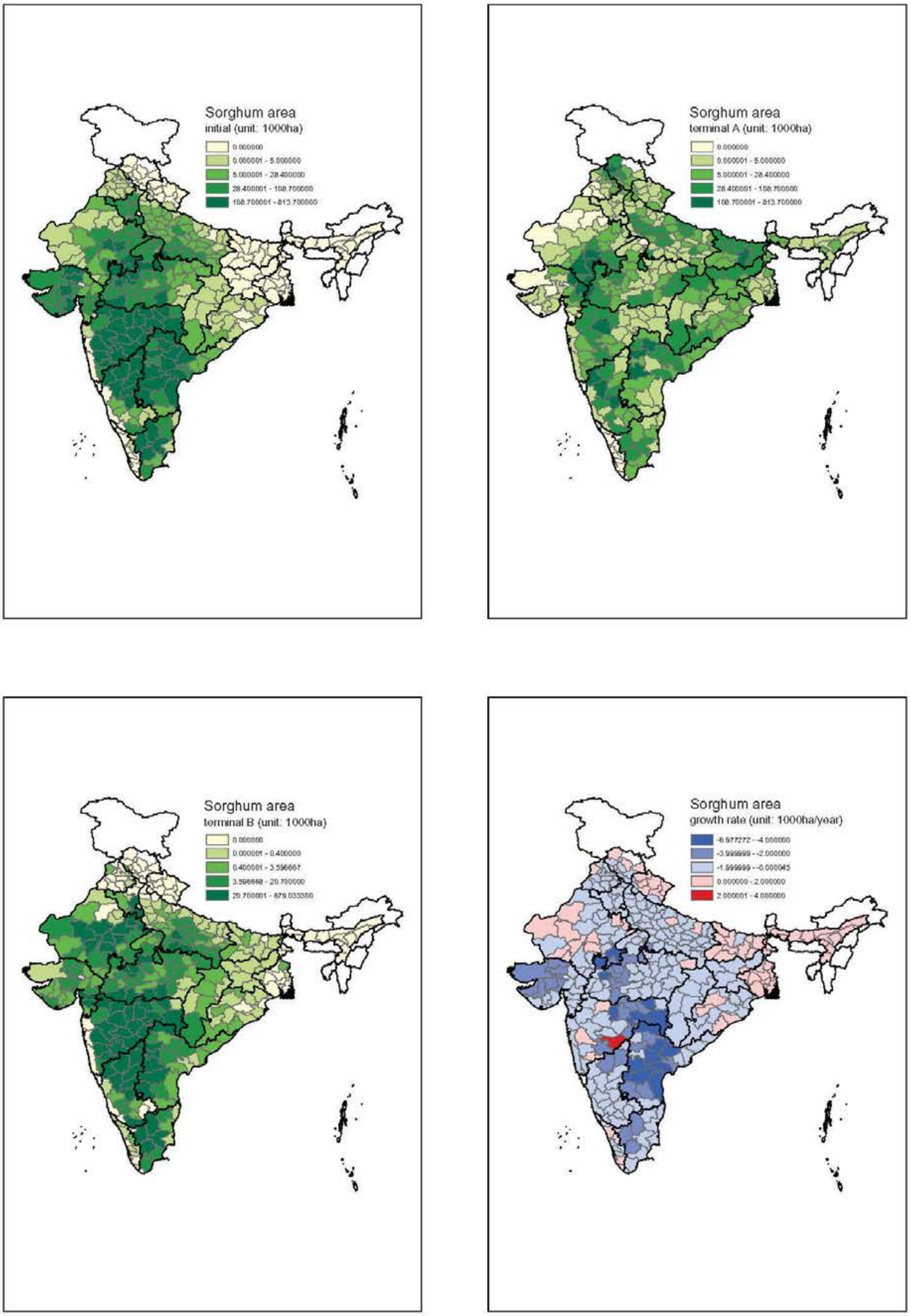




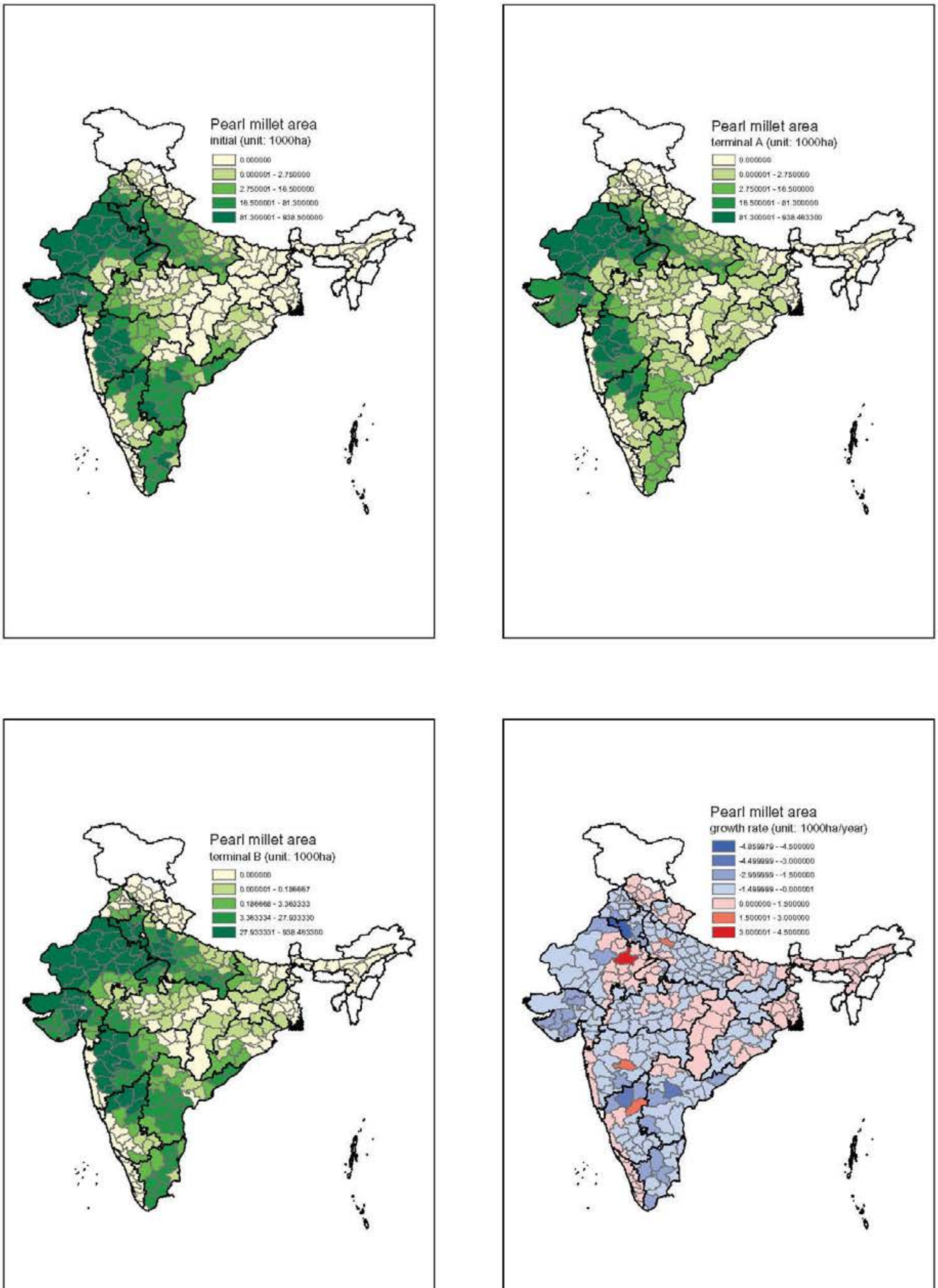




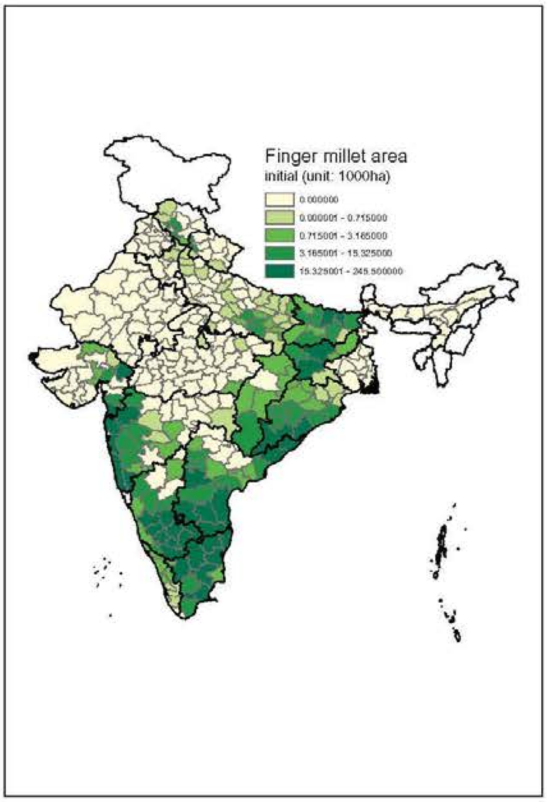
