# Assessment of the National Resources Inventory (NRI), the Census of Agriculture, the Cropland Data Layer (CDL), and Demand Drivers for Quantifying Land Cover/Use Change

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The following report is an assessment of different USDA produced data sets that are associated with land cover/use in the U.S. The focus of this research effort is to further clarify and understand factors regarding land cover/use change. With this said, this report is sub-divided into three primary sections, which are as follows:

**Section 1**: "Land Use Change Analysis with the National Resource Inventory." This section analyzed a customized NRI data set over three time-segments: (1) 2002-2007; (2) 2007-2015; and (3) 2002-2015. This analysis was different from previous land cover/use studies because it meticulously investigated the in and out movement of other land cover/uses with cultivated cropland.

**Section 2**: "Analysis of the Census for Change in Cropland." This section assessed three basic topics among the Census, NRI, and CDL data sets over time. The focus was on: (1) the relationship between cropland totals from the different data sets; (2) comparisons of the cropland changes over time for each of the data sets; and (3) an assessment of the adjustment mechanisms used by Lark et al. (2015) to correct the inaccuracies in the CDL over time.

**Section 3**: "National Demand Model Results." This section investigated the notion that increased demand for corn at corn ethanol plants would lead to land use change. The primary focus of this section looked at two potentially mitigating factors: (1) the increase in corn yield over time and (2) the production at ethanol plants of DDGs, an animal feed.

## Section 1: Land Use Change Analysis with the National Resource Inventory

Understanding the spatial distribution of different land cover/uses, and how these ebb and flow over time, is fundamental to the economic, social, political, and environmental well-being of the U.S. As such, the EPA has produced two reports to Congress regarding the "environmental and resource conservation impacts of the Renewable Fuel Standard Program" (EPA 2018, viii). In the EPA's most recent report (2018), a multitude of studies were cited that focused on assessing the biofuel industry's environmental impact, but specifically a collection of research was presented that suggested national increasing trends in agricultural extensification. This collection of research organized by the EPA (2018) that suggested agricultural extensification included data from the following sources: (1) USDA MLU 2017; (2) USDA Census 2017; (3) USDA NRI 2017; (4) USGS NWALT 2015; (5) Lark et al. (2015); and (6) Wright et al. (2017). In this assessment, the EPA attempted to harmonize these data sets to show corroborative trends of an increasing agricultural footprint into potentially sensitive non-agricultural environments. However, the EPA (2018) reiterated that the USDA's MLU and Census suffer from methodological changes (Bigelow and Brochers 2017), which limits the validity of these data sets for longitudinal trend analysis of land cover/use change. With this said, the EPA (2018) suggested that the USDA NRI is more advantageous for temporal analysis because it does not suffer from methodological changes inherent in the USDA's MLU and Census. Specifically, the EPA (2018, 29) stated:

> "The NRI reviews and revises historical estimates as necessary with each new Report as methods are updated (the Census and MLU do not); thus, changes due to methodology are removed from the NRI so long as historical comparisons are made within the same year's Report. A consistent methodology is a significant advantage when trying to examine trends through time. Thus, different reports have different strengths and weaknesses – estimates of trends may be better assessed with reports such as the NRI where methods through time are internally consistent, whereas estimates of acreages at a point in time are probably better reflected with more comprehensive assessments such as the MLU and NWALT."

Due to the above-mentioned limitations of the USDA MLU and Census, this study focused on analyzing agricultural land use trends using an EPA-provided NRI data sets from 2002-2015. The main focus of this portion of the report was to understand and map the in and out movement of different NRI-defined land cover/uses with cultivated cropland from 2002-2015 (for a full listing of NRI terms used in this section, see Appendix 1). The EPA's (2018) second triennial report to Congress compared all agricultural land use assessments to one another at the national level. Many of the cited studies only compared the net change between two different dates in total cropland acreage, without considering the between class movement of different land cover/uses. Additionally, the national trend provides an acreage change that is often not representative of different sub-geographies [e.g., state, Crop Reporting District (CRD), county, etc.]. The following sections will methodically breakdown the NRI at the national, state, and CRD levels to assess the in and out movement of land cover/uses with cultivated cropland.

## Data and Methods

The following section will detail the NRI data sets utilized in this research and the methodology used to calculate the interaction of different land cover/uses (specifically focused on in and out movement between cultivated cropland and other land cover/uses). For this analysis the EPA provided the following two data sets:

1. Customized NRI data set from 2007-2015 at the national, state, CRD, and county levels (Figure 1). These data were provided in matrix format, which allowed for assessment of in and out movement between all land cover/uses. In the example below, the highlighted light red numbers represent the gains to corn and soybean acreage from other land cover/uses between 2007-2015. The highlighted light green numbers represent the losses in corn and soybean acreage to other land cover/uses between 2007-2015.

| | Land Use in 2015 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cropland | | | | CRP Land | Pastureland | Rangeland | Forest Land | Other Rural Land | Developed Land | Water Areas & Federal Land | 2007 Total |
| | *Corn and Soybeans* | *All other Cultivated Cropland* | *Noncultivated Cropland* | *Total* | | | | | | | | |
| **Land Use in 2007** | **Est** | **Est** | **Est** | **Est** | **Est** | **Est** | **Est** | **Est** | **Est** | **Est** | **Est** | **Est** |
| Corn and Soybeans | 135,562.7 | 22,617.5 | 1,729.2 | 159,909.4 | 320.4 | 972.9 | 9.8 | 131.1 | 232.7 | 400.7 | 102.1 | **162,079.1** |
| Cultivated Cropland | 30,113.6 | 100,864.4 | 6,429.7 | 137,407.7 | 693.8 | 4,504.6 | 124.8 | 211.3 | 271.0 | 427.8 | 106.2 | **143,747.2** |
| Noncultivated Cropland | 4,641.3 | 5,070.1 | 39,152.3 | 48,863.7 | 109.2 | 3,574.3 | 36.7 | 225.0 | 192.8 | 284.7 | 40.3 | **53,326.7** |
| Total Cropland | 170,317.6 | 128,552.0 | 47,311.2 | 346,180.8 | 1,123.4 | 9,051.8 | 171.3 | 567.4 | 696.5 | 1,113.2 | 248.6 | **359,153.0** |
| CRP | 3,654.3 | 4,581.9 | 1,248.2 | 9,484.4 | 16,532.3 | 5,198.1 | 217.0 | 938.4 | 189.1 | 18.2 | 1.3 | **32,578.8** |
| Pastureland | 3,446.9 | 2,584.7 | 2,970.8 | 9,002.4 | 258.3 | 105,676.3 | 295.6 | 3,416.3 | 446.8 | 773.0 | 107.3 | **119,976.0** |
| Rangeland | 258.4 | 682.9 | 274.3 | 1,215.6 | 0.4 | 316.1 | 403,100.5 | 602.0 | 466.3 | 800.9 | 312.7 | **406,814.5** |
| Forest Land | 166.8 | 188.0 | 61.2 | 416.0 | 0.0 | 948.4 | 219.6 | 409,689.2 | 598.3 | 2,030.6 | 469.3 | **414,371.4** |
| Other Rural Land | 81.3 | 55.4 | 35.9 | 172.6 | 0.0 | 396.3 | 212.5 | 295.9 | 42,758.0 | 210.2 | 7.6 | **44,053.1** |
| Developed Land | 57.0 | 27.9 | 26.0 | 110.9 | 0.0 | 71.5 | 49.6 | 232.9 | 35.9 | 110,120.6 | 5.7 | **110,627.1** |
| Water Areas & Federal Land | 45.6 | 32.9 | 9.9 | 88.4 | 0.0 | 39.2 | 116.8 | 128.0 | 5.0 | 10.0 | 456,181.3 | **456,568.7** |
| **2015 Total** | **178,027.9** | **136,705.7** | **51,937.5** | **366,671.1** | **17,914.4** | **121,697.7** | **404,382.9** | **415,870.1** | **45,195.9** | **115,076.7** | **457,333.8** | **1,944,142.6** |

**Fig. 1**: EPA-provided NRI data set at the national level for acreage changes (in thousands) between 2007-2015 (margin of error columns were removed for presentation purposes).

2. Customized data set from 2002-2015 only at the CRD level, which were in the same matrix format (as shown above in Figure 1).

It is of importance and worth mentioning the following data characteristics and methods implemented for this study:

1. The national level data provided 81 possible in and out movement combinations. The state level provided over 3,500 combinations (not all land cover/uses were represented in all states). The CRD level provided over 30,000 combinations (not all land cover/uses were represented in all CRDs and not all states had the same number of CRDs). Although, county data was assessed, it was only provided for 2007-2015. The county level data provided approximately 240,000 combinations. The smallest common geography between the two data sets (2007-2015 and 2002-2015) was at the CRD level.
2. For this analysis, in and out movement of cultivated cropland was assessed by combining the corn and soybean category with the other cultivated cropland category to create a total cultivated cropland classification. However, these two separated land use types were also evaluated independently to determine the impact of corn and soybean at different geographies. The assessment of land cover/use changes with respect to <u>cultivated cropland</u> over the study

periods was selected since this was the analysis format presented by EPA (2018) in the triennial report when the NRI was evaluated.

3. These customized NRI data sets allowed for two distinct evaluations of the in and out movements between specific land cover/uses that interacted with cultivated cropland over a given time period:
    a. First, this analysis considered the net in/out movement of general CRP (not continuous CRP) and non-cultivated cropland with cultivated cropland. This is an important distinction because this movement was considered as intra-agricultural land use movement within an already existing agricultural footprint. For example, if non-cultivated cropland [such as, hayland as defined by the NRI (2015) – *a subcategory of cropland managed for the production of forage crops that are machine harvested*] was converted into row crop, this was determined to be a transition from one agricultural practice to another. Moreover, CRP transitioning to cultivated cropland was considered in the same manner as non-cultivated cropland, but under a different circumstance. CRP lands were assessed as land use that exited the program as once existing agricultural practices (i.e., part of the agricultural footprint that was once in production). While it is obvious that land receiving CRP payments could not be agriculturally productive, the land use was originally associated with agriculture, which was one of the factors for it to qualify for CRP in the first place. Ultimately, any land enrolled in general CRP experienced a change in land cover, but technically not in land use. So, any additions to cultivated cropland from CRP was also considered intra-agricultural movement.
    b. Second, all non-agricultural land cover/uses were assessed for the net in/out movement with cultivated cropland. The categories considered non-agriculture were: (1) forest land; (2) pastureland; (3) rangeland; (4) other rural land; (5) developed land; and (6) water areas and federal land. Pastureland was chosen to be placed in the non-agricultural category based on NRI (2017) definitions. Pasture acres that are in rotation with row crops were already included with the cultivated cropland acres; however, the separated pastureland category in the NRI was deemed as not in rotation and would then represent any non-agricultural land cover/use.
    c. It should be noted that the NRI is the only data set that was presented by the EPA (2018) that allows for this type of analysis and broader understanding of the complex in and out movements between different land cover/uses.
4. For data management, analysis, and mapping purposes all data was reorganized from matrix format to a relational database format. This reduced the time/effort and the potential for manual errors to calculate the in and out movement between land cover/uses. Furthermore, this reconstruction of the data enabled more efficient mapping and tabular presentation of the results.
5. Initially this research was only focused on assessing the NRI from 2007-2015. However, after further consideration and discussion with EPA personnel, it was determined that the 2007 starting point perhaps represented an abnormally low cropland acreage for longitudinal analysis. To this end, the EPA provided the 2002-2015 data set to help understand longer-term temporal trends in cropland movements.

## Results and Discussion

The results to this research will include the following sections:

1. General assessment of national land cover/use trends in national NRI (2017) data.
2. National level assessment of the in and out movement of different land cover/uses with cultivated cropland (analyzed with customized NRI data from EPA).
3. State level assessment of the in and out movement of different land cover/uses with cultivated cropland (analyzed with customized NRI data from EPA).
4. CRD level assessment of the in and out movement of different land cover/uses with cultivated cropland (analyzed with customized NRI data from EPA).

General National Level NRI Assessment

Data from the NRI (2017) between 1982-2015 was graphed to understand the 30-year long-term trends of selected NRI-defined land cover/use classes (Figure 2).

