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Is the use of no-till continuous or rotational? Quantifying tillage dynamics from timeordered spatially aggregated data

Lyubov A. Kurkalova
North Carolina Agricultural & Technical

Dat Quoc Tran
North Carolina Agricultural and Technical State University

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Is the use of no-till continuous or rotational? Quantifying tillage dynamics from time-ordered spatially aggregated data

Lyubov A. Kurkalova and Dat Quoc Tran

Abstract: Understanding and documenting historical agricultural land use and farming practices is important for assessment of environmental benefits of no-till (NT). To address the need for quantitative estimates of time patterns of tillage practices, this study proposes modeling the time patterns using the Markov chains framework and estimating the probabilities of transition from one tillage-crop combination to another tillage-crop combination from time-ordered spatially aggregated data. We developed a first-order, four-state Markov chain model of tillage-crop dynamics in corn (*Zea mays* L.)–soybean (*Glycine max* L.) production systems and estimated the transition probabilities for the state of Iowa using the 1992 to 1997 data collected by the Conservation Technology Information Center. The transition probabilities strongly suggest that the majority of NT acreage is not in continuous but rather in rotational NT, i.e., NT crop production in rotation with conventional or other tillage systems. We find that the probability of two-year continuous NT is 8%, and that 70% of Iowa cropland has never used NT over two consecutive years. When three-year tillage history is considered on corn acreage, 3% is in continuous NT, 62% has never used NT, and the rest of the acreage is in rotational NT. When three-year tillage history is considered on soybean acreage, 4% is in continuous NT, 56% has never used NT, and the rest of the acreage is in rotational NT. The methodology presented is applicable to corn–soybean production systems in other regions and is generalizable to other cropping systems. Regional estimates of the use of rotational and continuous NT are likely to benefit simulation modeling for the assessment of the environmental effects of alternative tillage practices.

Key words: continuous no-till—corn–soybean production—Iowa—rotational no-till

Accurate modeling for the assessment of the regional environmental effects of alternative tillage practices requires comprehensive knowledge on both spatial and time patterns of the practices. No-till (NT) is an umbrella term for the tillage practices under which producers disturb only a minimal amount of soil (CTIC 2015b). In comparison with conventional tillage practices, NT reduces soil erosion and nitrogen (N) and phosphorus (P) runoff, and effectively protects overall soil quality under most soil and climatic conditions (Arshad et al. 1990; Hussain et al. 1999; Tomer and Locke 2011; Rittenburg et al. 2015). When practiced continuously, NT can contribute to reduction in greenhouse gas emissions (West and Post 2002; West and Marland 2002; Lal et al. 2011). However, the potential of NT to mitigate carbon (C) and nitrous oxide (N_2O) emissions is realized only when the practice is used continuously over long periods of time (Six et al. 2004; Kessel et al. 2013), and even a single tillage event could result in significant increase in greenhouse gas emissions (Reicosky et al. 1995; Hill 2001; Six et al. 2004; Conant et al. 2007; Wilman 2011).

Understanding and documenting historical agricultural land use is important for assessment of environmental benefits of NT and other conservation practices (James and Cox 2008; Duriancik et al. 2008; Arabi et al. 2012; Gallant et al. 2011; Doering et al. 2013; Tomer et al. 2014). However, only few quantitative estimates of the time patterns of tillage practices are known. Thomas et al. (2009) note that alternating NT soybeans (*Glycine max* L.) with conventional tillage corn (*Zea mays* L.) was common in Indiana in 1990 to 2007, although no estimates of the share of land under the practice were reported in the study. A study based on tracking of a sample of 14,748 fields in Illinois and Indiana in 1994 to 1995 revealed that only 16% were in NT for both years, and the additional 30% on fields were in rotational NT, i.e., the system under which NT is yearly alternated with other tillage practices (Hill 1998). Hill (2001) tracked approximately 9,000 fields in corn–soybean rotation in Illinois, Indiana, and Minnesota for a longer time period, 1994 to 1999. The study estimated that only 13% and 9% of all observed fields were in NT all six years in Illinois and Indiana, respectively, and no fields have been in NT for six years in a row in Minnesota. Napier and Tucker (2001) conducted survey of farm operators in 1998 to 1999 and found that some 12% of the farmers used NT every year, and the additional 7% used NT every other year in a watershed in northeastern Iowa in the five years preceding the survey. For a watershed in southeastern Minnesota, the corresponding estimates were 3% and 1%, respectively. According to the National Resources Inventory–Conservation Effects Assessment Project (NRI–CEAP) cropland survey completed in 2007, out of those growing corn in the Upper Mississippi River Basin in the year of the survey, some 63% have never used NT in the three years, and an additional 12% have practiced NT for all three years. For those growing soybeans in the year of the survey, the numbers were 59% and 14%, respectively (Horowitz et al. 2010; USDA NRCS 2012).