Appendix Map 5. District-level changes, sorghum area (1965-2007)

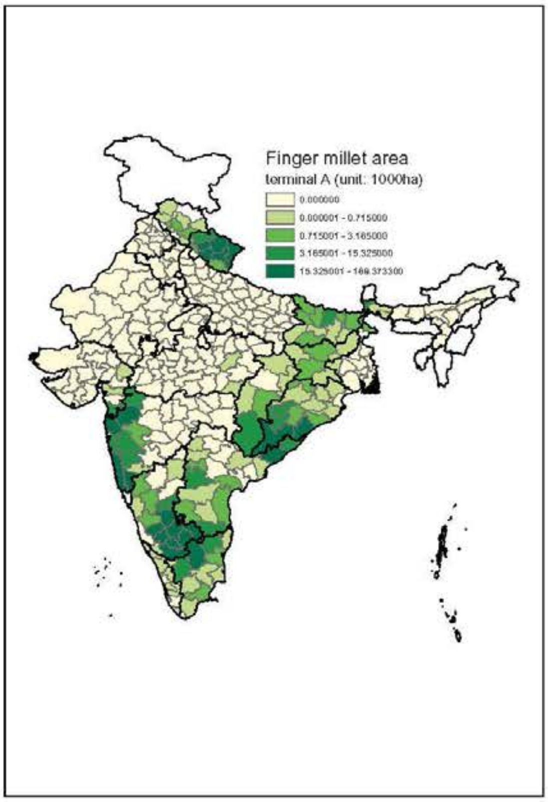