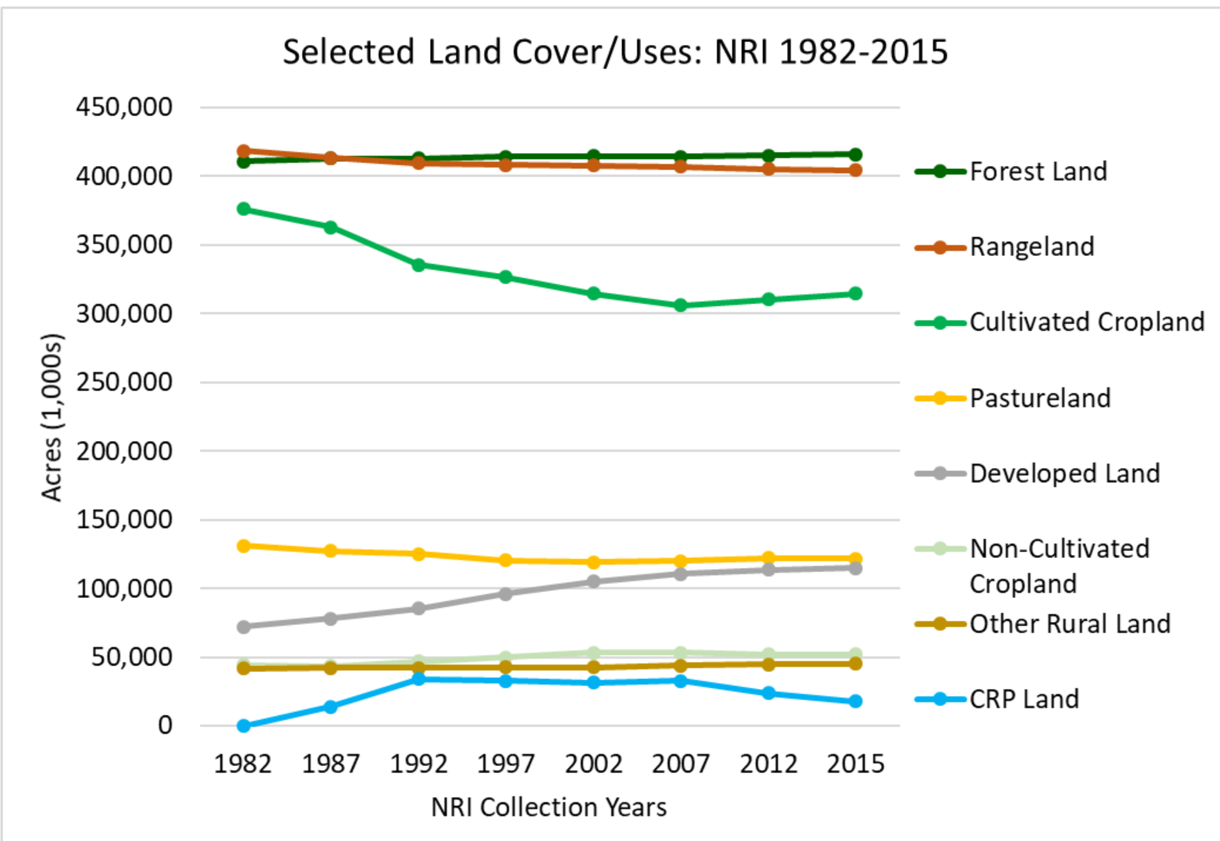



**Fig. 2**: NRI (2017) land cover/use trends from 1982-2015.

Broad trends in these data are as follows:

- **Forest** – minimal upward trend throughout the assessment period.
- **Rangeland** – minimal downward trend that flattened after 1997.
- **Cultivated Cropland** – downward trend until 2007, upward trend from 2007-2015.
- **Pastureland** – minimal downward trend that flattened after 1997.

- **Urban** – upward trend that began to flatten after 2012.
- **Non-Cultivated** – minimal upward trend that flattened after 2002.
- **Other Rural** – relatively flat trend throughout the assessment period.
- **CRP** – upward trend until 1992, then remained relatively flat until 2007, and downward trend after 2007.

Overall assessment of these broad trends are as follows:

- Cultivated cropland decreased from 1982-1992, while urban and CRP increased during the same time period.
- Cultivated cropland decreased at a lower rate from 1992-2007, while urban increased and CRP flattened during the same time period.
- Cultivated cropland increased from 2007-2015, while urban increased at a lower rate and CRP decreased during the same time period.
- There is an inverse relationship from 2007-2015 between cultivated cropland and CRP.
- Although these trends show the change in total area of each land cover/use over time, it does not account for the complex in and out movement of all land cover/uses with each other.
- Based on broad trends, 2007 was at a 30-year low in cultivated cropland acreage and supported the decision of extending the temporal sequence for the customized NRI analysis to 2002-2015.

## National Level NRI Assessment of Cultivated Cropland In and Out Movement

The national level assessment investigated the in and out movement of different land cover/uses from 2002-2015 for the conterminous U.S. This was done in three time-segments to capture the longitudinal NRI-based land cover/use movement along the 2002-2015 continuum. These time-segments included: (1) 2002-2007; (2) 2007-2015; and (3) 2002-2015. As mentioned previously, the NRI is more advantageous for longitudinal studies of land cover/use change because of standardized methods. Secondly, the format of the customized NRI data set (in matrix format, for example, see Figure 1) used in this analysis, allowed for a robust understanding of in and out movements for all land cover/uses.

*Conceptual Model of Land Cover/Use In and Out Movement with Cultivated Cropland*

Using the customized NRI matrices, the movement of cultivated cropland to and/or from each of the other land cover/uses were calculated. A generalized graphical representation of this potential movement (gains and/or losses) from all land cover/use categories to cultivated cropland is provided in Figure 3.

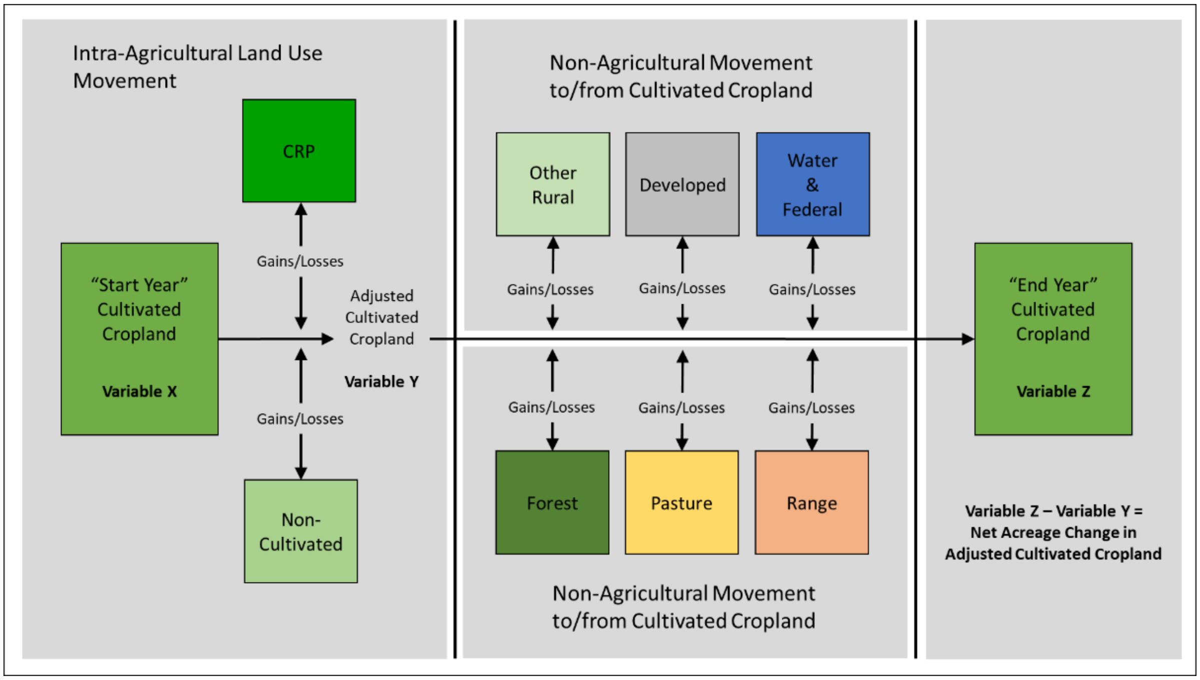



**Fig. 3**: Conceptual diagram of the between land cover/use movements with cultivated cropland.

The following describes the acreage flow (from left-to-right) of different land cover/uses in and out of cultivated cropland across a given time-segment of analysis (**note, these in and out movements are happening simultaneously over time and may not be linear in nature**):

1. "Start Year" for cultivated cropland acreage is represented as *Variable X*.
2. Intra-agricultural land use movement (as gains or losses) adjusts the "Start Year" cultivated cropland acreage. The net in or out movement of non-cultivated cropland and CRP with cultivated cropland was considered to be intra-agricultural movement within a given time-period and represents *Variable Y* (Adjusted Cultivated Cropland). These land cover/use interactions were assessed as movement within an already existing agricultural footprint.
3. Additional non-agricultural land cover/use movement (as gains or losses) results in the "End Year" cultivated cropland acreage, represented as *Variable Z*.
4. The net gain or loss to cultivated cropland (with respect to non-agricultural lands) is best captured by comparing *Variable Y* and *Variable Z*. This methodology of assessing changes between *Variable Y* and *Variable Z* was determined to be an improved representation of land cover/use change outside of the agricultural footprint. This method is clearly not the historic approach (*Variable Z – Variable X*) of viewing land cover/use change. Due to the simplistic nature of the historic approach (*Variable Z – Variable X*), this study proposes an insightful and more complete method (*Variable Z – Variable Y*), particularly with respect to understanding complex in and out movements between different land cover/uses. Furthermore, no other data

set presented in Table 4 of the Triennial Report (EPA 2018, 39) allows for this type of analysis and broader understanding of land movements with respect to the changing dimensions of the agricultural footprint in the U.S.

*2002-2007 Land Cover/Use In and Out Movement with Cultivated Cropland*

Using the generalized graphical model as a template, the 2002-2007 customized NRI data was assessed for the net change to cultivated cropland (Figure 4).

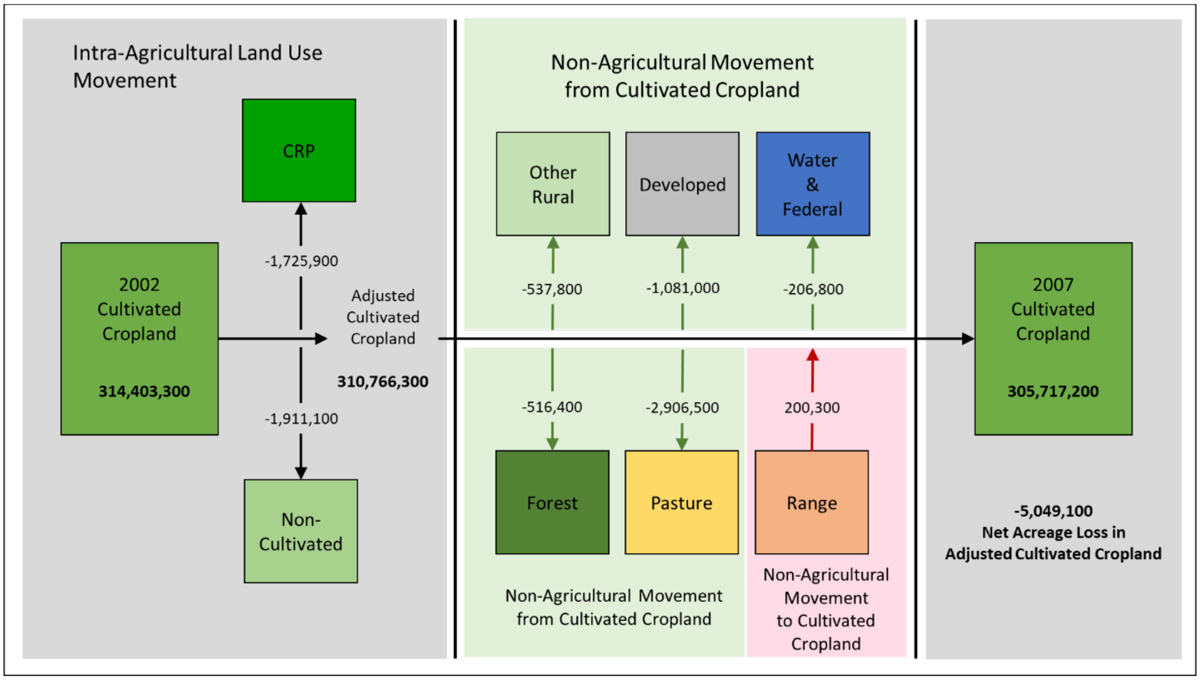



**Fig. 4**: In and out movement of different land cover/uses with cultivated cropland from 2002-2007 (these numbers exclude Hawaii and the Caribbean). Light green represents losses of cultivated cropland to non-agricultural lands and light red represents gains of cultivated cropland from non-agricultural lands.

The following results were indicated by the national 2002-2007 analysis:

- From 2002-2007, cultivated cropland lost just under 4 million acres to other agriculture-related land uses (CRP accounted for 1.7 million and non-cultivated accounted for 1.9 million acres).
- Cultivated cropland lost a total of 1.8 million acres to developed, other rural, and water/federal lands (developed was 59% of this movement).
- Cultivated cropland lost a total of 3.4 million acres to pasture and forest (pasture was 85% of this movement).
- Cultivated cropland gained 200,000 acres from rangeland.
- Although there were 200,000 acres of rangeland loss to cultivated cropland, over 4.5 million acres of cultivated cropland were collectively lost to forest, pasture, and developed lands.
- In total, from 2002-2007, cultivated cropland over the conterminous U.S. lost just over 5 million acres to non-agricultural lands. The simplistic historic approach of assessing land use change to cultivated cropland (which does not consider the complex in and out interactions of all land cover/uses) would result in a loss of nearly 8.7 million acres of cultivated cropland during the same time period, which is an overestimation of nearly 3.7 million acres.

