Estimation of the changes in the dynamics of tillage choices in Iowa, 1992-2008

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Abstract

The benefits of conservation tillage are only fully realized when conservation tillage is used continuously over a numbers of years. However, little is known about the dynamics of farmer's tillage choices. Panel tillage data are sparse and incomplete. This study presents a method that uses the data on tillage shares to infer the probabilities of rotational and continuous conservation tillage. Using the framework of first-order Markov chains, we model tillage dynamics and estimate the probabilities of transition from one tillage-crop combination to another tillage-crop combination with spatially aggregated data. We use the combination of Quadratic Programming and Generalized Cross-Entropy to infer the transition probabilities for the period of 1992-2008. We estimate that approximately one million acres of corn and soybeans moved away from continuous conservation tillage to greater tillage intensity practices during the period 2001-2008. Geographically, more acreage in the southern and eastern Iowa – where soils are of lower productivity and more likely to be classified as Highly Erodible Land – were taken out of continuous conservation tillage practice between 2001 and 2008, when compared with the rest of the state.

Introduction

- The benefits of conservation tillage (CT) are fully realized when conservation tillage is used continuously.
- Farmers often alternate conservation tillage with conventional tillage because farmers' crop and tillage choices are interdependent; farmers are more likely to adopt CT on soybeans than on corn (Hill, 2001; Wade et al., 2015; Claassen & Ribaudo, 2016; Kurkalova & Tran, 2017).
- Tillage adoption data for multiple consecutive years are spare and often incomplete.
- Due to confidentiality concerns, collected tillage data are often available to researchers in aggregated form only, such as county/state averages (e.g, USDA-NASS Census of Agriculture 2012, USDA ARMS, NRI-CEAP and CTIC tillage data).
- Most of previous studies did not explicitly consider the continuity of tillage (Knowler et al., 2014).
- Tillage dynamics are often overlooked when process-based model (e.g., Soil and Water Assessment Tool) is used (Panagopoulos et al., 2015).

Objectives

1) Estimate the non-stationary transition matrices of farmers' year-to-year tillage-crop choices in Iowa, 1992-2008.
2) Evaluate the spatial and temporal variability of the use of continuous conservation tillage, rotational conservation tillage, and continuous conventional tillage in the state.

Data and Methods

We use county-level tillage data from Conservation Tillage Information Center (CTIC); the data were collected annually 1992-1997, biannually 1998-2004, and annually for selected counties 2006-2008.

