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Identification of “ever-cropped” land (1984–2010) using Landsat annual maximum NDVI image composites: Southwestern Kansas case study

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Abstract

A time series of 230 intra- and inter-annual Landsat Thematic Mapper images was used to identify land that was ever cropped during the years 1984 through 2010 for a five county region in southwestern Kansas. Annual maximum Normalized Difference Vegetation Index (NDVI) image composites (NDVI_{ann-max}) were used to evaluate the inter-annual dynamics of cropped and non-cropped land. Three feature images were derived from the 27-year NDVI_{ann-max} image time series and used in the classification: 1) maximum NDVI value that occurred over the entire 27 year time span (NDVI_{max}), 2) standard deviation of the annual maximum NDVI values for all years (NDVI_{sd}), and 3) standard deviation of the annual maximum NDVI values for years 1984–1986 (NDVI_{sd84-86}) to improve Conservation Reserve Program land discrimination.

Results of the classification were compared to three reference data sets: County-level USDA Census records (1982–2007) and two digital land cover maps (Kansas 2005 and USGS Trends Program maps (1986–2000)). Area of ever-cropped land for the five counties was on average 11.8 % higher than the area estimated from Census records. Overall agreement between the ever-cropped land map and the 2005 Kansas map was 91.9% and 97.2% for the Trends maps. Converting the intra-annual Landsat data set to a single annual maximum NDVI image composite considerably reduced the data set size, eliminated clouds and cloud-shadow affects, yet maintained information important for discriminating cropped land. Our results suggest that Landsat annual maximum NDVI image composites will be useful for characterizing land use and land cover change for many applications.

Keywords

Landsat; NDVI; land use change detection; Conservation Reserve Program (CRP)

1. Introduction

The proportion of cropland in the Great Plains of the United States has remained relatively stable since the mid-twentieth century (Cunfer, 2005). Various crop and conservation measures put in place during the Great Depression, and resurrected after 1945, sought limits to land cultivation. Policies were intended both to retire marginal crop land and to reduce

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surpluses in principal crops like winter wheat (Gardner, 2002; Kirkendall, 1966; Serra et al., 2009; Sullivan, 2004). More recently, growing awareness of the benefits of biodiversity preservation and restoration have also contributed to the design of conservation programs. In general, conservation policies have largely succeeded in restraining production to levels recorded at mid-century, or even reducing them in certain regions (Lubowski et al 2006). Nevertheless the picture of relative stability is complicated by known patterns of shifting cultivation. Never-cropped grasslands are occasionally brought into cultivation and subsequently idled. The Conservation Reserve Program (CRP) has likely amplified this practice since 1985 (Wu, 2000; Wu & Lin, 2010), increasing encroachment on native grassland, as farms respond to short-term market forces.

The biophysical implications of patterns of prior cultivation are important for understanding the health of ecosystem services. Single year assessments offer a reliable assessment of current allocations of cropland, from a compliance perspective, but do not reflect the cumulative levels of disturbance. Only with a multi-year assessment of trends in disturbance, deep time series – of habitat loss and fragmentation, greenhouse gas emissions, soil and water integrity – can move beyond the kind of aggregate estimates of land cultivation that inform global change analysis (Licker et al., 2010; Ramankutty et al., 2008). The physical extent of native habitat is likely much smaller than the conventional, time-specific, monitoring recognizes. The highly resolved estimates provided in this article suggest that the cumulative magnitudes of past disturbance are higher than previously recognized.

Our goal was to identify land that was cropped one or more years during the 27-year time span 1984 through 2010 (“ever-cropped” land) using a time series of intra- and inter-annual Landsat satellite imagery. Use of Landsat time series of this size has been impeded in the past by multiple challenges including imagery costs, accessibility, quality, geo-registration, cloud cover, and hardware and software tools necessary for managing, processing, and analyzing these tremendously large multi-temporal multi-resolution datasets. Advances in computer technology and the new USGS policy of providing no-cost, high-quality, geo-referenced Landsat data offers new opportunities to explore land cover change at unprecedented spatial and temporal scales.

This paper presents a new method to identify ever-cropped land using intra- and inter-annual Landsat image time series. We developed the method using 230 intra- and inter-annual Landsat TM images (Path 30 Row 34) from 1984 to 2010, the most comprehensive Landsat image time series used in a land cover classification effort that the authors are aware of. The method was developed and applied to a five-county region in southwestern Kansas and the results compared to three reference data sets: County-level U.S. Agricultural Census records, 2005 Kansas land use map, and U.S. Geological Survey Trends Project maps.