The difficulty of measuring tillage time patterns directly is in the need for field-level survey data, which are costly to obtain and could be unavailable due to confidentiality concerns. Most large-region assessments of environmental benefits of NT rely on national NT data coming from the Conservation Technology Information Center (CTIC) (CTIC 2015a). The county-level, crop-specific CTIC estimates are in general of limited use in estimating the

Lyubov A. Kurkalova is a professor in the Department of Economics and Department of Energy and Environmental Systems at North Carolina A&T State University in Greensboro, North Carolina. **Dat Quoc Tran** is a Post-Doctoral scholar in the Department of Economics at North Carolina A&T State University in Greensboro, North Carolina.

proportion of land in rotational or continuous NT. (Consider a hypothetical example of a county where all the land is in corn–soybean rotation, and every year half of the land is in corn and half in soybeans. If the NT adoption rate was 10% for both corn and soybeans in the county for two consecutive years, it is impossible to infer what percentage of land was in continuous NT. The continuous NT percentage could be as high as 10% [if all NT acres just alternate between NT corn and NT soybeans], and as low as 0%, if all NT land under one crop goes to the other crop as tillage other than NT the next year.) The CTIC data allow for tracking year-to-year changes in county-average NT use, but the data were never designed for tracking year-to-year tillage choices on individual fields. In the absence of the data on time patterns of NT, many of the assessments have assumed that any land that is under NT is in this practice continuously over a large number of years (Adams et al. 2005; Kim and Dale 2005; Causarano et al. 2008; Srinivasan et al. 2010; Grace et al. 2011; Panagopoulos et al. 2014, 2015; Her et al. 2016). Challenging this assumption, our study shows that NT was practiced mostly as rotational NT in Iowa in 1992 to 1997. Importantly, we propose a new approach to estimating region-average probabilities of continuous NT and rotational NT that rely on time-ordered spatially aggregated data such as that provided by CTIC. We show that the proposed approach is capable of obtaining CTIC-based estimates that are consistent with the evidence provided by the survey-based studies.

We propose modeling year-to-year tillage choices using the framework of Markov chains. This model begins with the assumption that for any cropland region, there is finite number of states—in our case, tillage-crop combinations that can be practiced—and describes the process of transitions from one state to another at given time intervals—in our case, every year—via the probabilities of transition. We propose estimating the probabilities of transition from one tillage-crop combination to another tillage-crop combination from time-ordered spatially aggregated data. Estimation of Markov transition probabilities from spatially aggregated data has been successfully used to study land use dynamics including cropping patterns (Howitt and Reynaud 2003; Aurbacher and Dabbert 2011). However, to our knowledge, the framework has not been applied to study the dynamics of any conservation practices. Here we estimate the transition probabilities for the state of Iowa and use the estimated transition probabilities to infer the probabilities of continuous NT and rotational NT for the region.

Materials and Methods

Corn and soybeans are the only two crops considered in this study because they occupy the overwhelming majority of Iowa cropland: according to the Census of Agriculture, the combined share of corn and soybeans in Iowa harvested cropland was 91%, 92%, 93%, and 94% in 1992, 1997, 2002, and 2007, respectively (USDA 2016). We focus our analysis on NT and call a combination of all other tillage categories "till" (T) throughout the paper.

Statistical Model. The model we propose starts with the assumption that farming choices in any given year can be classified into four distinct, nonoverlapping tillage-crop states: NT corn, T corn, NT soybeans, and T soybeans. It is further assumed the choices possess the first-order Markov property, i.e., that given the entire history of tillage-crop choices in the area, the present state—current year tillage-crop choice—depends only on the state in the year before. These assumptions allow the model to be described in terms of a single cycle transition matrix. Each element of the transition matrix, P_{ij}, represents the probability of tillage-crop state j in the current year given tillage-crop choice i in the year before. Here i, j = 1 (NT corn), 2 (T corn), 3 (NT soybeans), 4 (T soybeans). Finally, we assume that the first-order Markov process is stationary, i.e., the transition matrix remains constant for the time period under consideration. By the basic properties of probabilities,

$$0 \le P_{ij} \le 1, \quad i,j = 1,\ldots,4; \qquad \sum_{j=1}^{4} P_{ij} = 1, \quad i = 1,\ldots,4 \quad . \tag{1}$$