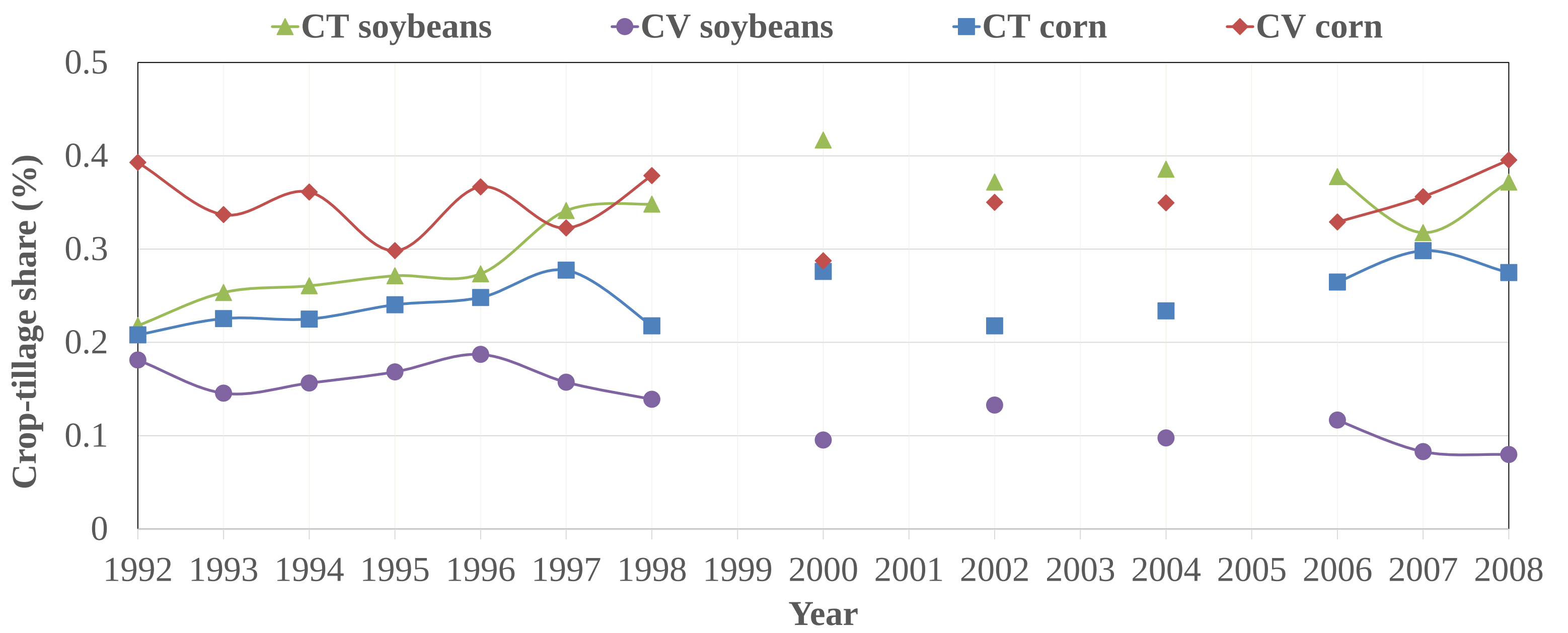


Figure 1. Collected tillage-crop share 1992-2008, Iowa

Note: CT = conservation tillage, CV=conventional tillage

Statistical model

Estimating transition matrices includes two steps:

1) We use Quadratic Programming to estimate prior transition matrices with time-ordered aggregate data from 1992 to 1997 (Kelton, 1994; Kurkalova & Tran, 2017; Lee et al., 1970; Tran & Kurkalova, 2016).
2) We then estimate non-stationary transition matrices for 99 Iowa counties.
    - We use Maximum-Entropy to recover tillage-crop shares for 1999, 2001, 2003, 2005 and 2006
    - We estimate transition matrices using Cross-Entropy approach.

Cross-Entropy and Markov model

$$\min I(\mathbf{p_{ij}(t)}, \mathbf{u_{jm}(t)}) = \sum_i \sum_j \mathbf{p_{ij}(t)} * \ln\left(\frac{\mathbf{p_{ij}(t)}}{\mathbf{q_{ij}(t)}}\right) + \sum_j \sum_m \mathbf{u_{jm}(t)} * \ln\left(\frac{\mathbf{u_{jm}(t)}}{\mathbf{w_{jm}(t)}}\right) \qquad (1)$$

Subject to

$$\mathbf{s(t+1)} = \mathbf{s(t)} * \mathbf{p_{ij}(t)} + \mathbf{e_j(t)} \quad \forall i, j = 1, 2, 3, 4 \qquad (2)$$

$$\sum_j \mathbf{p_{ij}(t)} = 1 \quad \forall i = j = 1, 2, 3, 4 \qquad (3)$$

$$\sum_n \mathbf{u_{jm}(t)} = 1 \quad \forall j = 1, 2, 3, 4, m = 1, 2, 3 \qquad (4)$$

$$\mathbf{e_j(t)} = \sum_j \sum_n \mathbf{u_{jm}(t)} * \mathbf{v_m} \quad \forall j = 1, 2, 3, 4, m = 1, 2, 3 \qquad (5)$$

And

$$\mathbf{p_{ij}(t)} \ge 0 \quad \forall i, j \ \text{and} \ \mathbf{u_{jm}(t)} \ge 0 \quad \forall j = 1, 2, 3, 4, m = 1, 2, 3 \qquad (6)$$

- s(t) = tillage-crop shares in time t, corresponding to CT corn, CV corn, CT soybeans, and CV soybeans
- $p_{ij}(t)$ = transition matrix
- u_{jm} and v_{jm} = error weight and error support, respectively
- $q_{ij}(t)$ = prior information
- We use Maximum Entropy to recover missing data by treating transition matrix and shares as unknowns, and assuming that prior information is uniformly distributed
- We estimate prior information using Quadratic Programming

Quadratic Programming and Markov model

$$\mathbf{s(t+1)} = \mathbf{s(t)} * \mathbf{q} + \varepsilon, \qquad (8)$$

$$\min_q (\mathbf{s(t+1)} - \mathbf{s(t)} * \mathbf{q})' * (\mathbf{s(t+1)} - \mathbf{s(t)} * \mathbf{q}) \qquad (9)$$