2. Methods

2.1 Study area

The study area covers five counties (Ford, Gray, Haskell, Seward, and Stevens) in southwestern Kansas (10,145 km²) centering on latitude 37.534N longitude 100.583W. Average annual precipitation (1971–2000) in this region ranges from 460 mm in the west to 610 mm in the east. The natural vegetation is primarily prairie grassland where short grass prairie (dominant genera: grama (*Bouteloua*), buffalograss (*Buchloë*)) and sandsage prairie (*Andropogon*, *Artemisia*, *Calamovilfa*) dominates the western region (Stevens, Seward, Haskell and western Gray Counties) and tall grass prairie (bluestem prairie (*Andropogon*, *Panicum*, *Sorghastrum*)) with scattered patches of sandsage prairie along river banks dominates the eastern region (eastern Gray and Ford Counties) (Küchler, 1974). At the

beginning of the century, only 37 percent of the land area in the five county region (10,008 km²) was reported as land in farms and a mere 7.3 percent of the total land area was reported as 'improved' in the 1900 census of agriculture (Gutmann, 2005). A little over a generation later, these landscapes were transformed unrecognizably. Nearly 73.5 percent of the total land area in the five counties was reported as cropland in the 1925 census (Gutmann, 2005). The proportions have remained very similar since. Reported cropland reached a peaked of 79.3 percent of the total land area in 1940, and then fluctuated for the remainder of the century between 75 and 80 percent of total land area. By 2005, farm land comprised nearly all of the land area in the region, and land in farms remains primarily cropped land (79.7%, including CRP land) with grassland dominating the remaining land (19.3%) (Peterson et al., 2008). The major crops grown in this region since the 1980's have been winter wheat (grown as crop/fallow annual rotation), corn, and sorghum (USDA NASS, 2011).

2.2 Landsat image selection and pre-processing

Landsat Thematic Mapper (TM) images (Path 30 Row 34) between March 1 (DOY 60) and October 31 (DOY 304) for all years 1984 through 2010 with a quality flag of nine and at least partially cloud-free were downloaded from the U.S. Geological Survey (USGS) Global Visualization Viewer (GloVis) website (<http://glovis.usgs.gov/>; accessed January 2011). 239 images constituted the original data set with a median of 9 images per year (range 2 to 12 images per year). Bands 3 (red visible) and 4 (near-infrared) were radiometrically corrected to at-sensor reflectance to correct for seasonal reflectance variances caused by sun angle and distance (Chander et al., 2009) and reprojected to Albers Conical Equal Area using cubic convolution resampling at 30 meter spatial resolution. The Normalized Difference Vegetation Index (NDVI) was calculated for each image date $((B4-B3)/(B4+B3))$. The NDVI, originally developed by Rouse et al. (1973), represents a measure of canopy 'greenness' where values below 0.2 are generally non-vegetated surfaces such as bare soil, clouds, cloud shadows, and dense green vegetation canopies are generally greater than 0.6 (Gamon et al., 1995; Wang et al., 2005).

NDVI images for all dates within a given year were layer stacked into a single file (i.e., all 1984 NDVI images in one file, all 1985 NDVI images in a second file, etc.). Each of the annual NDVI image stacks was then visually inspected using a rotation of color-band combinations to identify images that were misregistered. Nine of the 239 Landsat images were found to be mis-registered and removed from the annual NDVI image stacks resulting in a final count of 230 images used in the analysis. An annual maximum NDVI image ($NDVI_{ann-max}$) was then generated for each year by taking the maximum NDVI value that occurred in the time series. Since clouds and cloud shadows have generally low NDVI values ($NDVI < 0.2$), selection of the maximum NDVI value minimized cloud/cloud shadow features (Figure 1).