The specifics of Iowa crop production allow to simplify the transition matrix. Due to problems with soybean cyst nematode (*Heterodera glycines*), frogeye leaf spot (*Cercospora sojina*), and brown stem rot (*Phialophora* [*Cadophora gregata*]), among other diseases associated with this rotation (Mueller et al. 2010), as well as the significant yield decline associated with consecutive years of soybeans (Hennessy 2006), soybeans following soybeans is a very unlikely choice for Iowa farmers (Stern et al. 2008; Secchi et al. 2011; Sahajpal et al. 2014). Therefore, we set the four corresponding probabilities equal zero, i.e.,

$$P_{ij} = 0, \quad i, j = 3, 4. \tag{2}$$

The Markovian transition from one-year tillage-crop land allocation to next year tillage-crop allocation is specified as

$$s^n = P' s^{n-1} + \varepsilon^n \; , \tag{3}$$

where n = 2,…, N, N is the number of years for which tillage-crop shares are observed, s^n is the four-by-one vector of proportions s^n_j of the four tillage-crop areas of the region in year n such that $0 \le s^n_j \le 1$, $j = 1,\ldots,4$; $\sum_{j=1}^{4} s^n_j = 1$, P' is the transpose of the transition matrix, and ε^n is the four-by-one vector of year n random errors ε^n_j, j = 1,…, 4. The goal of the statistical analysis is to infer the probabilities of transition.

Data. The National Crop Residue Management (CRM) Survey by CTIC is the only nationwide survey that documents the type of tillage (NT, ridge tillage, mulch tillage, reduced tillage, or conventional tillage), by county and by crop. The CRM survey data are available annually from 1989 to 1998, biannually from 1998 to 2004, and for selected counties from 2005 to 2008 (CTIC 2015a). The CRM records are based on a combination of county conservation experts' opinions and the roadside transect method that requires visual assessment of tillage systems while driving a set course through the county. Quantitative measures of the precision of CRM survey data are not available, but in general, the data have been assessed to be complete and deemed reasonably accurate (Gassman et al. 2006; Baker 2011). The state-level four tillage-crop shares, corresponding to the four states that we model in the Markov process, are shown in figure 1.

Estimation of transition matrix with time-ordered aggregate data requires the number of time periods (N) be greater than the number of Markov model states, which is equal to four in our model. Based on the nature of state-aggregate NT dynamics (figure 1), we choose to estimate our model using the 1992 to 1997 data (i.e., N = 6). Specifically, the shares of NT corn and NT soybeans over the chosen time period increase in approximately monotone fashion, suggesting that the data are likely to come from a regular Markov chain (Lee et al. 1970). While a longer time series could improve the precision of estimation, the six years of data are the longest time span we can have that fits the task: there is little variation in the tillage shares over 1989 to 1991, and beginning with 1998 the data are available biannually only.

Model Estimation and Fit. To estimate the transition matrix P, we use the restricted least squares (RLS) approach (Lee at al. 1965, 1970), which is regarded as the preferred method for estimating the Markov model with time-ordered spatially aggregated data (MacRae 1977; Kelton 1981, 1994). Under RLS, the estimates of transition matrix probabilities are found by minimizing the sum of squared errors in model 1-3, i.e., by minimizing the

quadratic form $\sum_{n=2}^{N}\sum_{j=1}^{4}(\varepsilon_j^n)^2$ subject to constraints 1 and 2. We used MATLAB R2014a routine lsqlin solver to perform RLS.

We calculate two measures of the accuracy of the estimates of transition matrix probabilities. First, we follow the approach of Howitt and Reynaud (2003) and evaluate the mean relative error (MRE), which is defined by

$$MRE^n = \frac{1}{4}\sum_{j=1}^{4}\frac{\left|s_j^n - \hat{s}_j^n\right|}{s_j^n}, \quad (4)$$

where $\hat{s}_j^n$ is the predicted tillage-crop share j in year n, $j = 1,\ldots,4$, and n is any given year.

Small, and especially near-zero observed tillage-crop shares, could result in MRE^n distorting the picture of error because of the division operation in equation 4. Because of that, we also evaluate a second measure of accuracy of the estimates, mean absolute error (MAE), which is defined by

$$MAE^n = \frac{1}{4}\sum_{j=1}^{4}\left|s_j^n - \hat{s}_j^n\right|. \quad (5)$$

Let $\hat{P}$ be the estimated transition matrix. Depending on data available, $\hat{s}^n$ in both equations 4 and 5 could be computed in more than one way. For example, the 1993 predicted shares, $\hat{s}^2$, could be computed using the 1992 (n = 1) observed tillage-crop shares as $\hat{s}^2 = \hat{P}' s^1$. In contrast, the 1994 predicted shares, $\hat{s}^3$, could be computed using the 1993 observed shares or using those for 1992, i.e., as $\hat{s}^3 = \hat{P}' s^2$ or as $\hat{s}^3 = \hat{P}'\hat{P}' s^1$. The predicted shares for the last year of the sample, 1997, could be computed in five alternative ways, depending on whether the observed 1992, 1993, 1994, 1995, or 1996 shares are used as a starting point. To avoid ambiguity, both equation 4 and equation 5 use the $\hat{s}^n$ predicted from the 1992 observed tillage-crop shares, i.e., as