Subject to

$$0 \le \mathbf{q_{ij}} \le 1, \quad i, j = 1, \ldots, 4 \qquad (10)$$

$$\sum_{j=1}^{4} \mathbf{q_{ij}} = 1, \quad i = 1, \ldots, 4. \qquad (11)$$

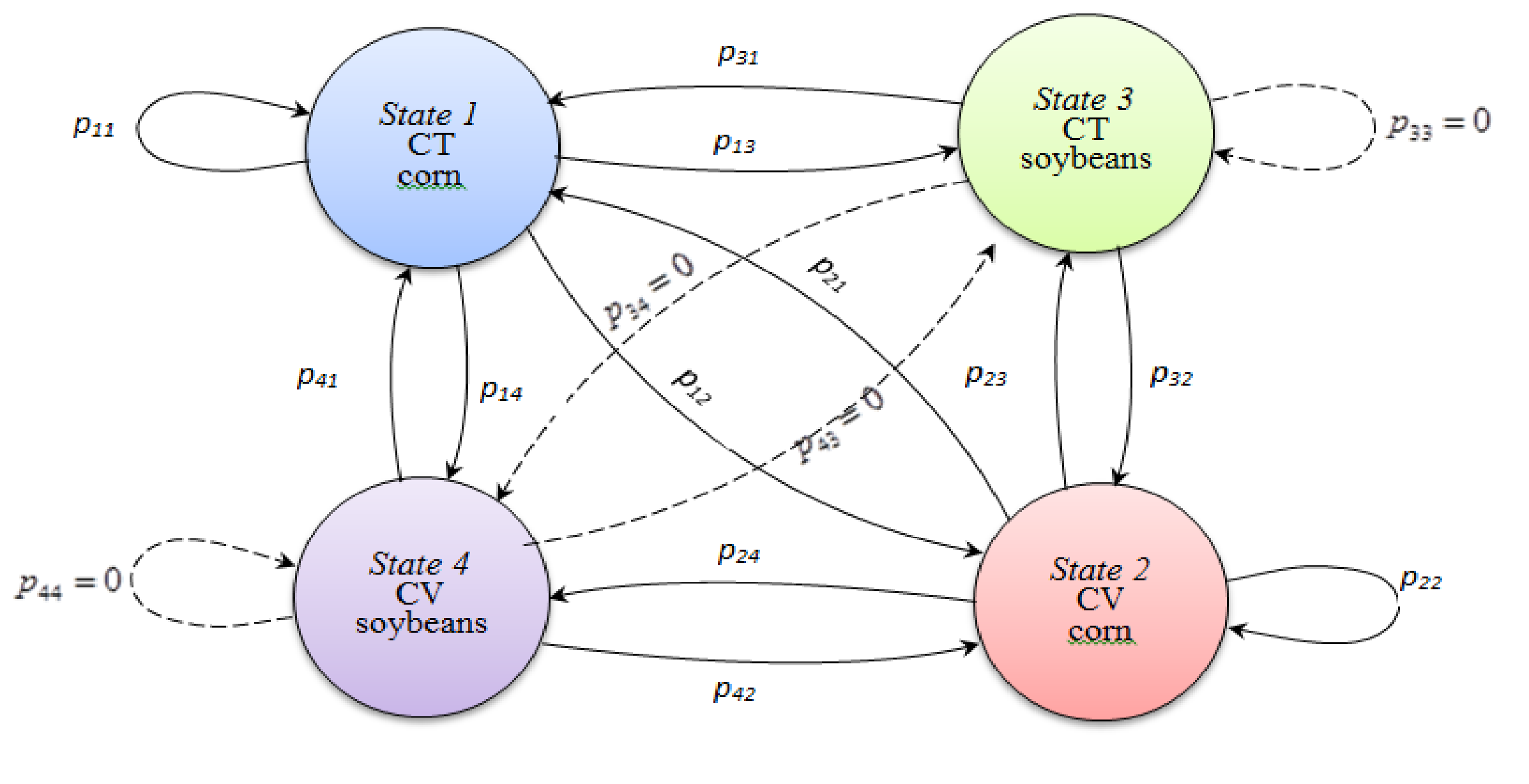


Figure 2. Transition matrix diagram

Markov chain model has 4 states: CT corn, CV corn, CT soybeans and CV soybeans.