2.3 Characteristics of ever cropped and never cropped lands using annual maximum NDVI values

The NDVI annual maximum composite images were then stacked into a single 27-layer file and characteristics of land cover change evaluated using time series plots for selected sample sites (Figure 2). Initial exploratory analysis of the 27-year maximum annual NDVI ($NDVI_{ann-max}$) time series revealed land that was never cropped had relatively stable $NDVI_{ann-max}$ values over the entire 27-year period where values typically ranged from 0.3 to 0.6 (Figure 2, lower right). In contrast, cropped land generally had very high NDVI values (> 0.7) at least once over the 27-year period (Figure 2, upper right and lower left), and/or the maximum annual NDVI values were highly variable from year-to-year (e.g., annual crop-fallow rotations typical for winter wheat) (Figure 2, upper right). High variability in $NDVI_{ann-max}$ values during the 1980's ($NDVI_{sd84-86}$), were also typical for land that had

been converted from cropped land to grassland (CRP land) (Figure 2, upper left). Low $NDVI_{sd}$ values represented land where peak annual greenness values were fairly stable throughout the 27-year period, such as for continuously irrigated cropped land or never cropped land (Figure 2, lower left and lower right).

2.4 Classification

Bivariate density-sliced histogram plots were used to explore and identify parameters that would maximize the separation of ever-cropped land from never-cropped land (Figure 3). Our initial analysis revealed that two parameters would provide good discrimination between ever- and never-cropped land: 1) the maximum 27-year NDVI value ($NDVI_{max}$) and 2) the standard deviation of $NDVI_{ann-max}$ ($NDVI_{sd}$). A threshold classification method was selected because of the high distinction between ever-cropped land and never-cropped land readily visible in the bivariate histograms. Initial tests revealed that better discrimination was achieved by setting the thresholds using bivariate histograms at the county-level as opposed to setting one single threshold for the entire study area (Figure 3). Threshold values ranged from 0.61 to 0.71 for $NDVI_{max}$ and ranged from 0.074 to 0.096 for $NDVI_{sd}$ (Table 1).

Preliminary classification results revealed that using only the $NDVI_{max}$ and $NDVI_{sd}$ parameters was not effectively identifying CRP lands. CRP land is important for our study as it represents land that was originally cropped but was converted at some point to grassland. CRP land is land that the U.S. government pays land owners not to plant crops on for a period of 10 to 15 years in an effort to improve environmental quality, such as to reduce soil erosion and improve water quality and wildlife habitat. The Food Security Act of 1985 established the current CRP. The largest increase in CRP land enrollments occurred in the first few years of the program (1986 to 1990) in Kansas (Figure 4) (USDA, 2011). As of 2010, 1.13 million hectares are enrolled the CRP in Kansas with the largest proportion occurring in western Kansas. 10.0% of land in our five county study area was classified as CRP (Peterson et al. 2008). Many of these CRP fields were cropped for only the first few years during the entire 27-year period. High inter-annual variability of the $NDVI_{ann-max}$ values was typical of these fields during the years 1984–1986, indicating the land was primarily crop/fallow annual rotation. We incorporated a third parameter ($NDVI_{sd84-86}$) representing the variability of maximum annual NDVI values for the years 1984–1986. Threshold values for the $NDVI_{sd84-86}$ parameter were set to the same threshold values applied for $NDVI_{sd}$.

Classification was performed using an object-based image classification approach (Definiens AG, 2009). Five layers were used in the classification process: the 2001 U.S. Geological Survey (USGS) National Land Cover Dataset (NLCD) general land cover map, a county boundary file, and the three images for the parameters $NDVI_{max}$, $NDVI_{sd}$, and $NDVI_{sd84-86}$. The NLCD c2001 land cover map was used to mask out built environments (e.g., urban, roads), forested land, and water. Land classified as barren, shrubland, grassland, hay/pasture, or cropped land in the NLCD map (NLCD codes = 52, 71, 72, 81, 82 respectively) was reclassified into either “ever-cropped” or “never-cropped” land based on the $NDVI_{max}$, $NDVI_{sd}$, and $NDVI_{sd84-86}$ threshold values (Table 1). The images were first segmented using parameters set at scale 30, shape 0.2 and compactness 0.8. A rule-based classification approach was then applied using the threshold values. The first rule delineated the region in the feature space images that was primarily never-cropped land using the $NDVI_{max}$ and $NDVI_{sd}$ parameters. For example, regions in Ford County where $NDVI_{max}$ values were less than 0.71 and $NDVI_{sd}$ values were less than 0.096 were identified as never-cropped land and all other regions were classified as ever-cropped land. A second rule was applied using the $NDVI_{sd84-86}$ parameter to re-classify the areas likely to be CRP land into

ever-cropped land. In Ford County, $NDVI_{sd84-86}$ values greater than 0.096 would be re-classified from never-cropped to ever-cropped land.