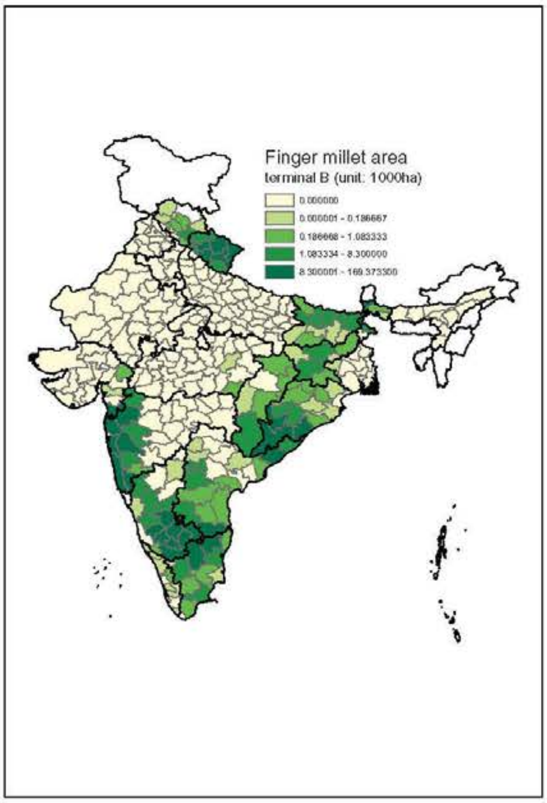
Appendix Map 6. District-level changes, pearl millet area (1965-2007)