Model performance

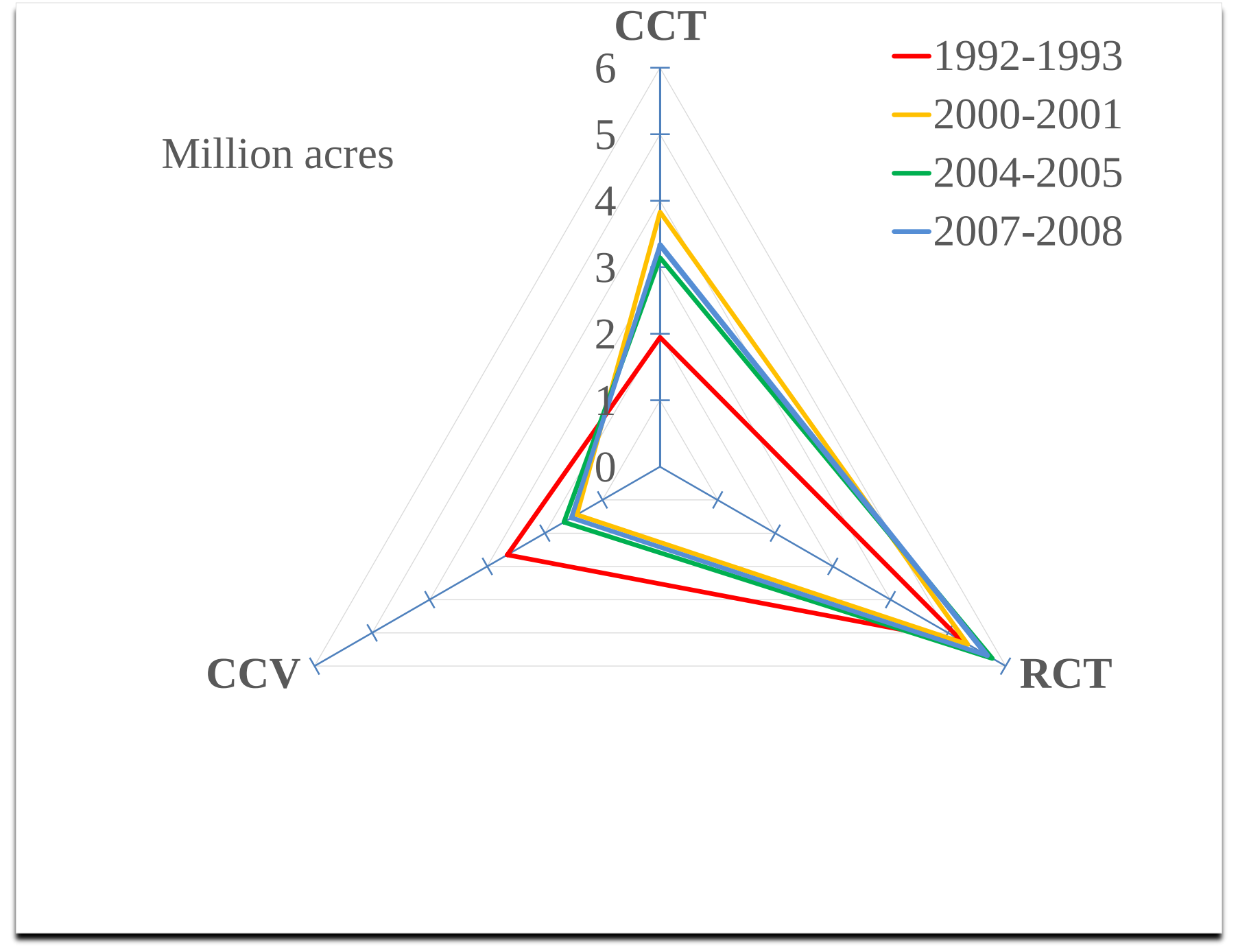
We use normalized Entropy, s_p and mean absolute error, MAE, to measure the performance for Entropy and Quadratic Programming models, respectively.

$$s_p = \frac{-\sum_i \sum_j p_{ij} * \ln(p_{ij})}{k * \ln(k)} \qquad (12)$$

$$MAE^n = \frac{1}{4} \sum_{j=1}^{4} \left| s_j^n - \hat{s}_j^n \right| \qquad (13)$$

All models yield relative low errors. All MAE are less than 10% whereas mean of s_p is 0.464 with standard deviation of 0.064

Results



- We estimate that approximately 0.5 million acres of corn and soybeans moved away from CCT during 2001-2008 when 48 out of 99 counties considered.
- Iowa farmers are more often than not rotate CT with conventional tillage; total acres under RCT is always higher than total acres of CCT and CCV combined.