*2007-2015 Land Cover/Use In and Out Movement with Cultivated Cropland*

Using the generalized graphical model as a template, the 2007-2015 customized NRI data was assessed for the net change to cultivated cropland (Figure 5).

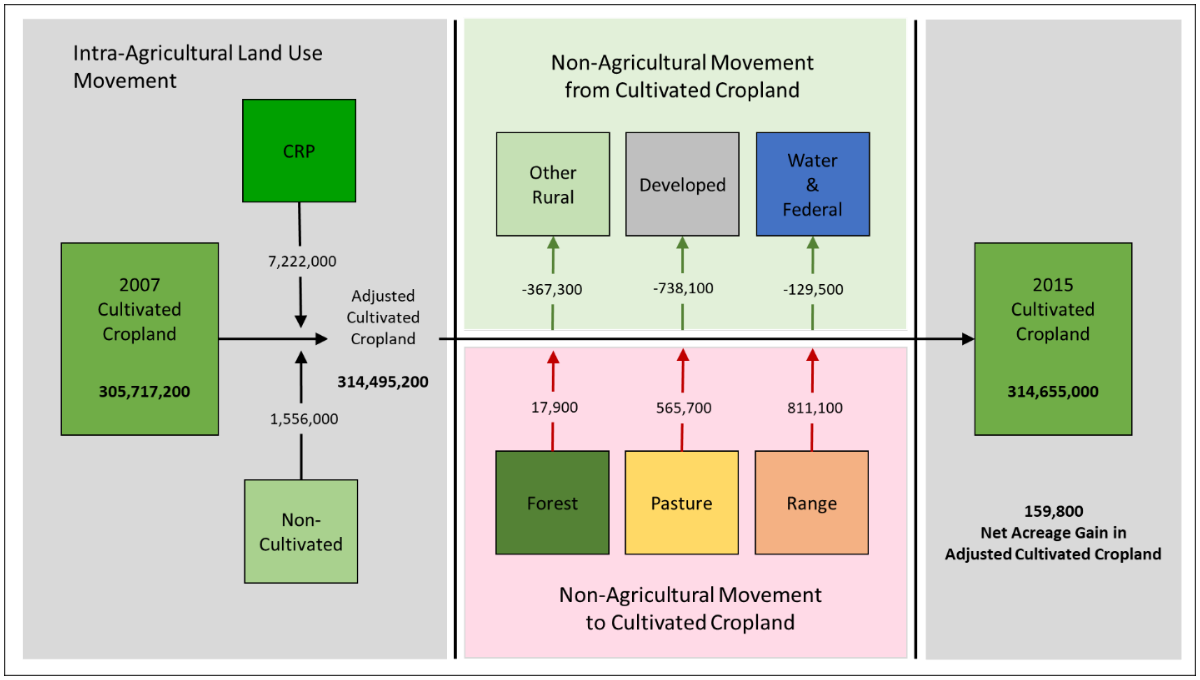



**Fig. 5**: In and out movement of different land cover/uses with cultivated cropland from 2007-2015 (these numbers exclude Hawaii and the Caribbean). Light green represents losses of cultivated cropland to non-agricultural lands and light red represents gains of cultivated cropland from non-agricultural lands.

The following results were indicated by the national 2007-2015 analysis:

- From 2007-2015, cultivated cropland gained a total of 8.8 million acres from other agriculture-related land uses (CRP and non-cultivated), of which CRP was 82% of this intra-agricultural movement.
- Cultivated cropland lost a total of 1.2 million acres to developed, other rural, and water/federal lands (developed was 59% of this movement).
- Cultivated cropland gained a total of 1.4 million acres from forest, pasture, and rangeland (rangeland was 58% and pasture was 40% of this movement).
- In total, from 2007-2015, cultivated cropland over the conterminous U.S. gained just under 160,000 acres from non-agricultural lands. The simplistic historic approach of assessing land use changes to cultivated cropland (which does not consider the complex in and out interactions of all land cover/uses) would result in a gain of just over 8.9 million acres of cultivated cropland during the same time period, which is an overestimation of nearly 8.7 million acres.

*2002-2015 Land Cover/Use In and Out Movement with Cultivated Cropland*

Using the graphical model as a template, the 2002-2015 customized NRI data was assessed for the net change to cultivated cropland (Figure 6).

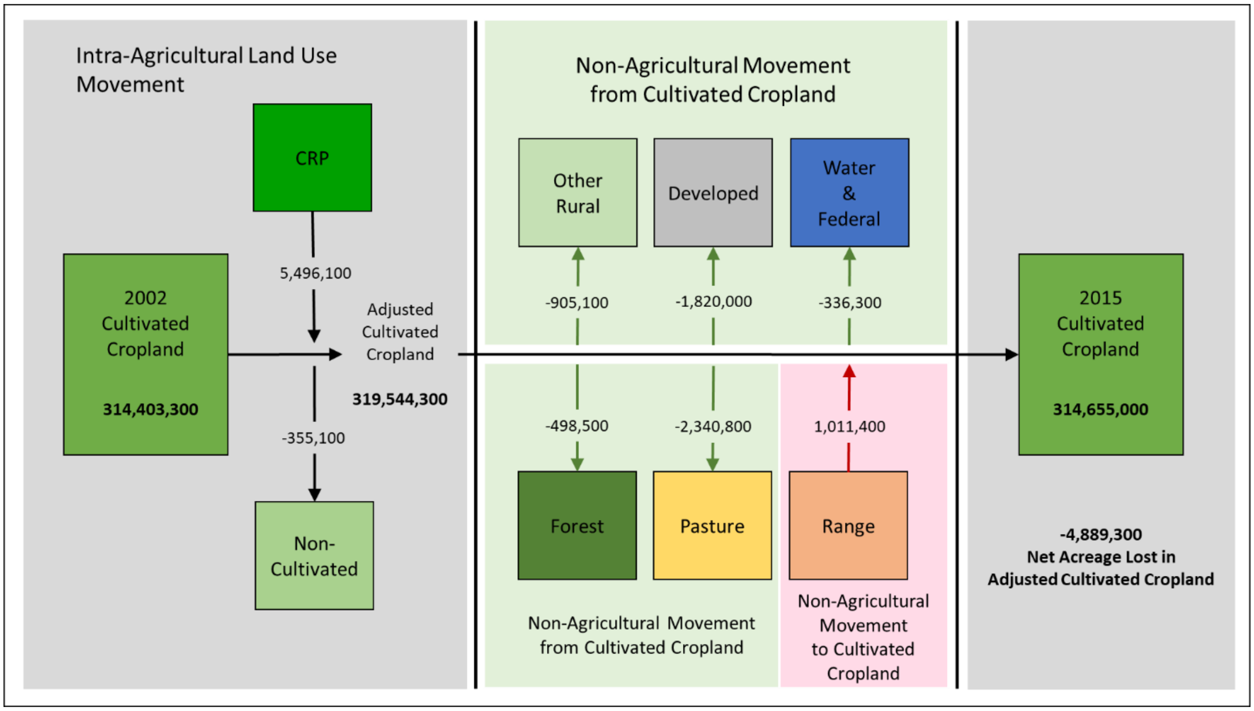



**Fig. 6**: In and out movement of different land cover/uses with cultivated cropland from 2002-2015 (these numbers exclude Hawaii and the Caribbean). Light green represents losses of cultivated cropland to non-agricultural lands and light red represents gains of cultivated cropland from non-agricultural lands.

The following results were indicated by the national 2002-2015 analysis:

- From 2002-2015, cultivated cropland gained nearly 5.5 million acres from CRP while losing just over 350,000 acres to non-cultivated cropland (a total gain of 5.1 million acres from other agricultural-related land uses).
- Cultivated cropland lost a total of 3 million acres to developed, other rural, and water/federal lands (developed was 59% of this movement).
- Cultivated cropland lost a total of 2.8 million acres to pasture and forest (pasture was 82% of this movement).
- Cultivated cropland gained 1 million acres from rangeland.
- Although the was a net decrease in cultivated cropland from 2002-2015, rangeland lost 1 million acres to cultivated cropland; however, there was a combined total of 5.5 million acres of cultivated cropland lost to forest, pasture, other rural, and developed lands.
- In total, from 2002-2015, cultivated cropland over the conterminous U.S. lost nearly 4.9 million acres to non-agricultural lands. The simplistic historic assessment of land use changes to cultivated cropland (which does not consider intra-agricultural movement) would result in a gain of just over 250,000 acres of cultivated cropland during the same time period, which is an overestimation of just over 5 million acres.

*Discussion of National Land Cover/Use In and Out Movement with Cultivated Cropland*

There are four key points to be discussed about the national land cover/use in and out movement analysis. These key points include: (1) the starting date of any temporal analysis can have a major impact on the results; (2) the method with which start and end year acreages are compared to calculate in and out movement between cultivated cropland and non-agricultural lands is important; (3) the role CRP has had in influencing these gains/losses to cultivated croplands is critical; and (4) historically national level assessments can be misleading because they do not fully capture the spatial variability of in and out movement at finer geographies (e.g., states, CRDs, counties, etc.). These four key points of discussion are as follows:

**Key Point 1**. Based on the NRI data, 2007 was a 30-year low in cultivated cropland acreage. Using 2007 as a start date for temporal analysis of land use change with respect to cultivated cropland can be potentially misleading. Therefore, this study analyzed these data in three different time-segments (2002-2007, 2007-2015, and 2002-2015). With that said, two different trends arose during the entire 2002-2015 study time. The first trend (2002-2007) showed a loss of 5 million acres in cultivated cropland to non-agricultural lands, with a second, and opposite, trend (2007-2015) of cultivated cropland increasing by 160,000 acres from non-agricultural lands. Equally interesting, the trend from 2002-2015 still showed a significant loss in cultivated cropland acres to non-agricultural lands, indicating that the loss in acreage from 2002-2007 was larger than the gains in acreage from 2007-2015.

**Key Point 2**. As previously mentioned, the EPA's (2018) second triennial report to Congress compared several agricultural land use assessments to one another at the national level. Many of the cited studies only compared the change between two different dates in cropland acreage totals, without considering the between class movement of different land cover/uses. The customized matrices of NRI data used in this study allowed for the assessment of in and out movement between all land cover/uses. Being able to understand this complex in and out movement provides pivotal insight that is missing from other data sets (e.g., USDA MLU or USDA Census).

**Key Point 3**. The interaction of CRP and cultivated cropland over the study period of 2002-2015 is paramount to capturing a more realistic understanding of agriculturally influenced land cover/use change. Specifically, it is important to understand that cultivated cropland gained 7.2 million acres from CRP during the 2007-2015 time-segment. For the spatial distribution of these 7.2 million cultivated cropland acres that were gained from CRP, see Figure 7.

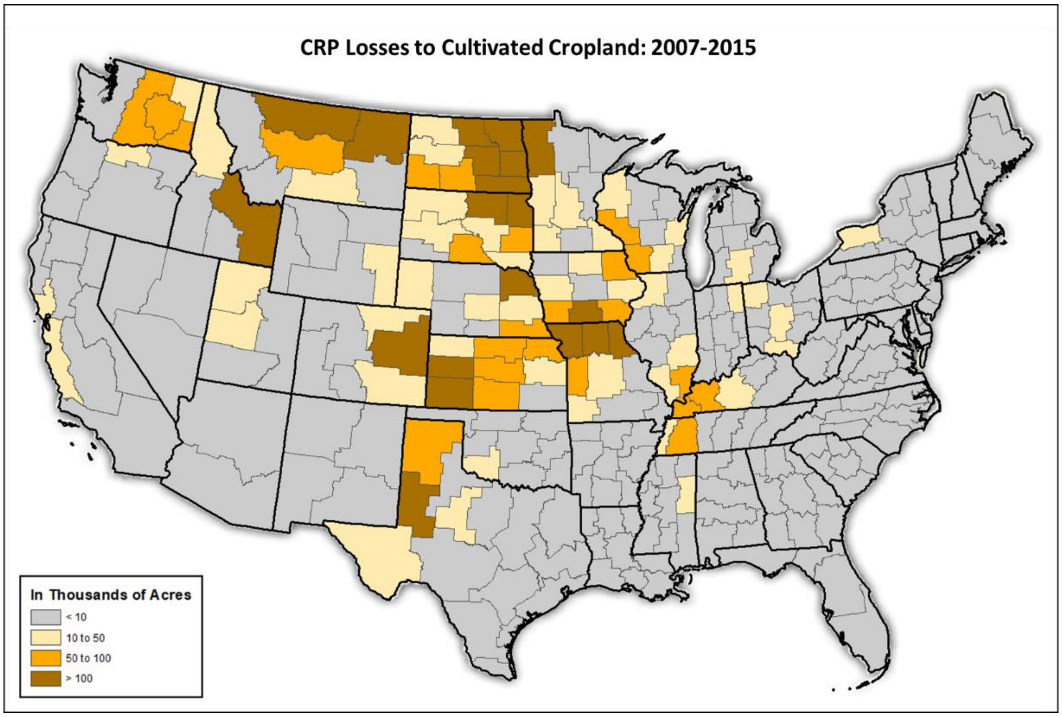



**Fig. 7**: Customized NRI CRP losses to cultivated croplands between 2007-2015 (CRD level).

These 7.2 million acres of CRP that transitioned were 81% of the increased acreage in cultivated cropland from 2007-2015. With that said, it is interesting to understand the changes in CRP enrollment between 2002-2015. Based on the analysis of in and out movement, CRP acreage totals have decreased and accounted for the vast majority of total gains in cultivated cropland. While other research (Coppess 2017; Hellerstein 2017) has also reported on the reduction in CRP acreage, it has noted a corresponding decrease in CRP acreage caps from 2002 to 2015 (Figure 8).