2.5 Comparison to reference data

Results were compared to three reference data sets: County-level U.S. Agricultural Census records, 2005 Kansas land use map, and USGS Trends Project maps. USDA Agricultural Census records were used to derive total area cropped for the years 1982, 1987, 1992, 1997, 2002, and 2007 within each county (Gutmann, 2005). Maximum area ever cropped within each county was determined by summing the area of cropland harvested, failed cropland, and fallow or idle cropland for each of the census years and then determining the maximum value that occurred over the time span.

A digital land cover map produced by the Kansas Applied Remote Sensing Program (KARS) of the Kansas Biological Survey (Peterson et al. 2008) was compared to our results at the pixel level. The 2005 Kansas map was generated using multi-temporal Landsat TM imagery from 2004 and 2005 with an overall accuracy of 90.7% when compared to ground reference data (interpreted aerial photographs and ancillary databases). Comparison of our results to a map generated with circa 2005 imagery has obvious limitations due to land use change. However, land that was classified as cropped land or CRP land in the Kansas 2005 map should be classified as ever-cropped land in our map. The 2005 Kansas map consisted of eleven land use/land cover classes. Land classified as cropland (69.6%), grassland (19.3%), and CRP (10.0%) land were evaluated individually with the remaining classes (e.g., urban woodland, water) lumped into an “other” class for comparison to our results.

We also compared our results to the USGS Trends Project maps at the pixel level. The Trends Project produced land use change maps for sample blocks (10 km by 10 km) spanning across the US using Landsat imagery and aerial photographs for target years 1986, 1993, and 2000 (Loveland et al., 2002). Six Trends blocks either partially or fully intersected the study area representing a total area of 469.2 km². Land classified in the Trends maps as water, developed, mechanical disturbance, mine/quarry, barren, forest, and wetland were grouped and re-classified into an “other” class. Land classified as cropped in any Trends map was re-classified as cropped land (85.7% of total area in the Trends maps). Land that was classified as grass or shrub in all maps in the Trends time series was re-classified as never cropped land (13.6%).

3. Results and discussion

3.1 Comparison of results to the 2005 Kansas map

Overall agreement between our results and the 2005 Kansas map was 91.9% with individual counties ranging from 88.2% (Seward County) to 96.3% (Haskell County) (Table 2). Omission and commission errors were low for the ever-cropped land class (3.0% and 6.7%) yet higher for the never-cropped land class (29.8% and 15.2%). At the county level, difference of area classified as cropped land (including CRP) in the 2005 Kansas map and land classified as ever-cropped was very low, varying from only 0.1% (Ford County) to 1.6% (Gray County) with average 0.2%.

As mentioned in the Methods section, comparison between a map produced using only 2005 Landsat imagery to our map generated with 1984–2010 imagery is limited. At a minimum, the ever-cropped class should include land classified as cropped land or CRP in the 2005 Kansas map. Comparison between the two maps was evaluated at the pixel level by generating a “difference” map with five classes: 2005 Kansas cropland/ever-cropped land, 2005 Kansas grassland/never-cropped land, 2005 Kansas cropland/never-cropped land, 2005

Kansas grassland/ever-cropped land, and other (Figure 5). Most of the discrepancies were in larger landscape patches or fields, as opposed to individual pixels or field edges.

Discrepancies between areas classified as grassland in the 2005 Kansas yet classified as ever-cropped land in our map (Figure 5, blue colors on the Difference map) were primarily due to the different time periods of the Landsat imagery used in developing the maps (2005 imagery for the Kansas map versus 1984 through 2010 imagery for our map). For example, the $NDVI_{ann-max}$ time series for the area labeled as “a” in Figure 5 (close-up map) had relatively low NDVI maximum values for the year 2005 (typical of grassland vegetation) yet during the years 1994–2003, the $NDVI_{ann-max}$ values clearly indicated the land was cropped as demonstrated by the crop/fallow annual rotation pattern. In this case, both maps were correct.