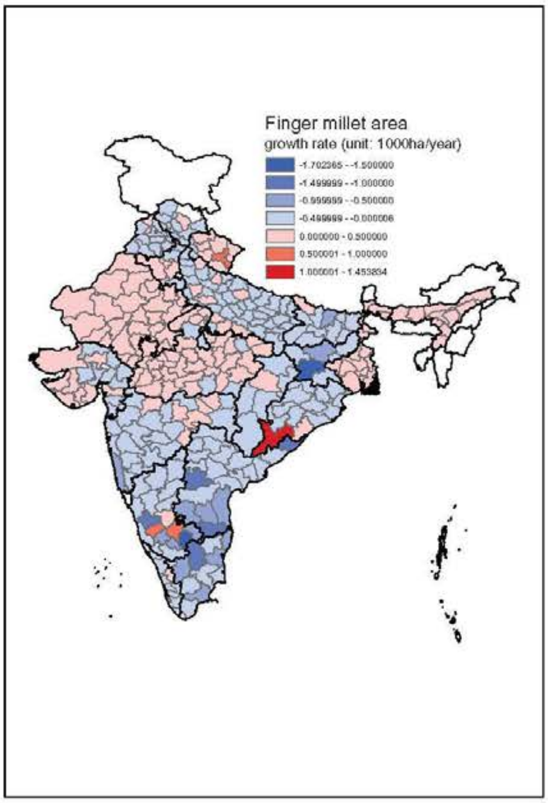


Appendix Map 7. District-level changes, finger millet area (1965-2007)