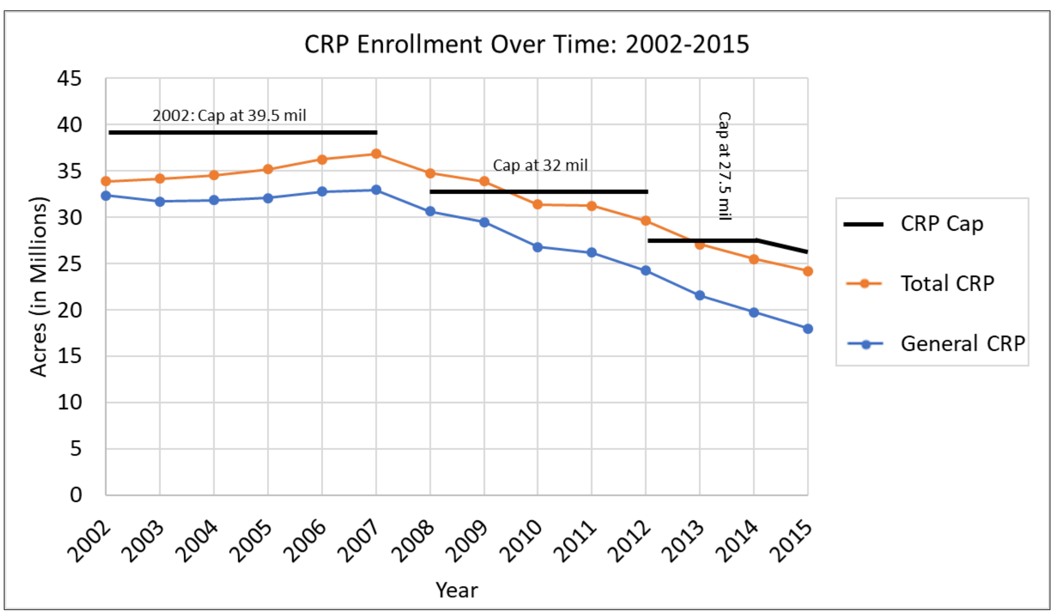



**Fig. 8**: CRP Enrollment from 2002-2015 with cap limits for acreage. Source: modified from Hellerstein 2017; Coppess 2017; FSA 2017. The difference between general CRP acres and total CRP acres is equal to continuous CRP acres.

Furthermore, it is not the intent of this report to dissect and evaluate the intricate interaction of the factors affecting this decline in CRP acreage. However, several key factors should be considered when assessing these trends:

- CRP acreage caps reduced from 2002 through 2015 and beyond (Coppess 2017; Hellerstein 2017).
    - 2002-2007: 39.5 million acres.
    - 2008-2012: 32 million acres.
    - 2012-2014: 27.5 million acres.
    - 2014-2018: 24 million acres (continuous reduction).
- A significant portion of general CRP acreage from 2002-2015 consisted of what was categorized by the NRI as "prime farmland", which also decreased by almost half over the study period (NRI 2017).
    - 2002: 8.4 million acres of CRP classified as "prime farmland".
    - 2007: 8.8 million acres of CRP classified as "prime farmland".
    - 2012: 6.4 million acres of CRP classified as "prime farmland".
    - 2015: 4.7 million acres of CRP classified as "prime farmland".
- Continuous CRP (the most environmentally sensitive lands) has consistently increased, while general CRP was relatively flat from 2002-2007, with a steady decline in general CRP after 2007 (FSA 2017; Hellerstein 2017; NRI 2017).
    - Note, the NRI land use classification of CRP consists of general sign-up acreage only; continuous sign-up CRP acreage totals are included with their associated NRI land cover/use (i.e., cropland, grassland, forest, etc.).

There are many potential drivers of changes in CRP acreages, such as farmer/landowner choices, government policies, commodity prices vs. rental payments, or alterations to the selection mechanisms within the CRP program (all of which are beyond the scope of this study). However, the most interesting observation is that between 2007-2015, cultivated cropland gained approximately 7.2 million acres from CRP in the conterminous U.S.; simultaneously, changes to CRP enrollment caps reduced the program's maximum allotted acreages by nearly 11 million acres.

**Key Point 4**. This national level land cover/use analysis of the NRI revealed that cultivated cropland lost approximately 5 million acres to non-agricultural lands from 2002-2007, but gained 160,000 acres from non-agricultural lands between 2007-2015 (with a net decrease from 2002-2015 of approximately 4.9 million acres). However, this national assessment was the combined effect of all smaller area's in and out movements. This is important to consider because the national trend is not always representative of the land cover/use changes in varying locations. Due to the nature of spatial variability in land cover/use changes, this in and out movement of other land covers/uses with cultivated cropland was characterized at sub-national levels in the following sections.

## State Level NRI Assessment of Cultivated Cropland In and Out Movement

As outlined in the national level assessment, the same methodology was used to assess the customized data matrices for all 48 states in the conterminous U.S. Similar to the analysis at the national level, cultivated cropland gains/losses to or from non-agricultural lands were calculated between the three time-segments of 2002-2007, 2007-2015, and 2002-2015 (Figure 9). The following trends were observed:

1. 2002-2007 showed that the majority of states had losses in cultivated cropland acreage totals. Three states had gains greater than 50,000 acres of cultivated cropland from non-agricultural lands (Missouri: 63,000 acres, Nebraska: 134,000 acres, and South Dakota: 90,000 acres). The primary land cover/uses that lost acreage to cultivated cropland were pastureland in Missouri, rangeland in Nebraska, and a combination of pasture/rangeland in South Dakota.
2. 2007-2015 resulted in 12 states with gains over 50,000 acres in cultivated cropland from non-agricultural lands, but also 10 states with losses over 50,000 acres. States like Missouri, Kentucky, Nebraska, Tennessee, and South Dakota were among the highest in acreage gains from non-agricultural lands, while the highest losses of cultivated cropland occurred in states like Texas, Oklahoma, North Dakota, and California. The primary land cover/uses that lost acreage to cultivated cropland were pastureland in Kentucky, Missouri, and Tennessee, with a combination of pasture/rangeland in Nebraska and South Dakota.
3. 2002-2015 identified that the majority of states had losses in cultivated cropland to non-agricultural lands. Six states had increases in cultivated cropland from non-agricultural lands. Missouri, Kentucky, Nebraska, South Dakota, Tennessee, and Iowa all had greater than 50,000 acres of gains to cultivated cropland. The primary land cover/uses that lost acreage to cultivated cropland were pastureland in Iowa, Kentucky, Missouri, and Tennessee, and a combination of pasture/rangeland in Nebraska and South Dakota.

| State | 2002-2007 Net Movement to/from Cultivated Cropland | | 2007-2015 Net Movement to/from Cultivated Cropland | | 2002-2015 Net Movement to/from Cultivated Cropland | |
|---|---|---|---|---|---|---|
| | Acres (in 1000s) | Bar Chart Acres (in 1000s) | Acres (in 1000s) | Bar Chart Acres (in 1000s) | Acres (in 1000s) | Bar Chart Acres (in 1000s) |
| Alabama | -209.1 | | 71.1 | | -138.0 | |
| Arizona | -2.3 | | -16.8 | | -19.1 | |
| Arkansas | -148.8 | | -149.1 | | -297.9 | |
| California | -245.3 | | -129.3 | | -374.6 | |
| Colorado | -67.1 | | 1.6 | | -65.5 | |
| Connecticut | 0.1 | | -1.8 | | -1.7 | |
| Delaware | -41.1 | | -19.6 | | -60.7 | |
| Florida | -34.9 | | 67.5 | | 32.6 | |
| Georgia | -124.4 | | 130.5 | | 6.1 | |
| Idaho | -77.3 | | -65.6 | | -142.9 | |
| Illinois | -174.9 | | -81.2 | | -256.1 | |
| Indiana | -91.5 | | 18.0 | | -73.5 | |
| Iowa | 2.7 | | 58.1 | | 60.8 | |
| Kansas | -289.0 | | 115.1 | | -173.9 | |
| Kentucky | 30.3 | | 359.8 | | 390.1 | |
| Louisiana | -273.2 | | -156.8 | | -430.0 | |
| Maine | -4.8 | | -0.4 | | -5.2 | |
| Maryland | -27.2 | | -10.2 | | -37.4 | |
| Massachusetts | 2.9 | | -3.0 | | -0.1 | |
| Michigan | -173.9 | | 72.9 | | -101.0 | |
| Minnesota | -219.1 | | 44.9 | | -174.2 | |
| Mississippi | -142.0 | | 74.9 | | -67.1 | |
| Missouri | 63.6 | | 548.9 | | 612.5 | |
| Montana | -84.5 | | -48.4 | | -132.9 | |
| Nebraska | 134.7 | | 245.2 | | 379.9 | |
| Nevada | 3.0 | | -2.3 | | 0.7 | |
| New Hampshire | -0.7 | | -2.3 | | -3.0 | |
| New Jersey | -32.6 | | -9.3 | | -41.9 | |
| New Mexico | -59.8 | | -48.5 | | -108.3 | |
| New York | -49.3 | | 46.2 | | -3.1 | |
| North Carolina | -159.4 | | -129.3 | | -288.7 | |
| North Dakota | -145.6 | | -137.3 | | -282.9 | |
| Ohio | -146.4 | | -6.4 | | -152.8 | |
| Oklahoma | -224.7 | | -158.2 | | -382.9 | |
| Oregon | -57.7 | | 43.3 | | -14.4 | |
| Pennsylvania | -75.8 | | 33.5 | | -42.3 | |
| Rhode Island | 0.5 | | -0.8 | | -0.3 | |
| South Carolina | -152.2 | | -67.5 | | -219.7 | |
| South Dakota | 90.8 | | 155.0 | | 245.8 | |
| Tennessee | -30.6 | | 174.0 | | 143.4 | |
| Texas | -1,520.9 | | -877.2 | | -2,398.1 | |
| Utah | -25.3 | | 6.4 | | -18.9 | |
| Vermont | 6.4 | | -5.0 | | 1.4 | |
| Virginia | -23.4 | | 23.8 | | 0.4 | |
| Washington | -62.9 | | -36.3 | | -99.2 | |
| West Virginia | -8.6 | | -1.1 | | -9.7 | |
| Wisconsin | -140.0 | | 48.1 | | -91.9 | |
| Wyoming | -37.8 | | -15.3 | | -53.1 | |
| **U.S. Total** | **-5,049.1** | | **159.8** | | **-4,889.3** | |

**Fig. 9**: Customized NRI state level data for three different time-segments: (1) 2002-2007 - left; (2) 2007-2015 - center; and (3) 2002-2015 - right. These net movements to/from are between cultivated cropland and non-agricultural lands. Losses of cultivated cropland are shown as negative numbers with green bars. This figure is formatted similarly to Lark et al. (2015).

The state level assessment revealed that specific areas displayed gains in cultivated cropland acreage from non-agricultural lands across the entire study time between 2002-2015 (e.g., Kentucky, Missouri, Nebraska, and South Dakota). Other states displayed losses in cultivated cropland acreage across the entire 2002-2015 study (e.g., California, Illinois, Louisiana, North Dakota, Oklahoma, and Texas). However, several states displayed decreases in cultivated cropland acreage from 2002-2007, with increases between 2007-2015 (e.g., Kansas, Minnesota, and Tennessee). Ultimately, this evaluation identified the spatial variability within the conterminous U.S.; however, a finer resolution (i.e., CRD level) provides valuable insight into the sub-state regions of agricultural land cover/use change.

## Crop Reporting District Level NRI Assessment of Cultivated Cropland In and Out Movement

As with the previously mentioned national and state methodology, cultivated cropland gains/losses to or from non-agricultural lands were calculated at the CRD level between the three time-segments of 2002-2007, 2007-2015, and 2002-2015. Of importance for this spatial delineation, CRD level margins of error for certain land cover/uses totals occasionally exceeded the total estimates. Therefore, the absolute acreage totals presented at individual CRDs may vary slightly, but the general spatial distribution of gains/losses within a state's geography was represented. With this said, the following analysis consists of the results from all CRDs.

The following sequence of maps display the total cultivated cropland gains/losses to or from non-agricultural lands by CRD through the three time-segments (2002-2007, 2007-2015, and 2002-2015) of this analysis (Figures 10-12).