$$\hat{s}^n = (\hat{P}')^{n-1} s^1, \; n = 2,\ldots,6. \quad (6)$$

Estimation of the Probabilities of Continuous No-Till and Continuous Till. The computation of predicted tillage-crop shares allows tracing the movement of land between the alternative states. The estimated probability of (or share of cropland in) two-year continuous NT in 1993 is the probability that tillage is NT in both years 1992 and 1993, i.e., as the sum of three shares of land: that in NT corn after NT corn, $\hat{P}_{11} s_1^1$; NT corn after NT soybeans, $\hat{P}_{31} s_3^1$; and NT soybeans after NT corn, $\hat{P}_{13} s_1^1$. The 1993 probability of (or share of cropland in) two-year continuous T is estimated as the probability that tillage is T in both years 1992 and 1993 in a similar way. The 1994 probabilities of three-year continuous NT and continuous T are calculated in a similar fashion. For example, the 1994 share of corn in continuous, three-year NT is estimable as

$$\Pr(\text{NT in } n = 1,2,3 \,|\, \text{corn in } n = 3) = (\hat{P}_{11}\hat{P}_{11}s_1^1 + \hat{P}_{11}\hat{P}_{31}s_3^1 + \hat{P}_{31}\hat{P}_{13}s_1^1)/(\hat{s}_1^3 + \hat{s}_2^3). \quad (7)$$

The shares of continuous NT for the other years under consideration could be calculated by replacing s^1 with $\hat{s}^n$, and $\hat{s}^3$ with $\hat{s}^{n+2}$ in equation 7 for the appropriate years n = 2,…,4 .

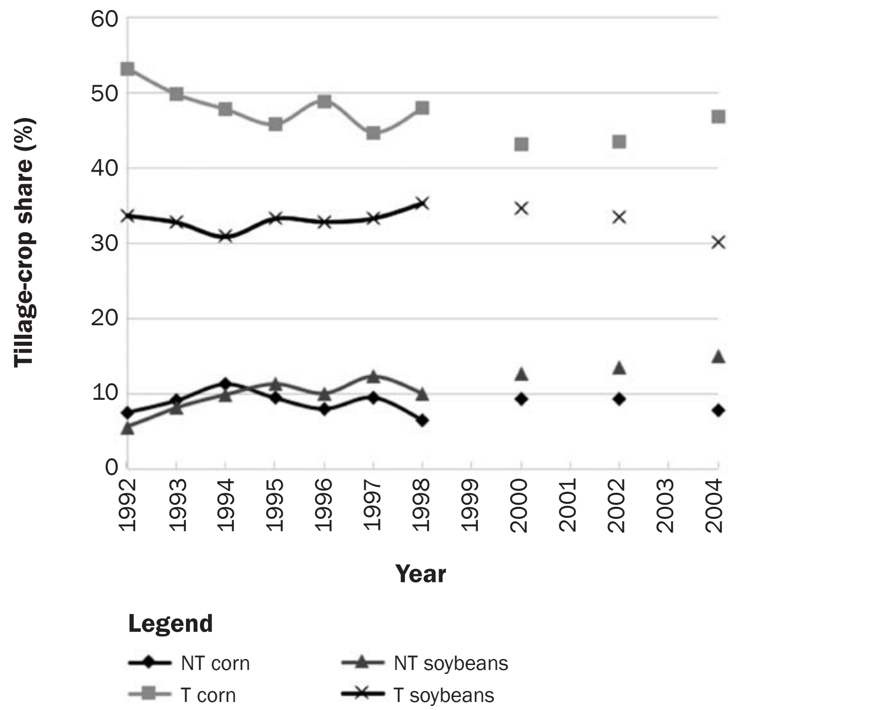
Another metric of continuity of NT use, the probability of NT conditional on NT the year before, is estimated as the combined proportion of NT corn after NT corn, NT corn after NT soybeans, and NT soybeans after NT corn in the total previous year NT acreage, i.e., as

$$\Pr(\text{NT in } n = 2 \,|\, \text{NT in } n = 1) = (\hat{P}_{11}s_1^1 + \hat{P}_{31}s_3^1 + \hat{P}_{13}s_1^1)/(s_1^1 + s_3^1). \quad (8)$$

The probabilities for the other years under consideration could be calculated by replacing s^1 in equation 8 with the corresponding $\hat{s}^n$ for the appropriate years n = 2,…,6.