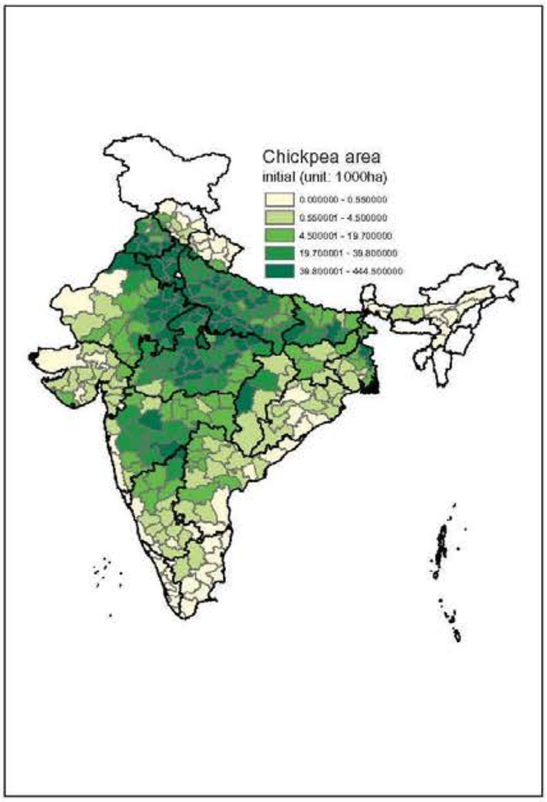


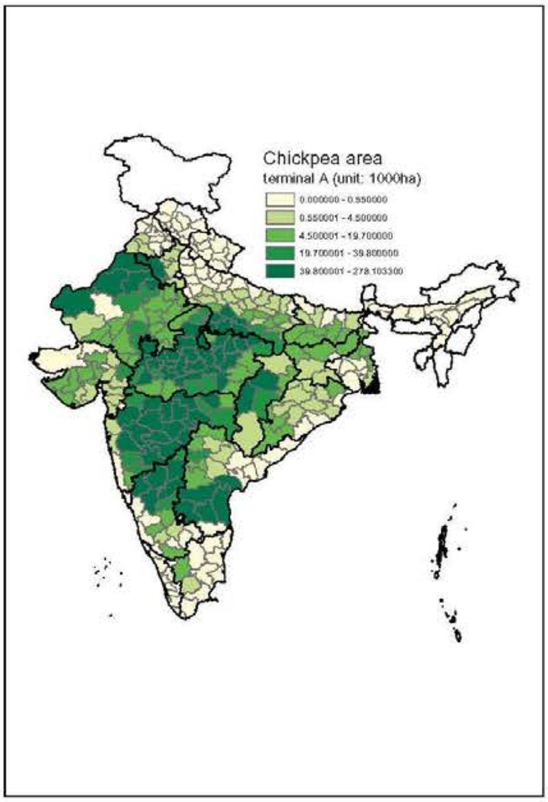


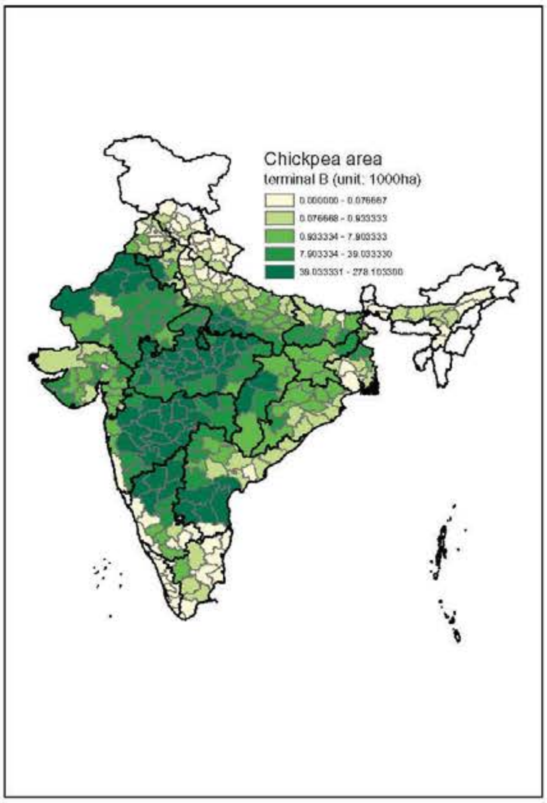


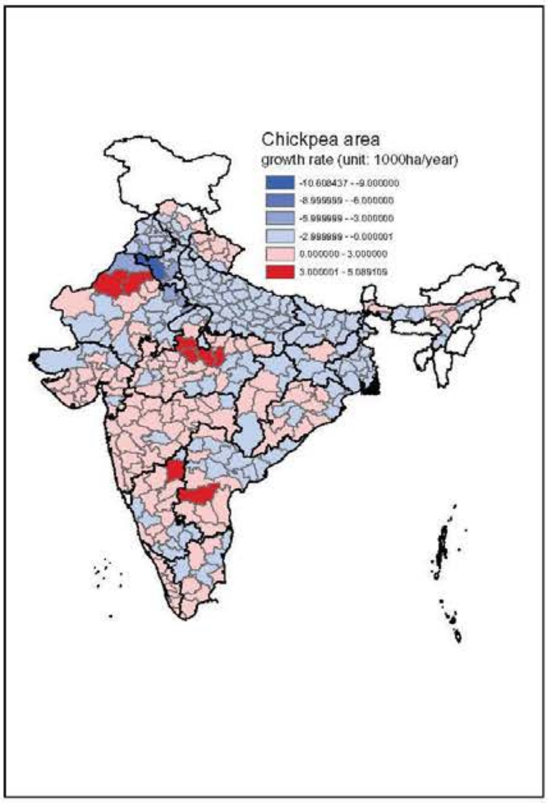


Appendix Map 8. District-level changes, chickpea area (1965-2007)