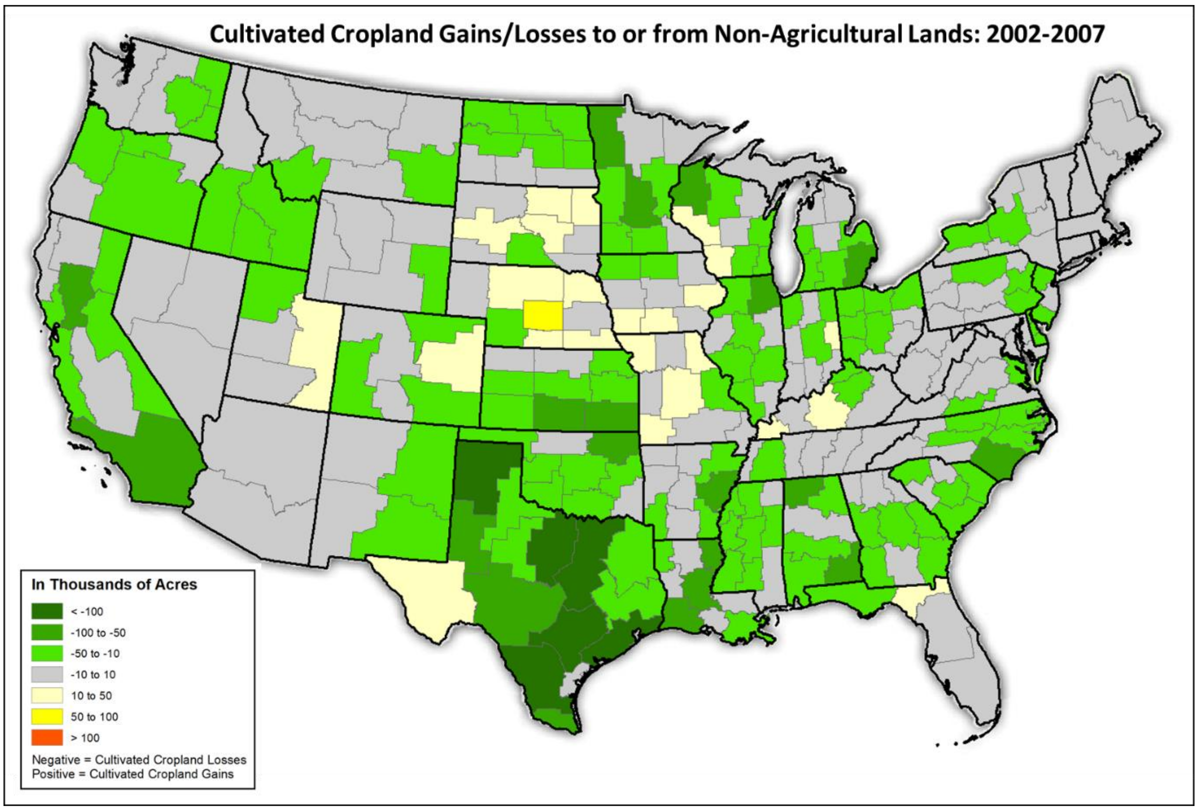



**Fig. 10**: Customized NRI cultivated cropland gains/losses to or from non-agricultural lands between 2002-2007 (CRD level). Losses of cultivated cropland are green and shown as negative numbers.

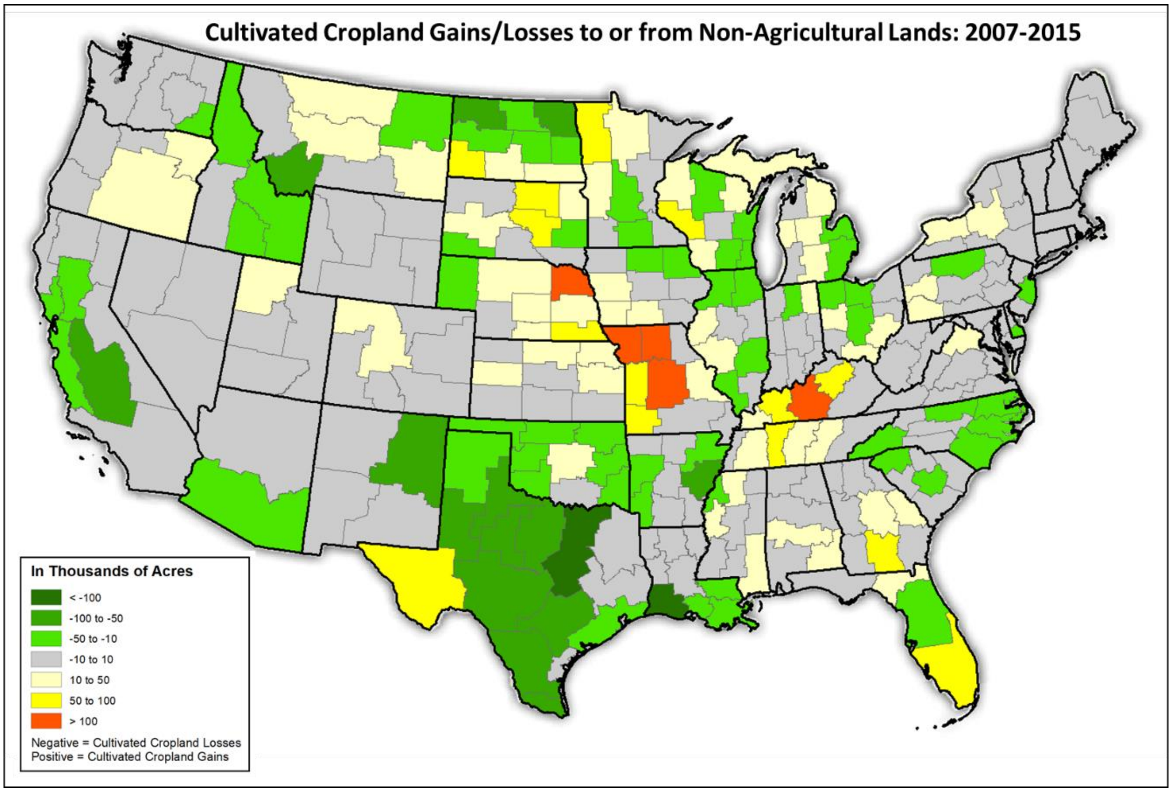



**Fig. 11**: Customized NRI cultivated cropland gains/losses to or from non-agricultural lands between 2007-2015 (CRD level). Losses of cultivated cropland are green and shown as negative numbers.

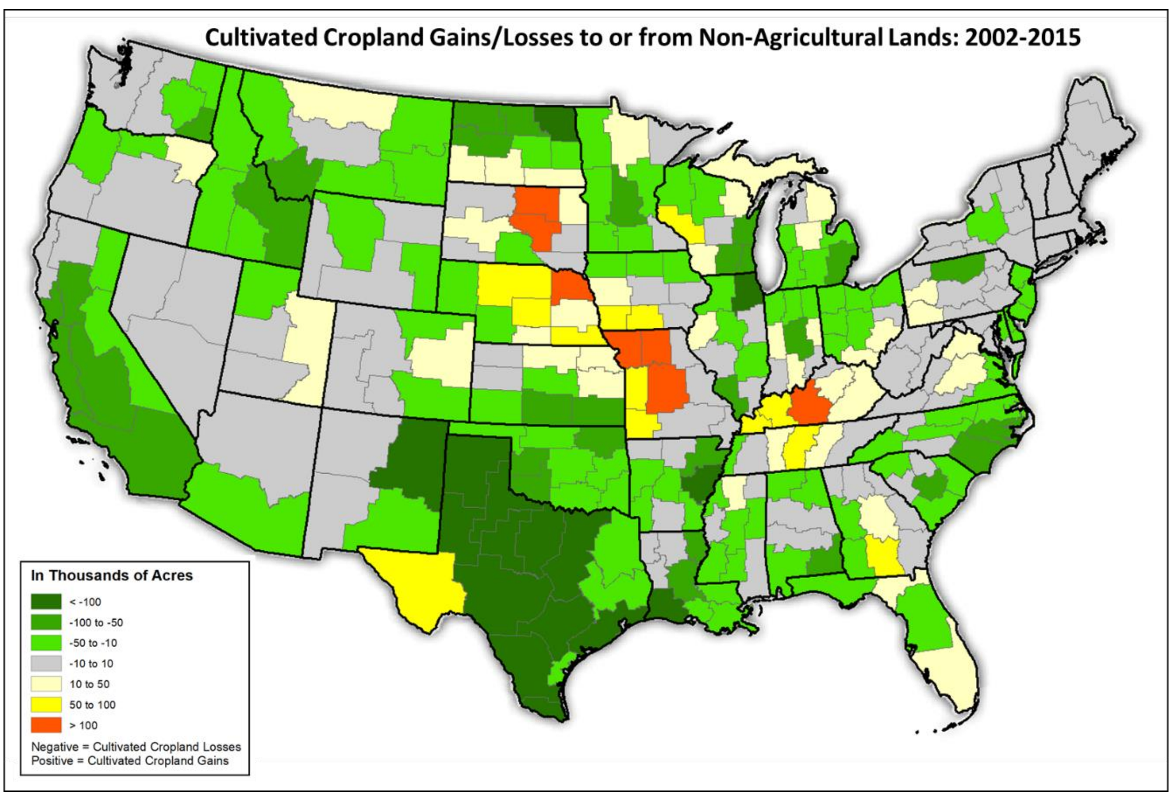



**Fig. 12**: Customized NRI cultivated cropland gains/losses to or from non-agricultural lands between 2002-2015 (CRD level). Losses of cultivated cropland are green and shown as negative numbers.

Although CRD level mapping can be considered a coarse resolution, these maps provided insight on the within-state variability. The following is a discussion on the assessment of the land cover/use change maps in cultivated cropland over the three time-segments at the CRD level:

1. From 2002-2007 there were large contiguous areas of losses to cultivated cropland across the conterminous U.S., with small pockets of gains in cultivated cropland from non-agricultural lands. These small pockets of gains to cultivated cropland were predominantly located in Iowa, Nebraska, and South Dakota. All CRDs (excluding one in central Nebraska) showed gains less than 50,000 acres from non-agricultural lands.
2. Between 2007-2015 the national assessment showed an increase of 160,000 acres of cultivated cropland from non-agricultural lands; however, the CRD level spatial distribution showed there were roughly equal amounts of gains and losses spread out into clusters over the entire conterminous U.S. Several pockets of gains from non-agricultural lands were identified in: (1) Kentucky and Tennessee; (2) Missouri to Nebraska, and (3) at the intersection of Minnesota with the Dakotas. Pockets of losses in cultivated cropland were detected in: (1) much of Texas and Oklahoma; (2) much of North Dakota; and (3) at the intersection of Iowa, Illinois, and Wisconsin.
3. The longer-term trend from 2002-2015 showed large contiguous areas of losses in cultivated cropland to non-agricultural lands throughout the conterminous U.S., but several regional areas of gains over 50,000 acres were present in: (1) Kentucky and Tennessee; (2) northwest Missouri, southwest Iowa, and central/eastern Nebraska; and (3) central South Dakota.

Based on these regionally specific areas with moderate-to-high gains (over 50,000 acres) in total cultivated cropland from non-agricultural lands, a more detailed investigation was completed to better understand how corn acreage contributed to the overall gains in cultivated croplands. One of the customized NRI data sets from 2007-2015 provided corn and soybeans as separate land use categories. These data were provided at the county level, which were aggregated to the CRD level for comparability with the net cultivated cropland gains from non-agricultural lands. The resulting Midwestern (plus Kentucky and Tennessee) map was created to help understand the impact that corn production has had in areas of moderate-to-high acreage gains (Figure 13).

The resulting map of corn production’s influence on cultivated cropland gains from non-agricultural lands between 2007-2015 showed:

- The pocket in both Kentucky and Tennessee, contained two CRDs with less than 20% contribution from corn to the total cultivated cropland gains from non-agricultural lands, in their respective CRD. However, two other CRDs had between 40-60% of corn contributions to total cultivated cropland gains.
- The area running from Missouri into Nebraska primarily contained CRDs within the 30-40% range, with one CRD over 60% and another below 30% contribution of corn to the total cultivated cropland gains from non-agricultural lands.
- Along the western flank of Wisconsin, one CRD’s corn acreage contribution was 70% of the total cultivated cropland gains from non-agricultural lands. However, this isolated area of change was just under 40,000 acres related to corn.
- The Great Plains and Drift Prairie of South Dakota contained two CRDs that ranged from approximately 10-30% corn contribution to total cultivated cropland gains from non-agricultural lands.

- All CRDs with moderate-to-high gains (each over 50,000-acre) resulted in a total of 1.3 million acres of gains in cultivated cropland from non-agricultural lands. However, corn acreage (collectively totaling just under 420,000 acres) accounted for less than one-third of the gains in these areas.