Figure 1

Shares of alternative tillage-crop areas in the combined corn and soybeans total area, Iowa. Graph obtained from authors' calculations based on Conservation Technology Information Center (CTIC 2015a) data. NT = no-till. T = tillage other than no-till.



Results and Discussion

Figure 2 presents the transition matrix estimated for the state of Iowa. Both MRE and MAE suggest that the model fits well with the data: the MAE values range from 0.005 to 0.016, and MRE values range from 0.031 to 0.107. Kalbfleisch and Lawless (1984) and McLeish (1984) note that aggregate data often do not contain much information about a Markov chain. However, in this case, the Markov model shows the ability to infer the parameters of interest with very limited data: the MRE values are below 10% for all but one year, and MAE values are below 2% for all five years. Moreover, since all the predicted tillage-crop shares in the MRE and MAE reported are computed from the 1992 observed tillage-crop shares, the model captures the time-path of the shares as well.

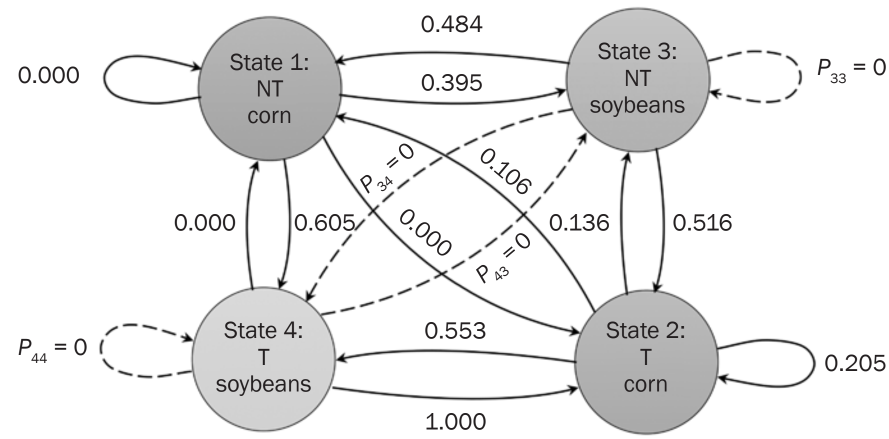
The transition matrix indicates that farmers' tillage choices are closely tied with crop rotations. The estimates suggest that NT corn is not likely to be followed by corn. In contrast, T corn has an approximately 31% chance of remaining in continuous corn. The majority of NT use happens in the corn–soybean rotation: almost 40% of NT corn is immediately followed by NT soybeans, and some 48% of NT soybeans is immediately followed by NT corn. Overall, the findings imply that when farmers use NT in corn–soybean rotation, they more often than not rotate NT with other tillage practices.

The estimated probabilities of two-year tillage-crop histories show that the greatest share of land, approximately 70%, has never used NT over two consecutive years: some 10% of land was in T corn after T corn, an additional 33% was in T corn after T soybeans, and another 27% was in T soybeans after T corn. Although not directly comparable because of the differences in study design and region, our results are in line with the statistics reported by Napier and Tucker (2001). The survey administered to 355 farmers in the northeast part of Iowa in 1998 to 1999 revealed that 56.5% of farmers never used NT during the preceding five years, with additional 4.5%, 0.8%, and 6.5% using NT only once every five, four, and three years, respectively (Napier and Tucker 2001).

We estimate the average of the five yearly estimates of the probability of two-year continuous NT at approximately 8%. Figure 3 and figure 4 depict the breakdown of the common statistic describing tillage use, the crop-specific rate of NT use, into continuous versus rotational NT use (the observed rates are included for comparison). The share of rotational NT in total NT differs notably between the crops. For corn, the overall NT use is approximately equally split between continuous NT and rotational NT in 1994 to 1997. In contrast, over 62% of the NT soybeans acreage had other tillage systems used in the previous year.

Figure 2

Estimated tillage-crop transition probabilities, Iowa, 1992 to 1997. NT = no-till. T = tillage other than no-till. The four circles represent the four tillage-crop states (choices) considered. The arrows represent transitions from one state to another. The probabilities of the transitions are listed next to the corresponding arrows. Dashed lines represent the transitions, for which the probabilities are all set to zero in the model: from soybeans (T or NT) to soybeans (T or NT).



The estimates of three-year continuous NT are predictably going down from the estimates of the two-year continuous NT, to 3% for NT corn and to 4% for NT soybeans, on average over 1994 to 1997 (figure 5 and figure 6). Again, although not directly comparable because of overlapping study regions (Iowa versus Upper Mississippi River Basin) and different years (1992 to 1997 versus 2003 to 2006), our results are qualitatively similar to those reported in USDA NRCS (2012): the overwhelmingly large share of T crop is in continuous T, and the overwhelmingly large share of NT is in rotational NT, both for corn and soybeans.