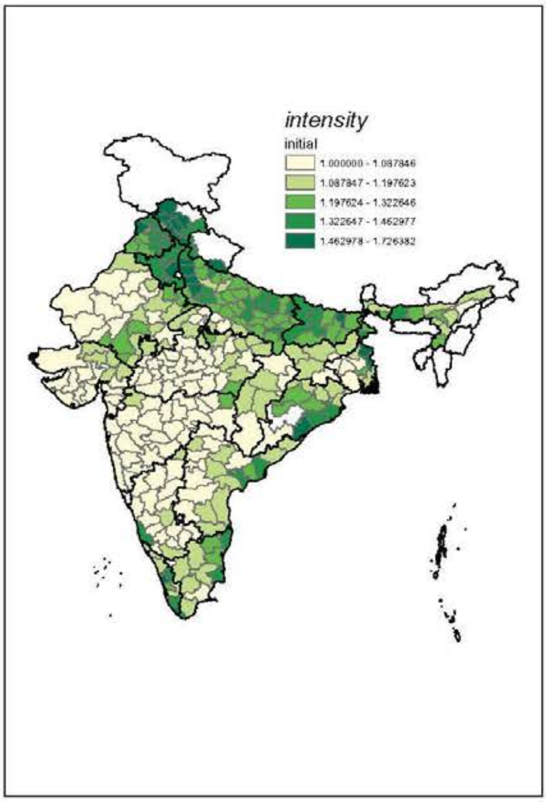


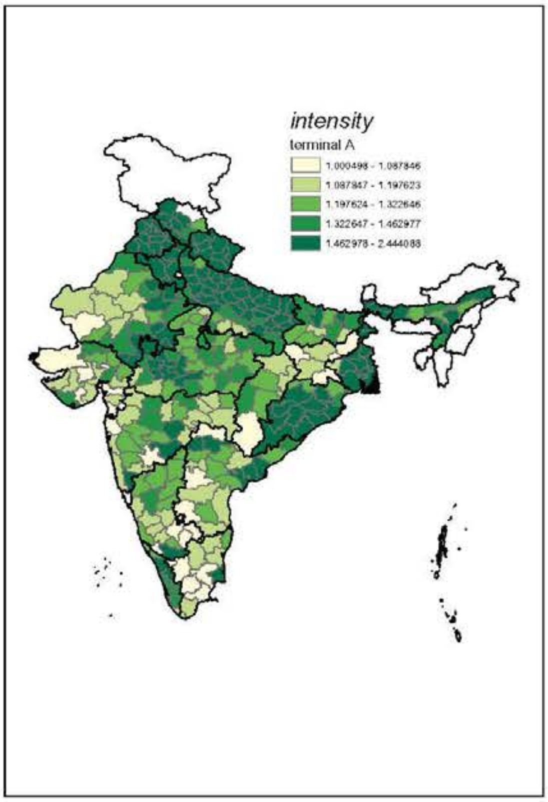


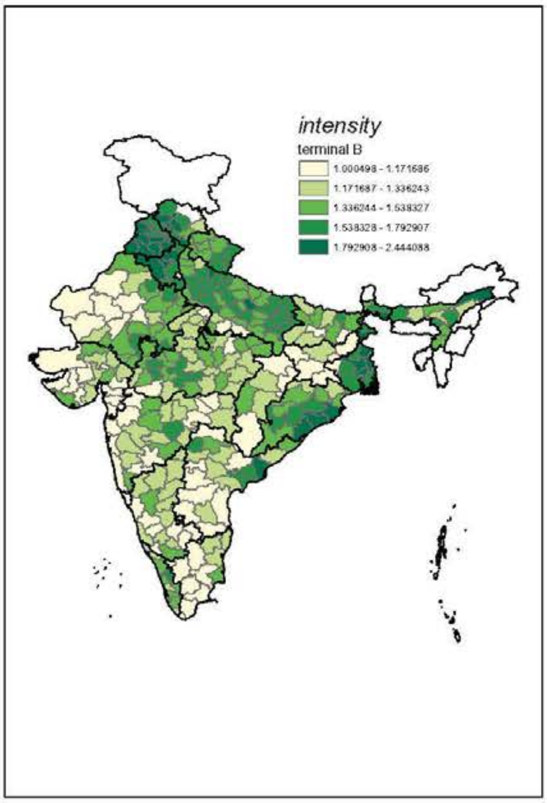


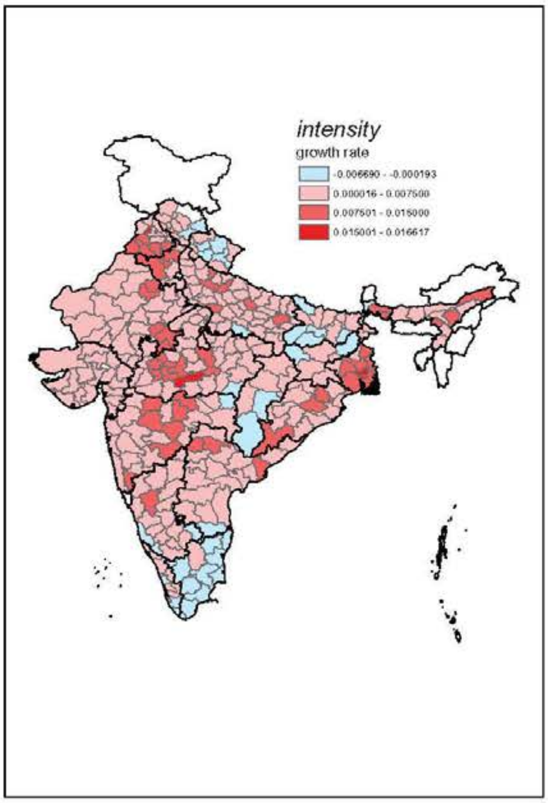


Appendix Map 9. District-level changes, *intensity* (= gca/net cultivated area) (1965-2007)