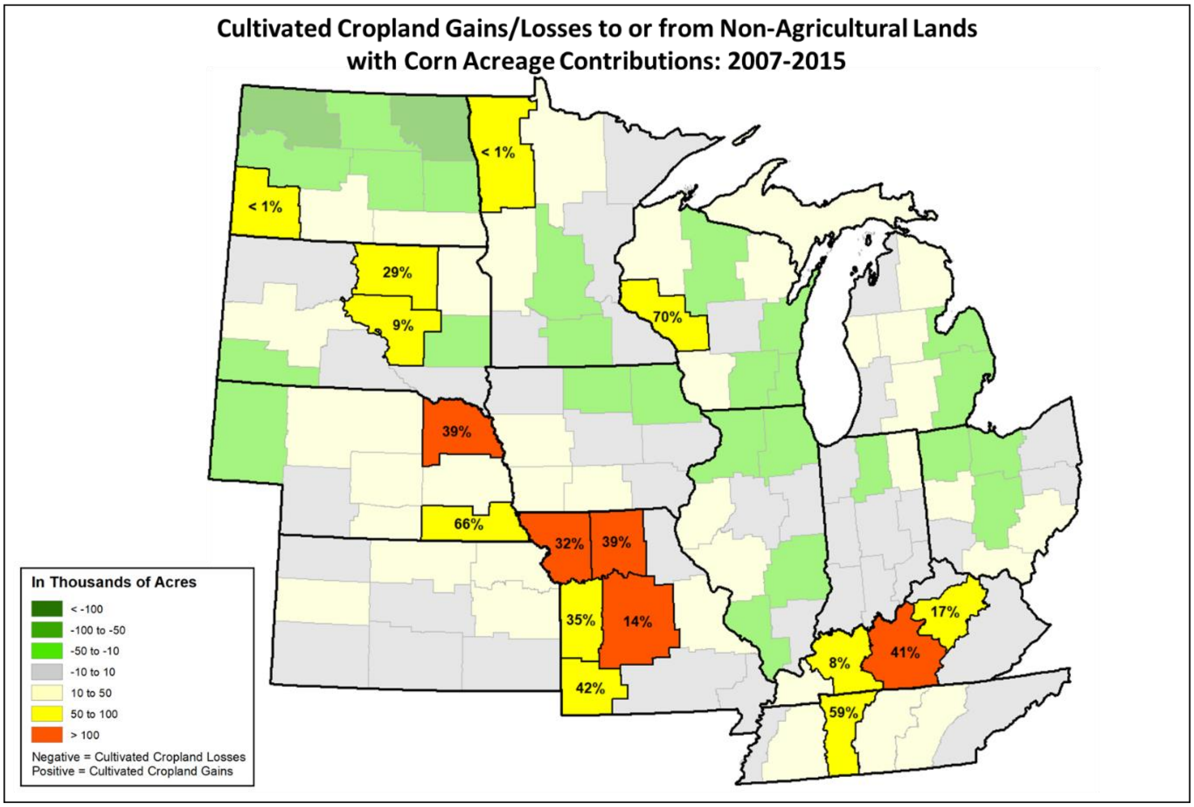



**Fig. 12**: Customized NRI cultivated cropland gains/losses to or from non-agricultural lands between 2007-2015 (CRD level). Overlaid are the percentages of corn acres gained in relation to the total cultivated cropland acres gained from non-agricultural lands.

## Conclusion

A general review of all findings to this portion of the study are outlined below:

1. The customized NRI national assessment indicated the following:
    a. From 2002-2007 cultivated cropland lost just over 5 million acres to non-agricultural lands. This was primarily driven by cultivated cropland losses to pasture (just under 3 million acres) and a combination of acreage losses to developed/forest/other rural lands (totaling just over 2 million acres).
    b. Between 2007-2015 cultivated cropland gained nearly 160,000 acres from non-agricultural lands. This was the net result of losses in cultivated cropland to developed/other rural/water and gains in cultivated cropland from forest/pasture/rangeland. Of importance in this time-segment is that 7.2 million acres of CRP were added to cultivated cropland via intra-agricultural movement. However, this movement of CRP corresponded to decreasing CRP enrollment caps that dropped 11 million acres between 2007-2014.

    c. From 2002-2015 cultivated cropland lost nearly 4.9 million acres to non-agricultural lands. Although there was an overall net loss of cultivated cropland, rangeland lost just over 1 million acres to cultivated cropland.
    d. National level assessment does not capture the state and sub-state variation that is important in understanding land cover/use change.
2. The customized NRI state level assessment indicated the following:
    a. From 2002-2015 the majority of states had losses in cultivated cropland to non-agricultural lands. Six states had increases in cultivated cropland from non-agricultural lands. Missouri, Kentucky, Nebraska, South Dakota, Tennessee, and Iowa all had greater than 50,000 acres of gains to cultivated cropland. The primary land cover/uses that lost acreage to cultivated cropland were pastureland in Iowa, Kentucky, Missouri, and Tennessee, and a combination of pasture/rangeland in Nebraska and South Dakota.
    b. Even at the state level, cultivated cropland gains/losses can be misrepresented when not looking at the within-state variation.
3. The customized NRI CRD level assessment indicated the following:
    a. During the upward trend in gains to cultivated cropland from non-agricultural lands, between 2007-2015, the CRD level spatial distribution showed there were roughly equal amounts of gains and losses spread out into clusters over the entire conterminous U.S. Several pockets of gains were identified in: (1) Kentucky and Tennessee; (2) Missouri to Nebraska, and (3) at the intersection of Minnesota with the Dakotas. Pockets of losses in cultivated cropland were detected in: (1) much of Texas and Oklahoma; (2) much of North Dakota; and (3) at the intersection of Iowa, Illinois, and Wisconsin.
    b. With this initial assessment at the CRD level, corn and soybeans were not separated into different classes. This lack of separation can be misleading on corn acreage impact to land cover/use change.
4. The customized NRI CRD level assessment of corn acreage in moderate-to-high gain areas (CRDs over 50,000 acres) indicated the following:
    a. From 2007-2015 20 of the 303 CRDs in the conterminous U.S. had cultivated cropland gains over 50,000 acres from non-agricultural lands. 16 of these 20 CRDs were located in the Midwest (plus Kentucky and Tennessee).
    b. Detailed analysis of these 16 CRDs, revealed that there was a total of 1.3 million acres of gains in cultivated cropland from non-agricultural lands. However, corn acreage (collectively totaling just under 420,000 acres) accounted for less than one-third of the gains in these areas.

As mentioned earlier, the main focus of this portion of the report was to understand and map the in and out movement of different NRI-defined land cover/uses with cultivated cropland from 2002-2015. Due to the NRI's longitudinal structure and the ability to track in and out movement of land cover/uses through the matrix-based NRI tables (provided by the EPA), the findings from this NRI analysis provided a different insight regarding the movement of cultivated cropland into potential environmentally sensitive lands (i.e., non-agricultural lands as identified in this study). The benefits/advantages of these customized NRI data sets in comparison to other land cover/use studies are as follows:

1. When compared with the USDA MLU and Census, the NRI has methodological advantages, enabling a more robust and perhaps a more reliable/representative longitudinal assessment of land cover/use change.
2. The customized matrix-based NRI data set provides deeper insights into complex land cover/use changes (all three time-segments combined for a total of over 600,000 possible combinations of in and out movement at all geographies) when compared to the USDA MLU and Census. These other two data sets do not allow for an in-depth analysis of the interactions between different land cover/uses over time. Specifically, the NRI allows for assessment of intra-agricultural and non-agricultural movements to and from cultivated cropland.
3. Since a large percentage of the cultivated cropland gains came from CRP between 2002-2015, any remote sensing-based assessment (e.g., CDL, NWALT, etc.) has the potential to suffer from two different, but loosely related and compounding issues: (a) the inability to reliably discriminate between certain land uses and land covers, and (b) simple misclassifications. These two issues are further discussed in the following:
    a. CRP as a land use is comprised of various land covers (e.g., grasses, forests, etc.) that cannot be reliably differentiated from other similar non-CRP land cover/uses when utilizing remote sensing-based land classifications. As such, the customized NRI is the only land cover/use data set that tracks and incorporates CRP's interaction with other land cover/uses in their classification system.
    b. Misclassifications are a common occurrence in remotely sensed land classifications. This is especially important and problematic when using these data sets for longitudinal land cover/use change studies. To this end, the CDL FAQ stated (USDA 2019a):

        > "*Unfortunately, the pasture and grass-related land cover categories have traditionally had very low classification accuracy in the CDL. Moderate spatial and spectral resolution satellite imagery is not ideal for separating grassy land use types, such as urban open space versus pasture for grazing versus CRP grass. To further complicate the matter, the pasture and grass-related categories were not always classified definitionally consistent from state to state or year to year*."

4. When compared with the NWALT, Lark et al. (2015), and Wright et al. (2017), the customized matrix-based NRI data set (which tracks in and out movement of CRP with other land cover/uses) provides a more robust and informative understanding of these complex land cover/use interactions.
5. Considering the above limitations of remote sensing-based land cover/use classification data sets, Lark et al. (2015), and subsequently Wright et al. (2017), have implemented GIS-based correction techniques in an attempt to resolve the inherent and recognized inaccuracies in the CDL. The next portion of this study will quantitatively assess the impact of the correction techniques introduced by these researchers.

## Section 2: Analysis of the Census for Change in Cropland

The USDA Census of Agriculture Data (Census) is conducted every five years (Census 2017), collecting information from a large proportion of agricultural producers. The Census estimates data across the entire agricultural population. The Census is a national survey with a 71.5 percent 2017 response rate. It contains results at the county, state and national level. For crop totals, these data include total cropland, harvested cropland, cropland pasture, idle, summer fallow and failed. The Census, with a margin of error nationally for total cropland estimated around 1 percent, could be considered a reliable source for cropland estimations.

Calculated "Total Cropland" in the Census includes harvested, idle, cultivated summer fallow, failed and other pasture and grazing land that could have been used for crops without additional improvement as sub-categories. The Census indicates a decline in total cropland from 2002 or 2007 to 2012 and 2017 (Table 1). However, when cropland/pasture is removed from the total, there is actually an estimated increase in cropland acres. Cropland/pasture is defined as "pasture and grazing land that could have been used for crops without additional improvements". The margin of error associated with these datasets is slightly above these estimated changes at least for 2012 and 2017 (Table 2). Total possible error based on the coefficient of variation for 2012 is close to 2.4 million acres while total error in 2017 is close to 5 million acres. The combined error is over 7,000,000 acres while the change in cropland is just over 5.7 million. Margin of error for 2007 is not available. Coefficients of variation are not included for years before 2012. Therefore, the Census, while a reliable measure of total cropland, should be used to estimate changes in cropland with caution realizing that acres in error may approach acres estimated as change.

| Year | Total Cropland | Total w/out Pasture | Change in Crop Acres | Harvested | Idle | Fallow | Failed | Cropland/Pasture |
|---|---|---|---|---|---|---|---|---|
| 2002 | 434,164,946 | 373,607,081 | | 302,697,202 | 37,281,096 | 16,559,229 | 17,069,554 | 60,557,805 |
| 2007 | 406,424,909 | 370,653,755 | -2,953,326 | 309,607,601 | 37,968,749 | 15,671,507 | 7,405,898 | 35,771,154 |
| 2012 | 389,690,414 | 376,887,567 | 6,233,812 | 314,964,600 | 36,382,032 | 14,145,567 | 11,395,368 | 12,802,847 |
| 2017 | 396,433,817 | 382,607,842 | 5,720,275 | 320,041,858 | 36,003,378 | 17,020,026 | 9,542,580 | 13,825,975 |

**Table 1**: Census values for Total Cropland and sub-categories for 2002 to 2017.

| Year | Harvested | C.V. | Idle | C.V. | Fallow | C.V. | Failed | C.V. | Total Cropland | Possible Error |
|---|---|---|---|---|---|---|---|---|---|---|
| 2012 | 314,964,600 | 0.4% | 36,382,032 | 1.7% | 14,145,567 | 2.2% | 11,395,368 | 1.7% | 376,887,567 | 2,383,277 |
| 2017 | 320,041,858 | 1.2% | 36,003,378 | 1.2% | 17,020,026 | 2.0% | 9,542,580 | 3.7% | 382,607,842 | 4,966,019 |
| | | | | | | | | | **+5,720,275** | **7,349,295** |

**Table 2**: Coefficients of variation for different cropland sub-categories and their potential impact on error.

- When including cropland/pasture, the Census indicates declining total cropland from 2002 to 2007, again declining between 2007 to 2012 and then increasing from 2012 to 2017

- The Census indicates decreasing total cropland from 2002 to 2007, increasing from 2007 to 2012 and increasing again from 2012 to 2017 when not including cropland/pasture.
- The Coefficient of Variation for the different categories that go into total cropland without pasture (harvested, idle, fallow, failed) exceeds the estimated changes in years.
- The Census should be used with caution when estimating changes in total cropland with and without cropland/pasture as possible error is greater than the estimated change.

## Comparing the Census, the NRI and the CDL

A comparison of the relationship between different USDA datasets that estimate cropland, land cover, land use and possible change may give some insight into the accuracy of each. For this analysis, we compared the Census, the NRI and the CDL on a state-by-state basis. Each of these datasets are developed using a different methodology (Census using farmer surveys, NRI using sampling and CDL using satellite imagery) and may have different categories (i.e. the breakout of cropland in the Census was previously mentioned, the NRI includes corn, soybeans, cultivated crop and uncultivated crop and the CDL has classes for many crop types including tree fruits), but in general, these different categories could be compared to determine if trends and approximate total acres are similar when comparing the three datasets. For instance, a strong relationship was found ($R^2$ = 0.9873) when comparing total cropland in the Census (total cropland minus cropland/pasture (land which could be easily converted to crops but is currently being used for pasture)) to total cropland (cultivated and uncultivated) in the NRI in 2007 (Figure 13). However, total acres for the two datasets are different by over 22,000,000 acres with the Census having higher acreage (Census = 380,984,460; NRI = 358,891,000). The Census tends to estimate more cropland than the NRI. Further analysis may be warranted to understand the sources of these differences.