Comparison with Selected Hill (2001) Estimates. Since the Markov chain approach we propose here has not been previously applied to study tillage dynamics, to provide an additional informal test of the model's validity, we apply it to selected counties that were surveyed in 1994 to 1999 in the Hill (2001) study. We surmise that natural resources, weather, economic conditions, and cropping patterns in the Illinois and Minnesota counties that border Iowa are in general similar to those in Iowa.

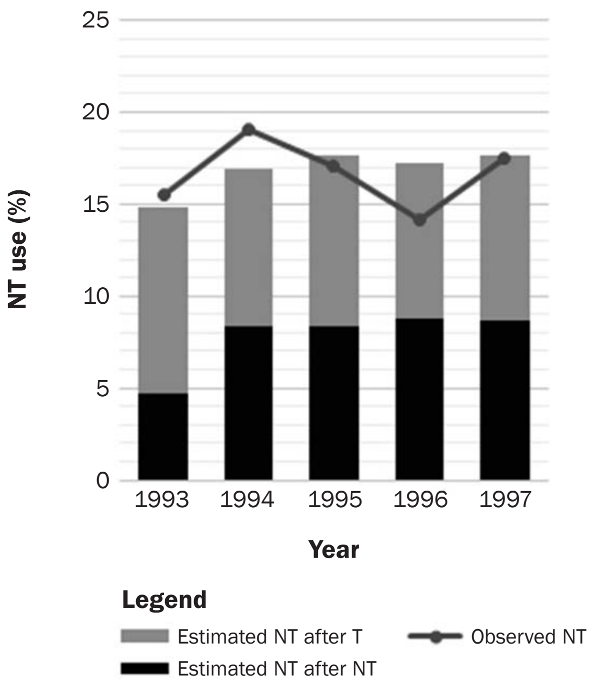
Two features of crop production are important for applicability of model 1-3 to the areas outside of Iowa: the overwhelming predominance of corn and soybeans in crop production, and the extreme rarity of soybeans after soybeans rotation, i.e., satisfaction of constraint 2. We are not aware of any sources reporting the frequency of occurrence of soybeans after soybeans in Illinois or Minnesota at the county level for the years 1992 to 1997. The data available at the state level suggest that soybeans after soybeans are an uncommon practice in these two states (USDA ERS 2016).

A total of four Illinois counties and two Minnesota counties analyzed by Hill (2001) border Iowa. Out of these six counties, we chose the ones that have the highest share of cropland under corn and soybeans, one per state: Mercer, Illinois, and Jackson, Minnesota. According to the 1992 and 1997 Censuses of Agriculture, the combined share of corn and soybeans in the total area harvested was 95% and 98% or above, in Mercer and Jackson, respectively (USDA 2016).

Tillage-crop shares show that the use of NT in Jackson County is much lower, and in Mercer County is much higher, when compared to that in Iowa. The six-year average NT corn shares are 0.5%, 9.2%, and 21.6% for Jackson, Iowa, and Mercer, respectively. The six-year average NT soybean shares are 5.5%, 9.5%, and 19.6% for Jackson, Iowa,

Figure 3

No-till (NT) use rate by previous year tillage for corn in Iowa. NT = no-till. T = tillage other than no-till. Observed rate of NT use is calculated as the share of observed NT corn in the total observed corn area. Estimated rate of NT use after NT is calculated as the combined share of estimated NT corn after NT soybeans and estimated NT corn after NT corn in the total estimated corn area. Finally, estimated rate of NT use after T is calculated as the combined share of NT corn after T corn and estimated NT corn after T soybeans in the total estimated corn area.



and Mercer, respectively. The differences in the transition matrixes estimated (figure 7) reflect the differences between tillage-crop rotation patterns in the two counties. When compared to Mercer, Jackson not only has a much lower overall rate of use of NT, but also virtually no continuous NT.

Our estimates of the probabilities of NT conditional on NT the year before are reasonably close to those reported in table 1, column 2 of Hill (2001). For Jackson, Minnesota, we estimate the same 0% probability that is reported by Hill (2001). For Mercer, Illinois, the estimate we obtain is 55.2% versus 58.1% reported by Hill (2001). Note that the higher estimate obtained by Hill (2001) could be attributed to the later time period considered in that study (1994 to 1999 versus our 1992 to 1997) and the overall upward trend in the use of NT nationwide (Horowitz et al. 2010) and/or to the statistical error in both studies. In either case, the Markov chain model estimated with time-ordered spatially aggregated (county-average) data shows the ability to distinguish the two, almost opposite NT dynamics displayed in these counties: very low overall NT use with no continuity of the practice in Jackson, Minnesota, versus over half of NT fields repeating NT the year after in Mercer, Illinois.