Discrepancies between land classified as cropped or CRP in the 2005 Kansas map yet classified as never-cropped land in our analysis (Figure 5, red colors on the Difference map) were related mainly to CRP land. CRP land represented 10.0% of the total area classified as cropped land in the Kansas 2005 map. 79.6% of the area classified as CRP land was correctly classified as ever-cropped land in our map. Examination of the $NDVI_{ann-max}$ time series for land that was classified as CRP land in the Kansas map yet classified as never-cropped land in our map showed that many of these areas had typical grassland patterns throughout the 27-year time period (Figure 5, lower right time series graph labeled “b”) indicating the land may have been cropped prior to 1984 and had remained in grassland for the years 1984–2010. Collection and analysis of imagery prior to 1984 (e.g., Landsat MSS) would be needed to identify pre-1984 cropped land. In other areas, the $NDVI_{ann-max}$ time series indicated the land was originally grassland, then cropped for a few years (e.g., 1990–1993) and then converted back to grassland. The $NDVI_{ann-max}$, $NDVI_{sd}$, and $NDVI_{sd84-86}$ were all relatively low, hence the land was classified as never-cropped. Including additional multi-year $NDVI_{ann-max}$ variation parameters, similar to the $NDVI_{sd84-86}$, may improve the identification of these areas (e.g., $NDVI_{sd87-90}$, $NDVI_{sd91-95}$).

3.2 Comparison to Trends project maps

Overall agreement between our results and the Trends maps (1986, 1993, and 2000) was very high with an overall agreement of 97.2% (Table 3). Omission and commission errors were less than 10.3%. Differences covered only 2.7% of the land area and were represented as fields or field edges as opposed to scattered pixels, similar to the Kansas 2005 map comparison. Discrepancies between land classified as grassland in all three of the Trends maps and land classified as ever-cropped land in our map were primarily due to the different image data sets used in the classification (Figure 6, blue colors on the Difference map). Closer evaluation of the $NDVI_{ann-max}$ time series for these areas revealed that most appeared to have been cropped at some point over the 27-year period suggesting our map was correct. For example, in Figure 6, the $NDVI_{ann-max}$ time series for area “a” shows a typical crop/fallow rotation pattern for the years 1984–1987. Our image data set that spanned consecutive years allowed for better identification of cropped lands in a crop/fallow annual rotation because of the high inter-annual variability recorded in the continuous time series.

Areas in red in the Difference map in Figure 6 were classified as cropped in at least one of the Trends map years, yet classified as never-cropped land in our map. Some evidence was noted in the time series graphs that cropping may have occurred in these areas. The time series graph “b” for one of these areas indicated crop/fallow cycles during the years 1984–1992. We included the $NDVI_{sd84-86}$ parameter for distinguishing CRP lands that were cropped during the 1984–1986 time period as the vast majority of the CRP land was converted during the years 1986–1990 (Figure 4). As mentioned above, additional multi-

year $NDVI_{ann-max}$ variation parameters, such as $NDVI_{sd87-90}$, may help improve the identification of these cropped lands.

3.3 Comparison of results to Agricultural Census county-level data

Our results showed that the area classified as ever-cropped land was higher in all counties as compared to Agricultural Census area estimates. Area of land classified as ever-cropped for the five counties was on average 11.8 % higher than Census estimates (maximum area of land ever cropped during the period 1982 to 2007). Differences ranged from 8.1% (Haskell County) to 16.5% (Seward County) (Figure 7). De Wit and Clevers (2004) have found overestimates sometimes occur from land cover at the edge of crop fields being classified as cropped land when the pixels actually contain a mixture of land cover types (e.g., cropped land and grassland). The higher estimates could also be a result of setting the $NDVI_{max}$, $NDVI_{sd}$, and/or $NDVI_{sd84-86}$ threshold values too low. The differences may also be due to underestimates in the Census. The county-level Census data are increasingly subject to error from non-response and incompleteness of mailing lists (www.agcensus.usda.gov/Help/FAQs/2002_Census/index2.asp; accessed March 2011). In 2002 approximately 2.8 M questionnaires were mailed with only an 88.0% response rate (2002 Census of Agriculture). Nevertheless, comparison of our ever-cropped map to both the 2005 Kansas map and Trends maps indicate that there is high agreement with other recent analyses, and that the time series method presented here represents an important advance in accounting for past disturbance. Without this temporal dimension, baseline estimates of land cover change remain inaccurate.