Figure 3. The change of tillage use over time for 46 counties, Iowa

Note: CCT=continuous conservation tillage, RCT = rotational conservation tillage and CCV=continuous conventional tillage

- Figure 4 shows that Iowa farmers used less CCT in 2008 compared with 2001.

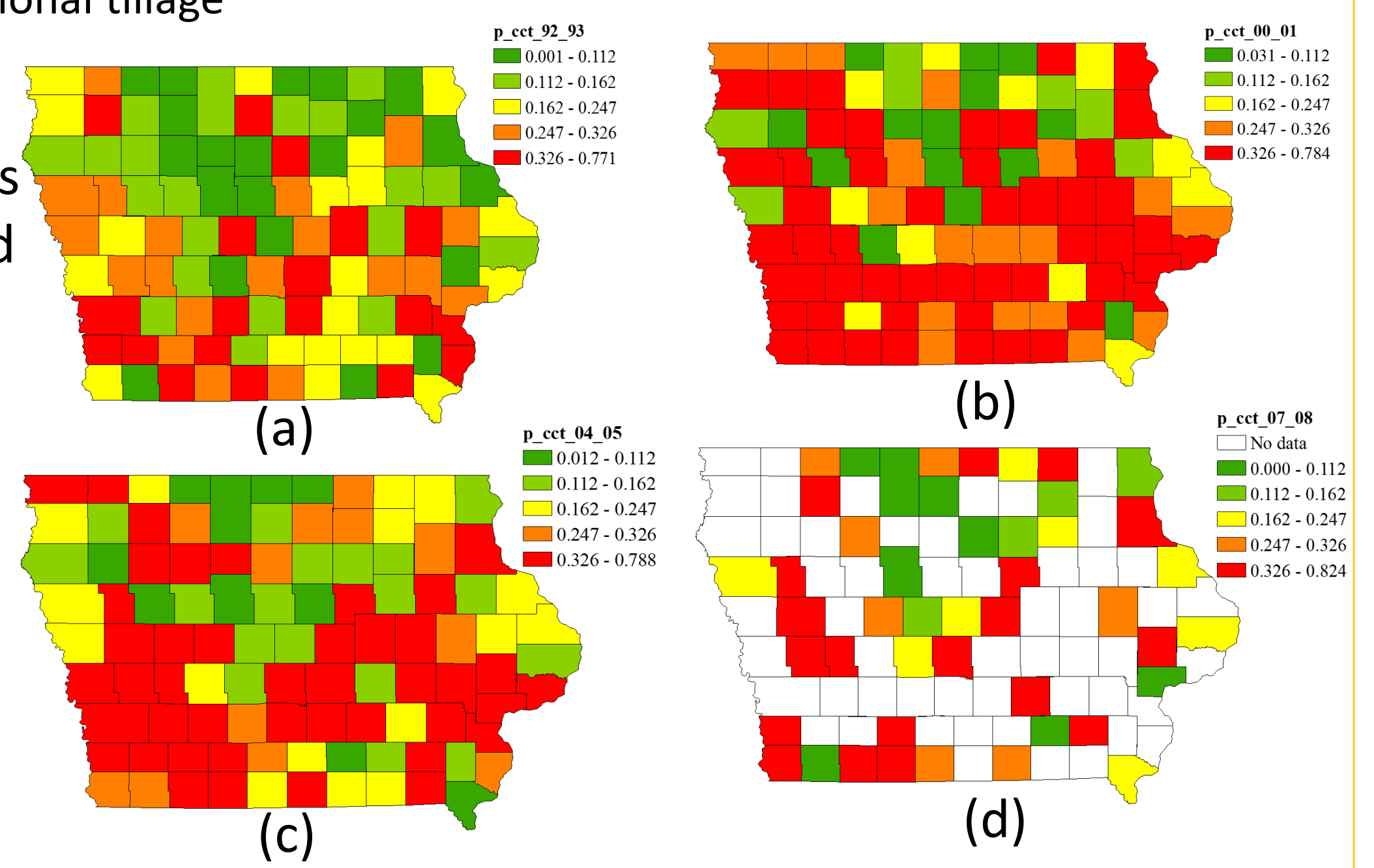


Figure 4. Spatial and temporal variability of continuous conservation tillage

(a) = 1992-1993, (b) = 2000-2001, (c) = 2004-2004 and (d) = 2007-2008

- Figure 5 reveals that more acreage in the southern and eastern Iowa were taken out of CCT practice between 2001 and 2008, when compared with the rest of the state.