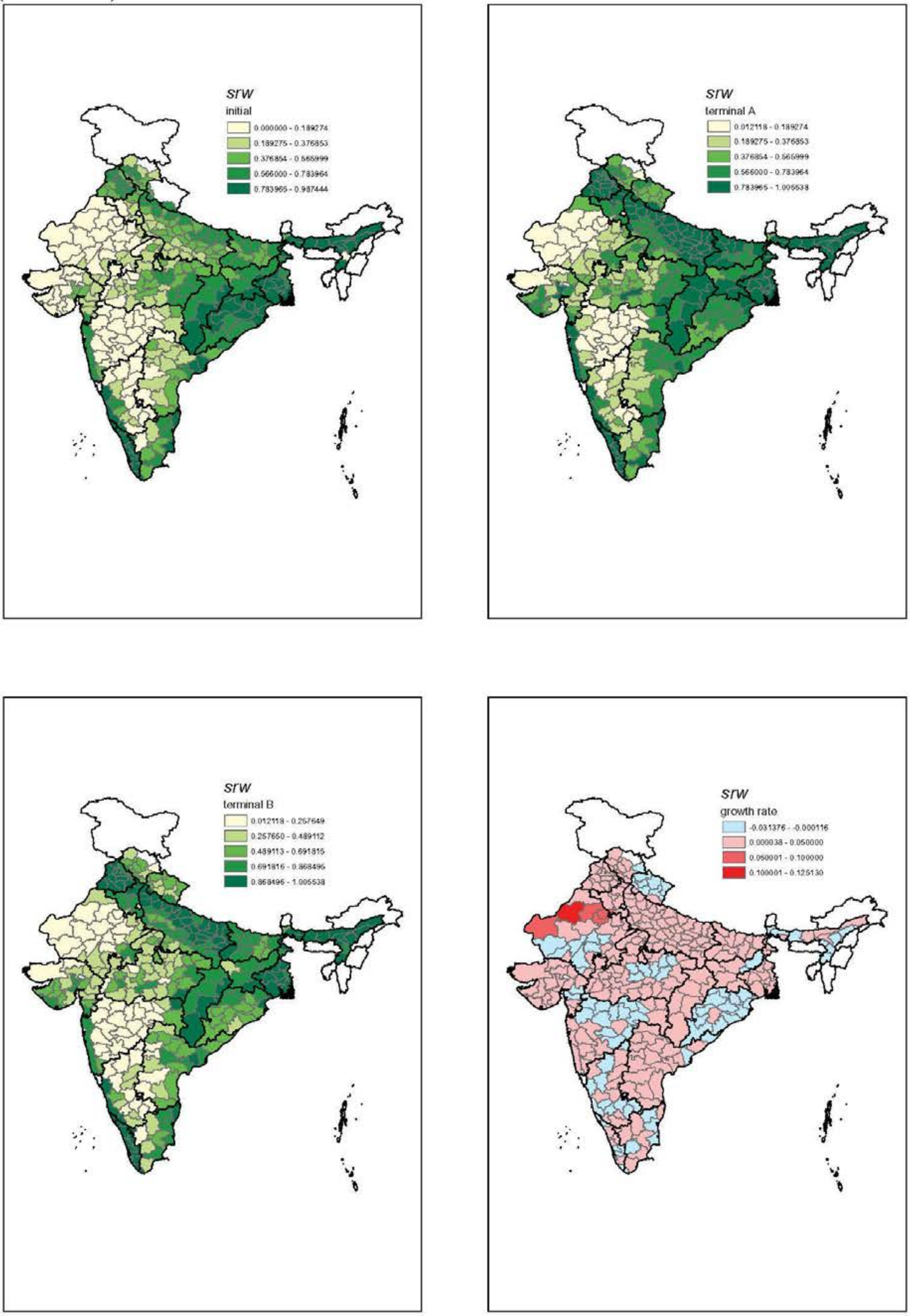








Appendix Map 10. District-level changes, *srw* (= share of rice and wheat area in food grain area) (1965-2007)



Appendix Map 11. District-level changes, *snfg* (= share of non-foodgrain crops area in gca) (1965-2007)