3.4 Summary

The initial goal of our project was to develop a method to identify cropped and non-cropped land using individual target years (e.g., c1995, c2005) for ten sample sites within the Great Plains region. The new Landsat image policy implemented by USGS in 2009 provided an opportunity to explore the potential for identifying land that had ever been cropped over a continuous time period, spanning the entire Landsat TM archive. We developed and tested a novel approach using a dense time series of intra- and inter-annual Landsat TM data in southwestern Kansas. Further testing in other regions in the Great Plains is necessary to determine if the approach is flexible enough to accommodate the wide variability in crop management and climates. Never-cropped land in our study area had relatively low $NDVI_{ann-max}$ values and low $NDVI_{sd}$ values, compared to cropped lands, enabling good separation of the two classes. In other areas the distinction may not be as clear. Misclassifications will occur in cases where never-cropped land consistently reaches very high $NDVI_{max}$ values from year-to-year resulting in high $NDVI_{ann-max}$ values and low $NDVI_{sd}$ values. Also, non-irrigated crops planted every year in regions where vegetation is constrained by moisture, temperature, or poor soil conditions will result in relatively low $NDVI_{max}$ values and low $NDVI_{sd}$ values and therefore be misclassified as never-cropped land.

We evaluated the potential for using Landsat Multispectral Scanner (MSS) imagery in the analysis to extend the time series back to 1972, which may have allowed for better identification of CRP land without the need for the second rule based on the $NDVI_{sd84-86}$ parameter. However, we found that many of the MSS images were misregistered and would require extensive manual effort to correct which was not feasible to complete within the time constraints of our project. The USGS also notes that variations in the geometric quality of MSS imagery requires manual processing which limits its usefulness in time series studies (<http://landsat.usgs.gov/NewMSSProduct.php>; accessed April 2011). Incorporation of Landsat ETM+ imagery in deriving the annual maximum NDVI composite image, including slc-off images, is also a possibility.

Much time and effort can be expended trying to select cloud-free images (Homer et al., 2001; Huang et al., 2009). We found that the annual maximum NDVI composite image provided a cloud-free representation of the landscape eliminating the time consuming task of identifying cloud-free images or performing cloud and cloud shadow classification. Use of this method for reducing/removing cloud contamination in satellite data sets has been applied to AVHRR and MODIS image data sets since the 1980's (Justice et al., 1985; Holben, 1986). Although high-speed computing resources and internet access are needed to download and process the large number of images needed for this method, much of the processing was automated, allowing for fairly rapid image processing. An automated process for identifying the $NDVI_{max}$ and $NDVI_{sd}$ threshold values would be useful for mapping large geographical regions (Maxwell et al., 2004; Sezgin et al., 2004).

Annual maximum NDVI image composites may be useful for identifying specific years when land use changes occur, such as conversion of cropped land to CRP or non-irrigated to irrigated. Characterization of forest land changes may also benefit from this approach (Cohen et al., 2010; Huang et al., 2010; Kennedy et al., 2010).

4. Conclusion

Advances in hardware and software technology, and the recent no-cost Landsat data policy, open up new opportunities to derive information from the vast archive of Landsat imagery. We used 230 intra- and inter-annual Landsat TM images spanning 1984 through 2010 to generate 27 annual maximum NDVI composite images ($NDVI_{ann-max}$). The annual $NDVI_{ann-max}$ time series eliminated cloud and cloud shadow effects, and allowed for visualization and analysis of inter-annual cropland dynamics such as crop/fallow rotation, changes in cropping practices (e.g., crop/fallow to irrigated), and land use conversion (e.g., cropped land to CRP). Effective discrimination of ever-cropped land from never-cropped land resulted using three parameters derived from the 27-year $NDVI_{ann-max}$ composite images: 1) maximum NDVI value that occurred over the entire 27 year time span ($NDVI_{max}$), 2) standard deviation of the annual maximum NDVI values for all years ($NDVI_{sd}$), and 3) standard deviation of the annual maximum NDVI values for years 1984–1986 ($NDVI_{sd84-86}$) to improve Conservation Reserve Program land discrimination. Our study suggests that Landsat annual maximum NDVI image composites may be useful for many applications.

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Highlights

- 230 Landsat images were used to identify ever-cropped land (1984–2010).
- We compared the results to USDA Census records and two digital land use maps.
- Area of ever-cropped land was 11.8 % higher than Census record estimates.
- Agreement with the two digital land use maps was 91.9% and 97.2%.

Figure 1.