Summary and Conclusions

The quantification of the NT time patterns presented complements the documentation of historical land use for assessing the effects of current and future conservation programs on Iowa cropland (Gallant et al. 2011). We propose to model tillage-crop time patterns within the framework of Markov chain models, and apply the methodology to time-ordered, crop-specific proportions of NT and its alternatives available at the state level. As such, our work provides a new approach to increasing the use of the existing data collected (Doering et al. 2013). The methodology allows obtaining the estimates of the extent of rotational tillage in two- and three-year tillage-crop histories in Iowa in 1992 to 1997. The major finding of the study is that the majority of NT acreage is not in continuous but rather rotational NT. On average, out of the land that was in NT during the study period, only 40% was in this practice for two years in a row, and only 17% was in this practice continuously for three years. The resulting more detailed representation of tillage-cropping patterns is likely to improve the precision of environmental assessments that use hydrological and biophysical process models that are capable of quantifying the impacts of alternative tillage systems, such as Environmental Policy Integrated Climate and Soil and Water Assessment Tool (Williams et al. 1984; Zhang et al. 2015; Arnold et al. 1998; Arabi et al. 2008).

The unavailability of longer time series on crop-specific NT proportions did not let us test and/or relax the assumption on stationarity of the transition matrix. As a shift toward corn monoculture in Iowa and elsewhere has been noted in recent cropland assessments (Stern et al. 2008, 2012; Plourde et al. 2013), we expect that the transition matrix is likely to change over time to account for the higher overall probability of corn after corn. We are currently exploring the availability of more recent time series on crop-specific proportions of NT to assess these changes. Where longer time series on NT are available, the model could also be extended to incorporate movement of land in and out of production; longer crop rotations, such as corn–corn–soybeans; and additional row crops.

Although the study's major focus is on Iowa, the application of our model to Mercer, Illinois, and Jackson, Minnesota, provides estimates of continuous use of NT that are comparable with the estimates obtained from tracking fields in the Hill (2001) study. Two implications of these encouraging findings are worth noting. First, with the transition matrixes for the two counties that border Iowa being different from each other and from the transition matrix estimated for the state itself, it is worth exploring within-Iowa variation in the tillage-crop transition probabilities using the county-level data from the CRM survey. Secondly, the four-state Markov chain model of tillage-crop dynamics in corn–soybean production systems is likely to be applicable to a sizable portion of US cropland outside of Iowa. For example, corn and soybeans represented 89% of planted acres in Upper Mississippi River Basin in the NRI-CEAP survey in 2004 (Horowitz et al. 2010). An intriguing question is whether the regions with the same overall use of NT are likely to have similar NT dynamics patterns, including similar rates of continuous and rotational NT.

Figure 4

No-till use rate by previous year tillage for soybeans in Iowa. NT = no-till. T = tillage other than no-till. Observed rate of NT use is calculated as the share of observed NT soybeans in the total observed soybeans area. Estimated rate of NT use after NT (after T) is calculated as the share of estimated NT soybeans after NT corn (after T corn) in total estimated soybeans area.

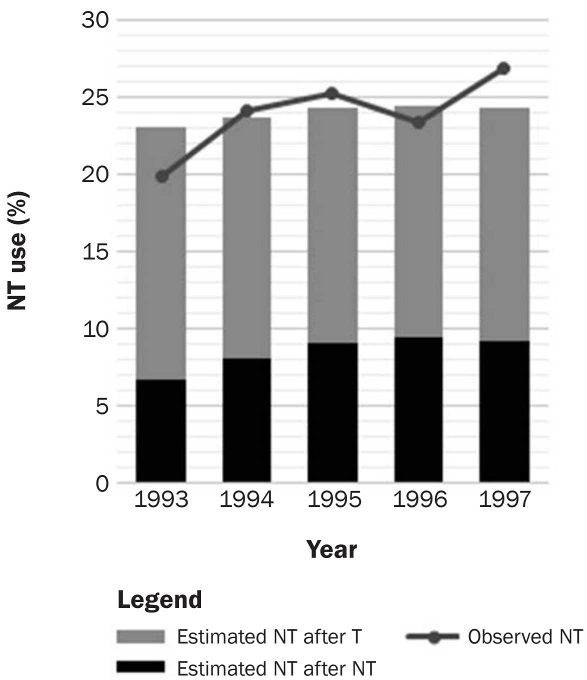


Figure 5

Tillage dynamics based on estimated three-year tillage-crop history with corn planted in the year evaluated in Iowa. NT = no-till. T = tillage other than no-till. Percentages displayed are the averages over 1994 to 1997 predictions.