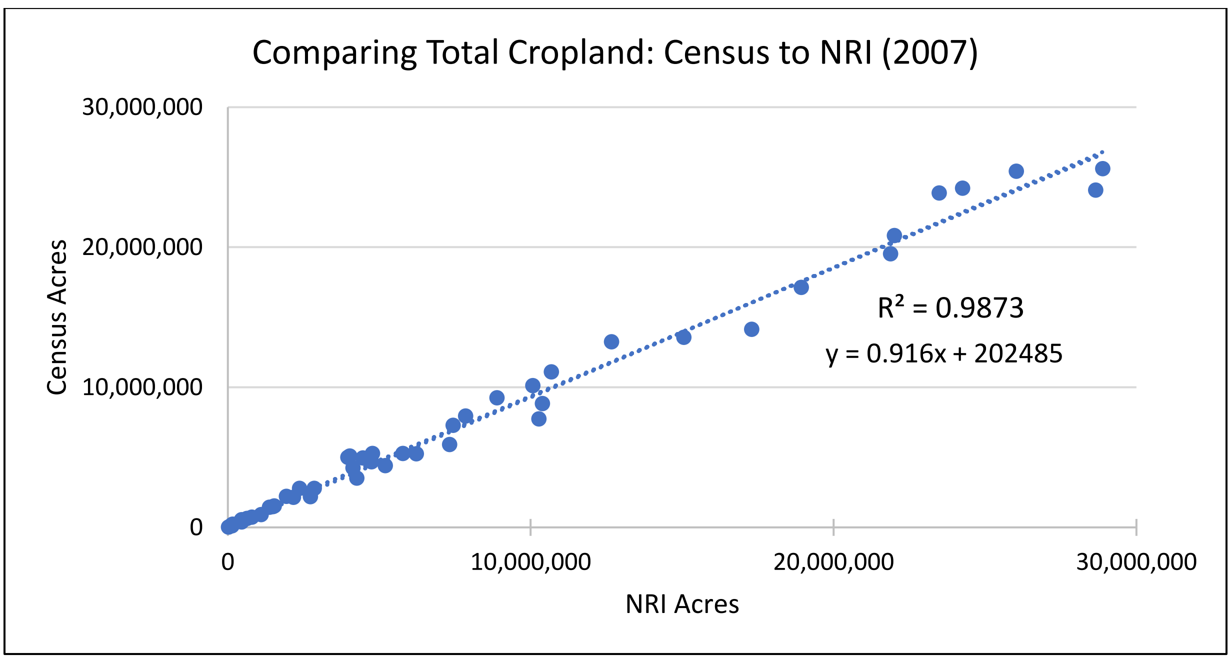



**Fig. 13**: Comparing the State Level 2007 Census to the 2007 NRI (Total Cropland minus pasture for the Census).

- Total cropland in the Census and NRI have a strong relationship.

In 2007, the USDA only generated the CDL for certain states (Figure 14). These states did represent an estimated 75% of total cropland in the United States but the datasets do not allow for the comparison of potential conversion to cropland for every state. Therefore, many analyses have started with the 2008 CDL which included all 48 contiguous states and allows for a country-wide analysis (without Hawaii or Alaska). The Census and NRI have 2007 datasets but not 2008. What is not clear is how the change in using the 2008 CDL instead of 2007 as a starting year could impact accuracy of comparisons with the Census and NRI from 2007. The states in the 2007 CDL, while not allowing for a complete analysis, should allow the opportunity to better understand the relationship between the CDL, the Census and the NRI. Much of the following analysis will focus on comparisons between the 2007 available CDL states and the Census and NRI to understand how strong of a relationship exists.

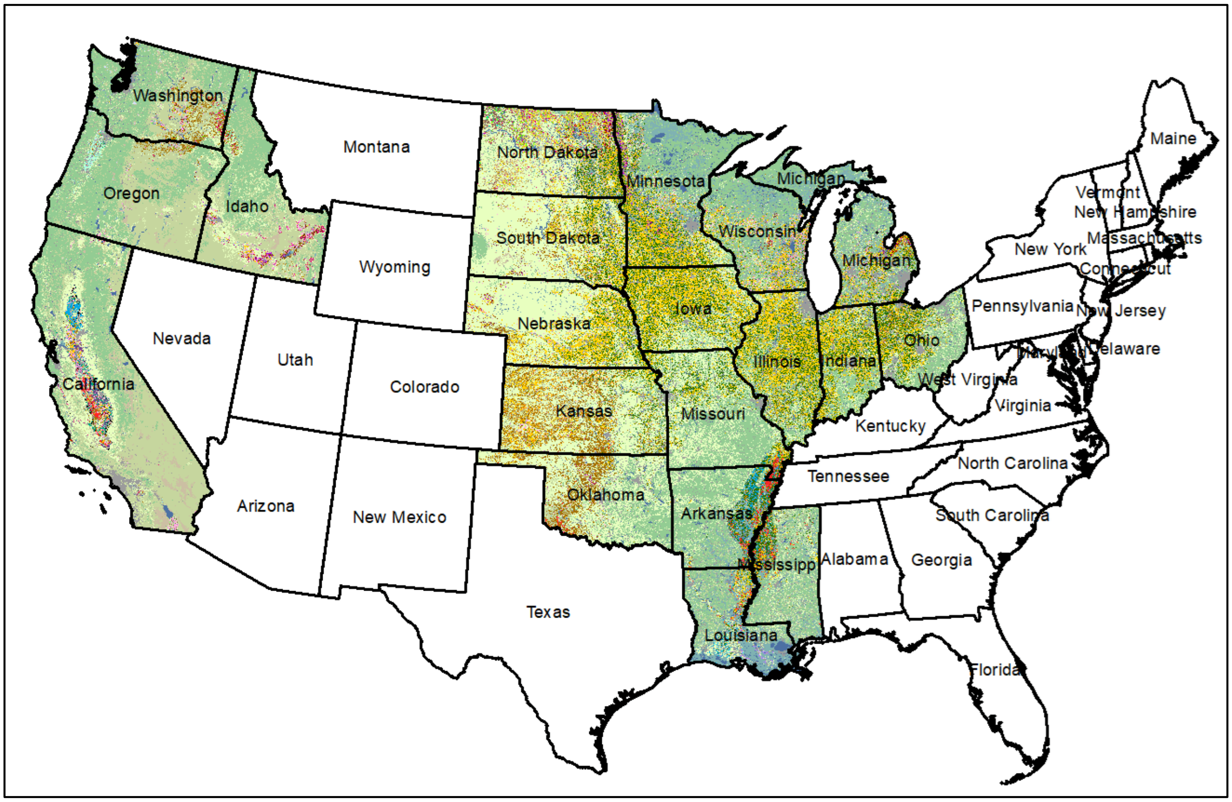
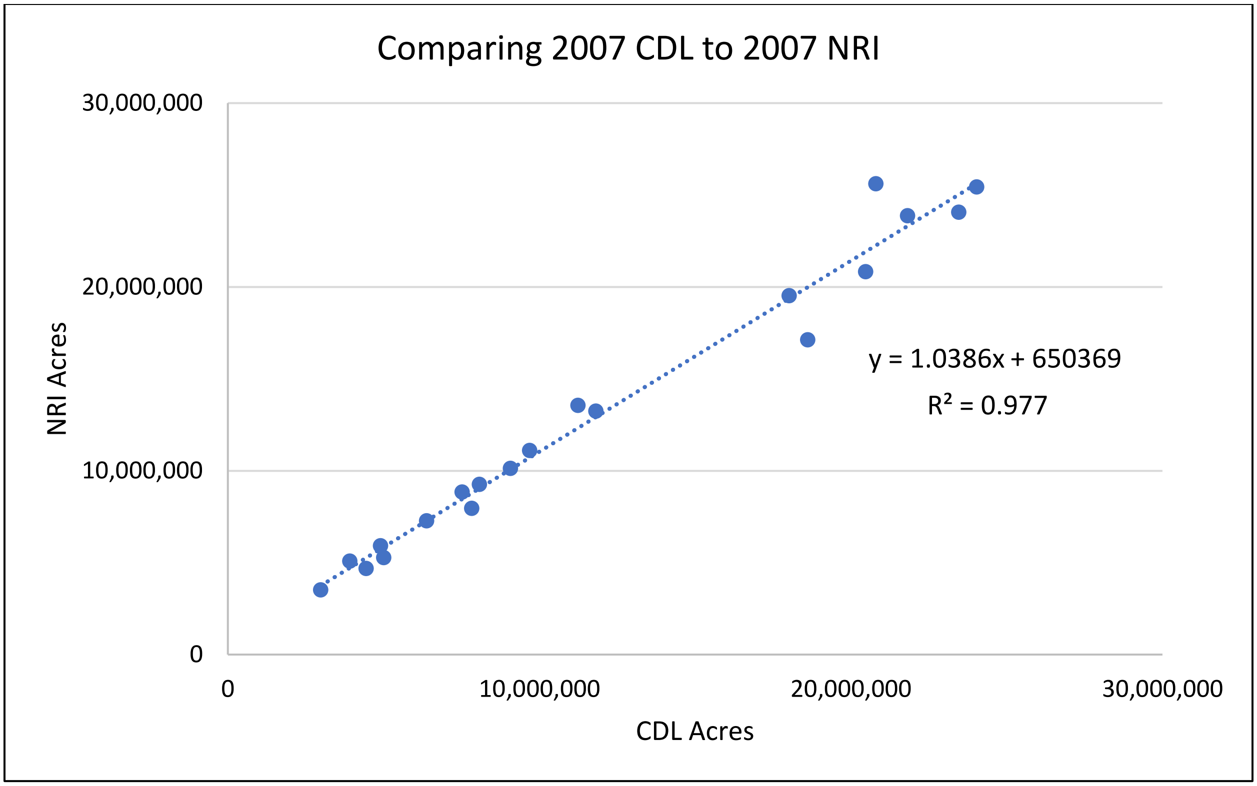



**Fig. 14**: States with 2007 CDL datasets (represent approximately 75% of total cropland).

- Only certain states have a 2007 CDL (AR, CA, ID, IL, IN, IA, KS, LA, MI, MN, MS, MO, NE, ND, OH, OK, OR, SD, WA and WI – 20 states representing approximately 75% of cropland).
- Because the Census and NRI have state level data in 2007, comparing these years to the CDL as opposed to using the 2008 CDL may offer a more accurate assessment.

A comparison was made between the states available in a 2007 CDL and the same states in the NRI and Census to determine if agreement exists between total cropland at the state level (see Appendix 2 for conversion of CDL classes to total cropland). Strong relationships were indicated (Figure 15). The Census included total cropland with cropland/pasture subtracted, the NRI included cultivated and uncultivated cropland and the CDL included all classes representing crops including hay and tree fruits. Totals for each dataset (Census = 279,080,554; NRI = 262,327,400; CDL = 240,057,001) do indicate the CDL may be underestimating cropland. This could impact any efforts to compare 2007 CDL to cropland in future years (if these years do not also underestimate total cropland).



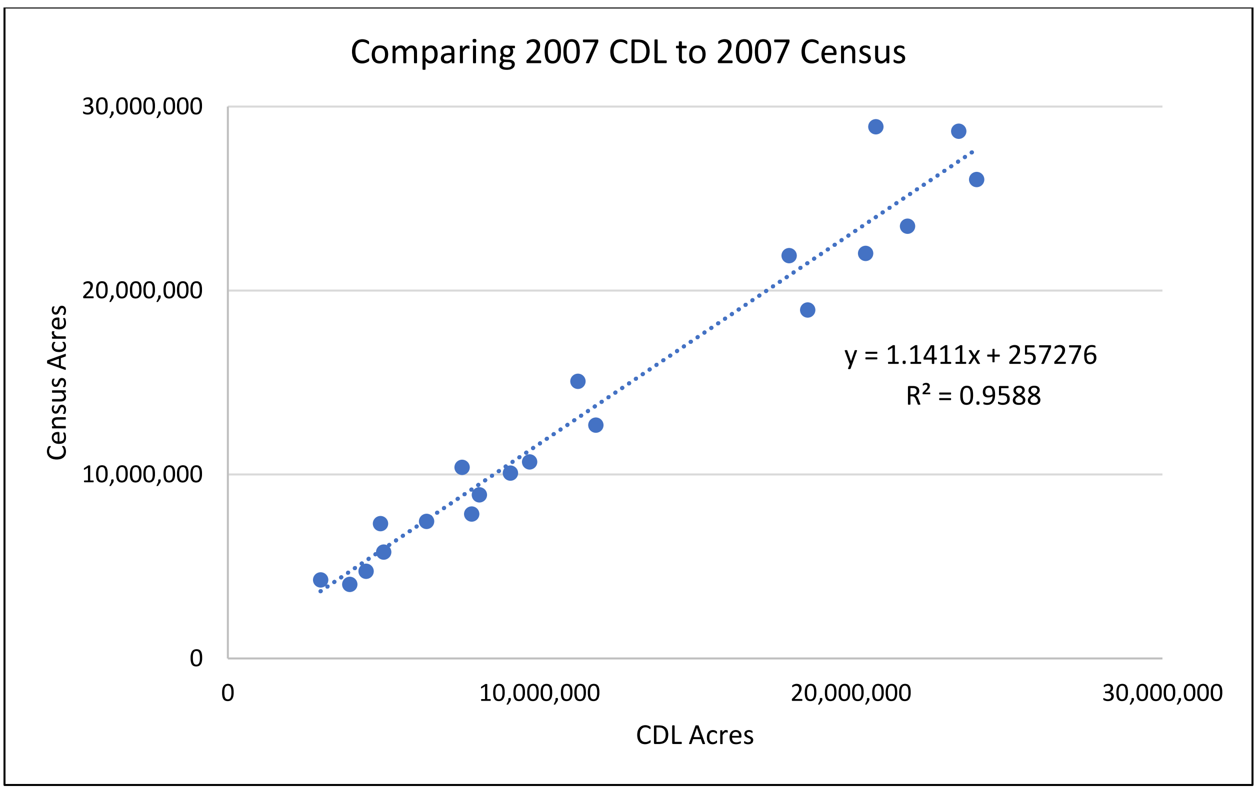




**Fig. 15**: Comparing the 2007 CDL to the 2007 NRI and 2007 Census (Total Cropland minus pasture for the Census).

- A strong relationship ($R^2 = 0.977$ and $R^2 = 0.9588$) exists when comparing the CDL to the NRI and Census in 2007.
- The CDL has lower total acres than the Census or NRI.