Comparison of 1) Landsat TM natural color images (left), 2) the corresponding NDVI images (right), and 3) the maximum 2008 NDVI image (lower right). NDVI values for clouds and cloud shadows are relatively low (dark: tones) as compared to green vegetation. Cropped lands are at various stages of growth in each image. Using the maximum NDVI value occurring in any image over the year (lower right image) minimizes clouds and cloud shadows and allows for better discrimination of cropped land and non-cropped land.

Figure 2.

Landsat color composite image of maximum 27-year NDVI ($NDVI_{max}$) value and standard deviation of annual maximum NDVI ($NDVI_{sd}$) value with time series graphs showing the annual maximum $NDVI_{ann-max}$ values for four land cover types. Dark green tones are typical for land that has never been cropped (low $NDVI_{max}$ and low $NDVI_{sd}$). Bright green tones represent near-continuous irrigated crop land (high $NDVI_{max}$ and low $NDVI_{sd}$). Light green tones represent land that was converted from non-cropped to irrigated cropped land (high $NDVI_{max}$ and high $NDVI_{sd}$ values). Light purple tones are typical of land in continuous crop-fallow annual rotation (medium high $NDVI_{max}$ and high $NDVI_{sd}$).

Figure 3.

Bivariate density-sliced histogram plots of the maximum 27-year (1984–2010) NDVI value [$NDVI_{max}$, x-axis) and the standard deviation of the annual maximum NDVI values ($NDVI_{sd}$, y-axis) for all counties combined and each individual county. Red colors represent the spectral regions with the highest frequency, yellow the next highest frequency, and violet the lowest frequency. The area noted as “a” represents high $NDVI_{max}$ and high $NDVI_{sd}$ values which are characteristic of land in crop/fallow rotation [see Figure 2, upper right time series plot]. The area noted as “b” [high $NDVI_{max}$ and low $NDVI_{sd}$ values) are characteristic of continuous irrigated cropland (see Figure 2, lower left time series plot). The area noted as “c” (low $NDVI_{max}$ and low $NDVI_{sd}$ values) is characteristic of land that has never or rarely been cropped. Note how the separation between ever-cropped (“a” and “b”) and never-cropped (“c”) land cover types is improved by using bivariate histogram plots for the individual counties as opposed to using all counties combined.

Figure 4. Cumulative Conservation Reserve Program (CRP) land 1986 through 2010 for Kansas (left) and for each county in the study area (right).

Figure 5.

Difference map for the Kansas 2005 map compared to our results for the entire study area with a close-up of the map near Hugoton, Stevens County, Kansas. Annual maximum NDVI time series graphs are shown for areas labeled as “a” and “b” on the close-up map. The red vertical lines on the time series graphs identify the year of the Kansas map (2005). Brown and green colors on the Difference map represent areas where the two maps agree. Brown areas were classified as cropped or CRP land in the Kansas 2005 map and ever-cropped land in our map. Green areas were classified as grassland in the Kansas 2005 map and never-cropped land in our map. Blue and red colors represent areas where the two maps disagree. Areas in blue were primarily due to the different Landsat image data sets used in the classification process (2005 for the Kansas map, 1984–2010 for the ever-cropped map). A typical NDVI_{ann-max} time series example is given for the blue areas at the point labeled “a”. The time series indicated crops were grown in many years yet when looking at a single year (2005) the NDVI_{ann-max} values appeared similar to grassland. Many of the areas in red were labeled as CRP in the Kansas map yet classified as never-cropped in our map. The NDVI_{ann-max} time series graph for the area marked as “b” shows no indication of crops grown during the entire 27-year period.

Figure 6.

Difference map for the USGS Trends maps compared to our results. Annual maximum NDVI time series graphs ($NDVI_{ann-max}$) are shown for areas labeled as “a” and “b” on the close-up map. The red vertical lines on the time series graphs identify the years of the Trends maps (1986, 1993, 2000). Brown and green colors on the Difference map represent areas where the two maps agree. Brown areas were classified as cropped land in any year of the Trends maps (1986, 1993, 2000) and ever-cropped (1984–2010) land in our map. Green areas were classified as grassland in all years of the Trends maps and never-cropped land in our map. Blue and red colors represent areas where the two maps disagree. Areas in blue were primarily due to the different Landsat image data sets used in the classification process where the $NDVI_{ann-max}$ values were typical of grassland for years the Trends maps were generated yet $NDVI_{ann-max}$ values clearly indicated cropping occurred during other years over 1984–2010 time period. For example, note the typical crop/fallow pattern in the 1984–1987 years in the time series graph labeled “a”. Red colored areas were labeled as cropped land in one or more Trends maps yet labeled as never-cropped in our map. The $NDVI_{ann-max}$ time series graph for the area marked as “b” shows there may have been crops grown in this field during the 1984–1992 time period after which a continuous grassland pattern is indicated.