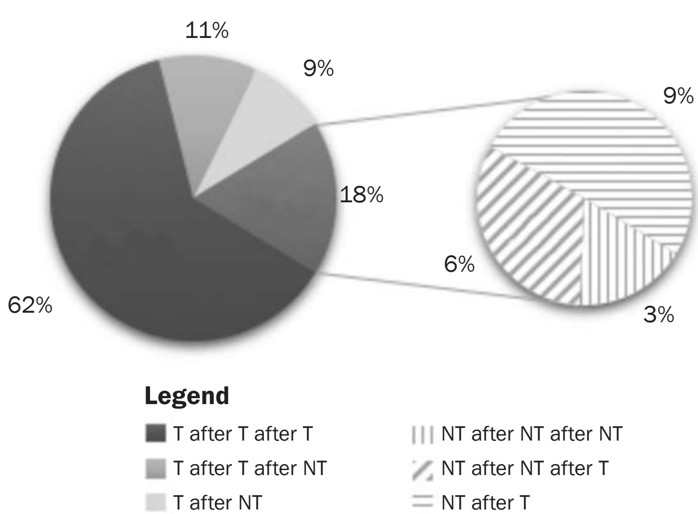


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Figure 6

Tillage dynamics based on estimated three-year tillage-crop history with soybeans planted in the year evaluated in Iowa. NT = no-till. T = tillage other than no-till. Percentages displayed are the averages over 1994 to 1997 predictions.

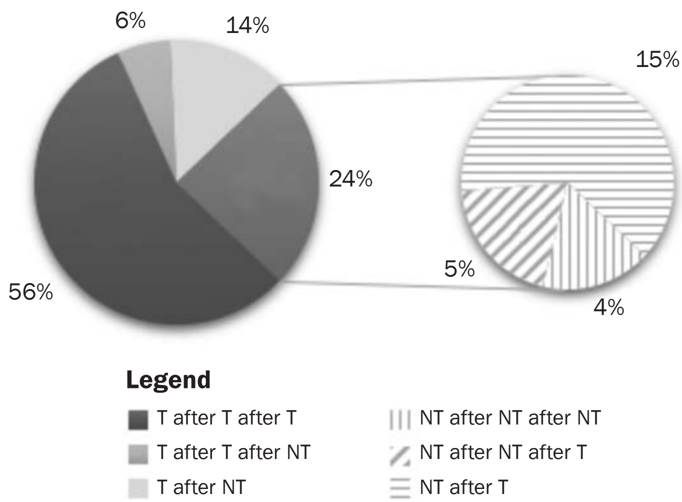
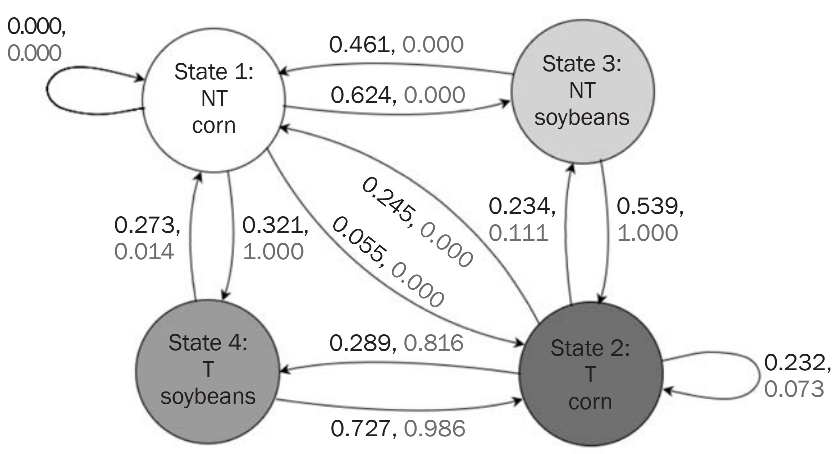


Figure 7

Estimated tillage-crop transition probabilities in selected counties from the Hill (2001) study, 1992 to 1997. For every transition, the first probability listed, in black, is for Mercer, Illinois, and the second, in gray, for Jackson, Minnesota. NT = no-till. T = tillage other than no-till. For Mercer, Illinois, mean absolute error (MAE) values range from 0.010 to 0.026, and mean relative error (MRE) values range from 0.049 to 0.097. For Jackson, Minnesota, MAE values range from 0.005 to 0.018, and MRE values range from 0.132 to 0.268. The transitions, for which the probabilities are set to zero in the model—from soybeans (T or NT) to soybeans (T or NT)—are omitted from the figure.



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