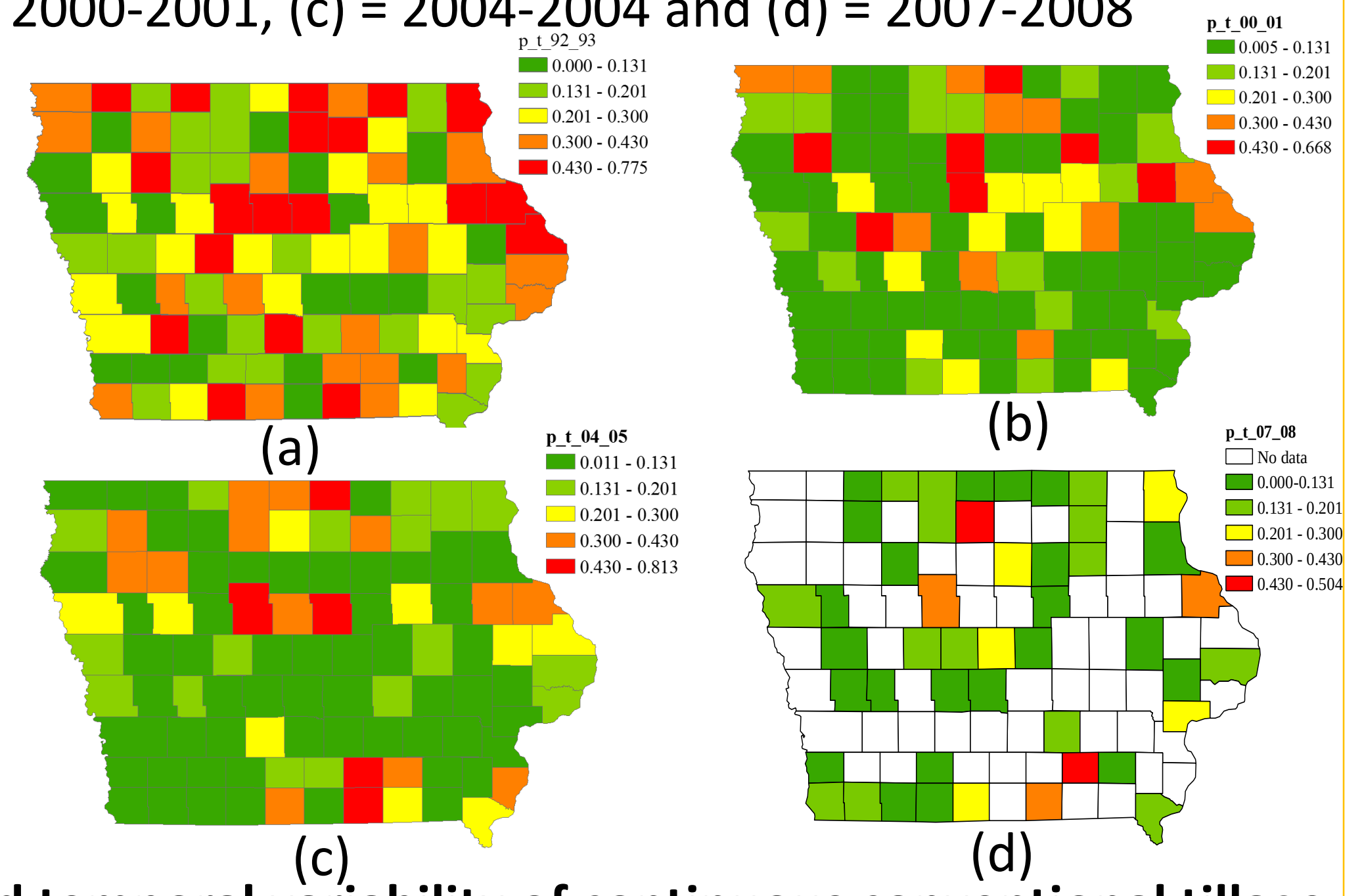


Figure 5. Spatial and temporal variability of continuous conventional tillage

- We also found that the increase in CT adoption rates do not always transfer to higher use of CCT. Thus, using CT adoption rates as a criteria to evaluate the success of conservation efforts might be misleading.

Conclusions

- Entropy approach is successfully applied to study the dynamics of tillage in Iowa and thus the proposed model can be generalized to study the dynamics of tillage in the U.S. Midwest, where cropping patterns are similar to Iowa.
- A potential extension of this model is to evaluate the effect of natural and economic conditions on the dynamic of tillage by treating transition matrices as a function of these conditions.

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