Figure 7. Comparison of area estimates from USDA Agricultural Census data and land classified as ever-cropped land. The Census values represent the maximum area ever cropped for census years 1982, 1987, 1992, 1997, 2002, and 2007.

Table 1

Threshold values for $NDVI_{max}$, $NDVI_{sd}$, and $NDVI_{sd84-86}$ used in the classification of each county in the study area.

<u>County</u>	<u>$NDVI_{max}$</u>	<u>$NDVI_{sd}$ and $NDVI_{sd84-86}$</u>
Ford	0.71	0.096
Gray	0.67	0.091
Haskell	0.67	0.098
Seward	0.64	0.085
Stevens	0.61	0.074

Table 2

Contingency matrices comparing the Kansas 2005 map to our results. Counts are in hectares.

Ford County, KS					Seward County, KS				
Kansas 2005 Map					Kansas 2005 Map				
Ever-cropped Land Map	cropland/CRP	grassland	Total	Omission Error %	Ever-cropped Land Map	cropland/CRP	grassland	Total	Omission Error %
ever-cropped	201,509	6,003	207,512	2.9	ever-cropped	96,966	5,993	102,959	5.8
never-cropped	14,161	44,577	58,738	24.1	never-cropped	12,410	40,271	52,681	23.6
Total	215,670	50,580	266,250		Total	109,376	46,264	155,640	
Commission Error %	6.6	11.9			Commission Error %	11.3	13.0		
Total Samples	266,250				Total Samples	155,640			
Total Correct Samples	246,086				Total Correct Samples	137,237			
Overall Agreement %	92.4				Overall Agreement %	88.2			

Gray County, KS					Stevens County, KS				
Kansas 2005 Map					Kansas 2005 Map				
Ever-cropped Land Map	cropland/CRP	grassland	Total	Omission Error %	Ever-cropped Land Map	cropland/CRP	grassland	Total	Omission Error %
ever-cropped	186,017	2,069	188,086	1.1	ever-cropped	139,163	8,347	147,510	5.7
never-cropped	10,657	16,617	27,274	39.1	never-cropped	12,428	20,166	32,594	38.1
Total	196,674	18,686	215,360		Total	151,591	28,513	180,104	
Commission Error %	5.4	11.1			Commission Error %	0.1	0.3		
Total Samples	215,360				Total Samples	180,104			
Total Correct Samples	202,634				Total Correct Samples	159,329			
Overall Agreement %	94.1				Overall Agreement %	88.5			

Haskell County, KS					All Counties, KS				
Kansas 2005 Map					Kansas 2005 Map				
Ever-cropped Land Map	cropland/CRP	grassland	Total	Omission Error %	Ever-cropped Land Map	cropland/CRP	grassland	Total	Omission Error %
ever-cropped	130,348	618	130,966	0.5	ever-cropped	754,004	23,031	777,035	3.0
never-cropped	4,649	6,384	11,033	42.1	never-cropped	54,308	128,017	182,325	29.8
Total	134,997	7,002	141,999		Total	808,312	151,048	959,360	
Commission Error %	3.4	8.8			Commission Error %	6.7	15.2		
Total Samples	141,999				Total Samples	959,360			
Total Correct Samples	136,732				Total Correct Samples	882,021			
Overall Agreement %	96.3				Overall Agreement %	91.9			

Table 3

Contingency matrix comparing the USGS Trends maps to our results. Counts are in hectares.

Ever-cropped Land Map	Trends Maps			
	ever-cropped	never-cropped	Total	Omission Error %
ever-cropped	37,890	641	38,531	1.7
never-cropped	595	5,564	6,159	9.7
Total	38,485	6,205	44,690	
Commission Error %	1.5	10.3		
Total Samples	44,690			
Total Correct Samples	43,454			
Overall Agreement %	97.2			