Also, when comparing the CDL to the NRI in 2015, the relationship remains strong ($R^2 = 0.9898$) (Figure 16). Here also, however, the total cropland acres for the CDL (330,241,414) is below the total cropland in the NRI (366,334,100).

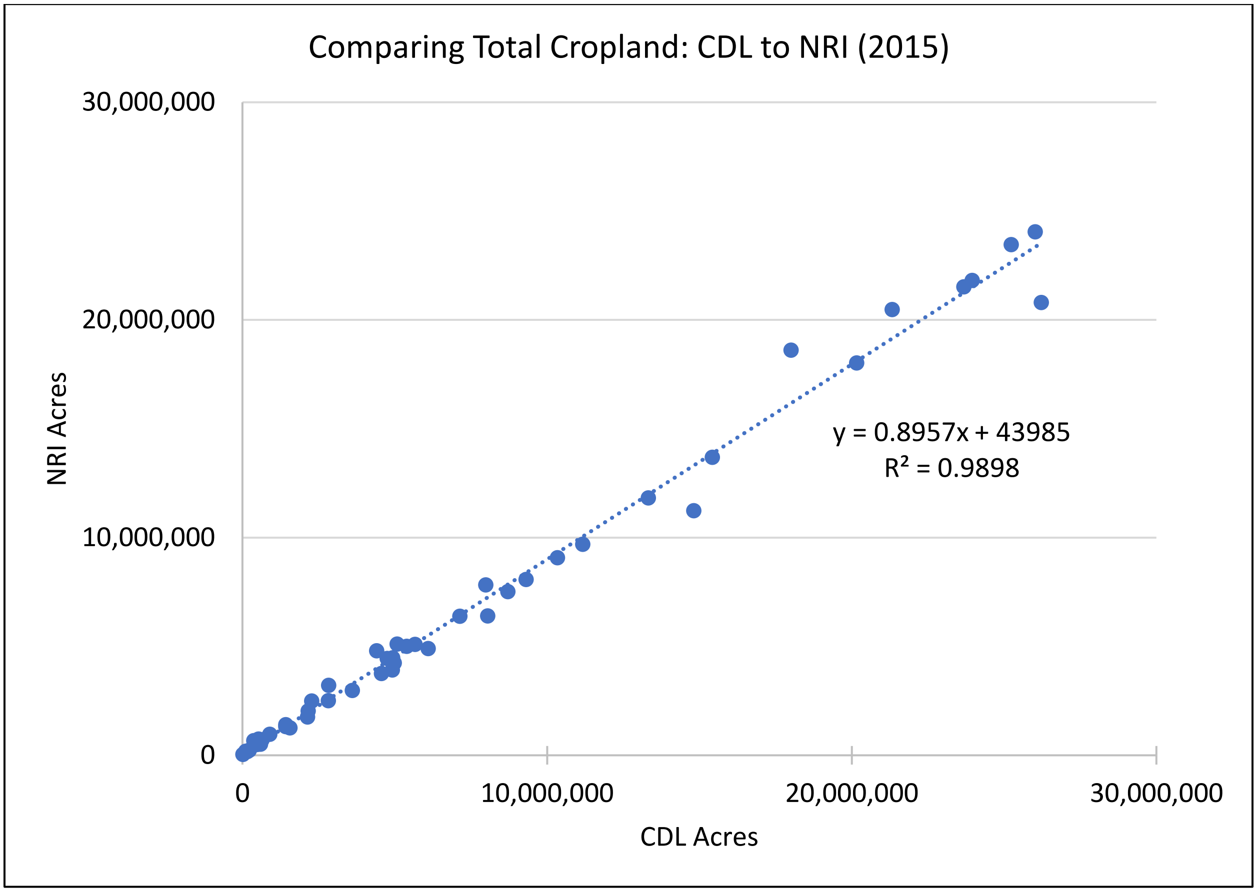



**Fig. 16**: Comparing Total Cropland Estimated by the 2015 NRI to the 2015 CDL.

- A strong relationship also exists for total cropland in the CDL and total cropland in the NRI by state in 2015.

Finally, when comparing total cropland in the 2017 CDL to the 2017 Census (by state) the strong relationship continues (Figure 17). An $R^2 = 0.9702$ indicates the two datasets have strong agreement.

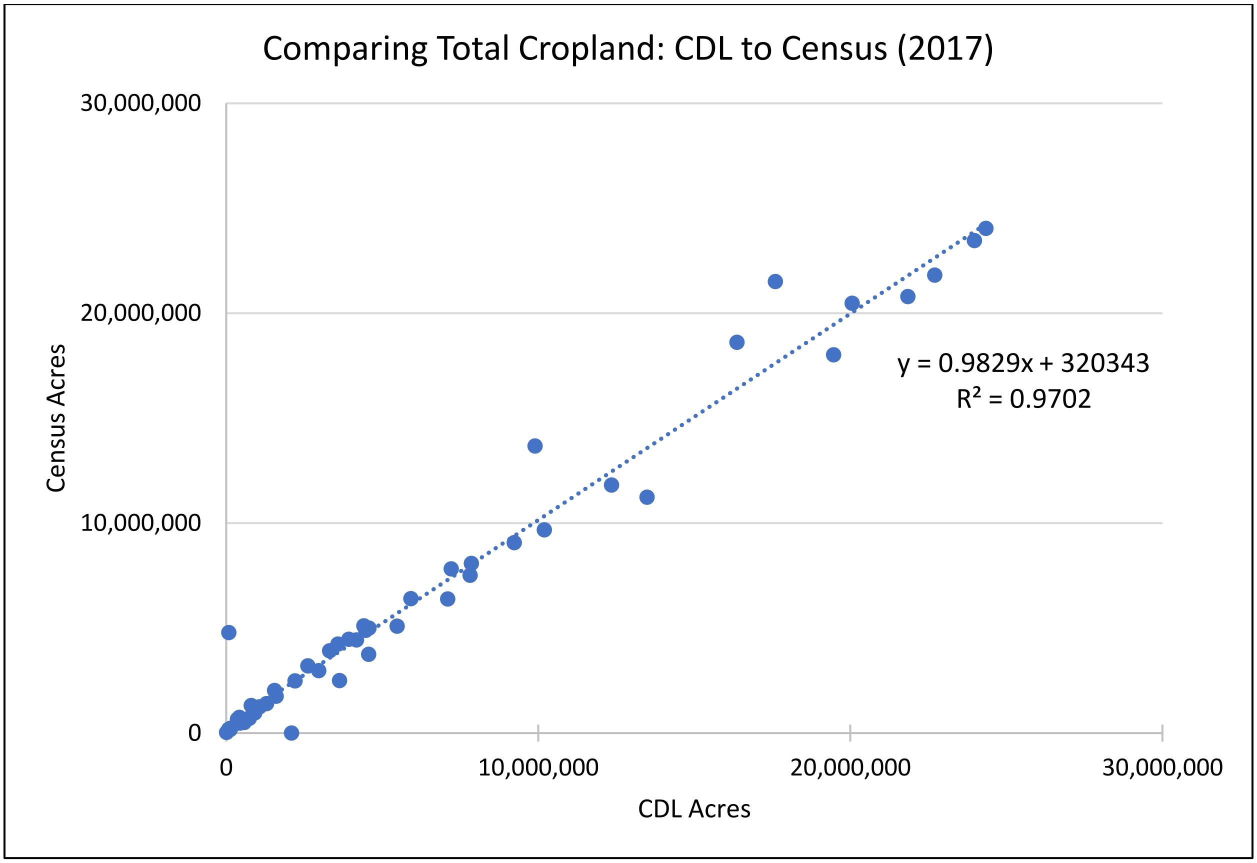



**Fig. 17**: Comparing Total Cropland Estimated by the 2015 NRI to the 2015 CDL.

- Strong relationships between total cropland by state for the CDL, NRI and Census in different years indicate that all three datasets perform a similar assessment of total cropland, but total cropland can vary by more than 10%.

Strong agreement between these three USDA datasets, all of which could measure changes in cropland in the United States, indicate they all appear to agree for the same year, which may also indicate they all accurately measure total cropland in a given year. The question remains as to whether they can measure year to year change or if the errors in each dataset are too great. One way to measure this would be comparing changes in cropland and land cover/use change estimated by each data set. Agreement would potentially indicate accuracy for each of the datasets.

A comparison of the 2007/2015 total cropland change estimated by the NRI to a 2007/2015 CDL net conversion to cropland estimate (conversion to crop minus reversion to other land cover/uses) did indicate a good relationship ($R^2 = 0.7613$) (Figure 18). Several states indicated declines in total cropland in the NRI but not in the CDL (which always had positive conversion in 2007) but the overall relationship is still good.

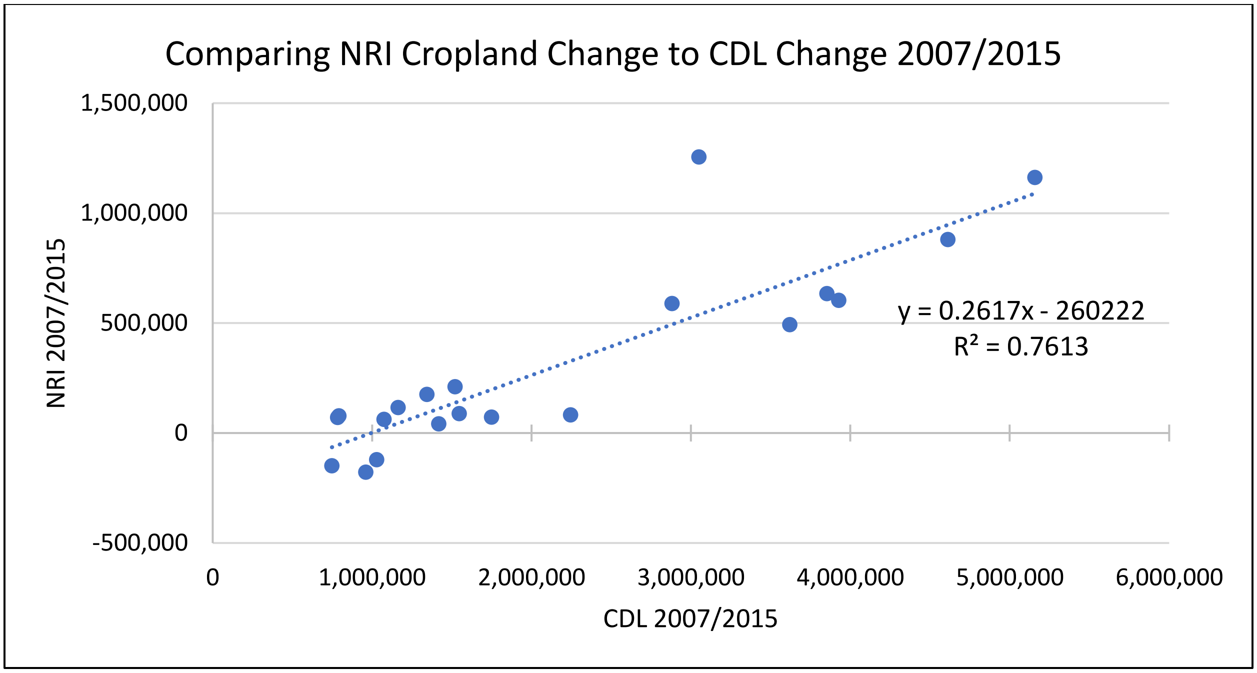



**Fig. 18**: Comparing NRI to CDL Change (2007 to 2015).

Likewise, a comparison was performed for cropland change estimated by a difference between cropland acres for the 2007 and 2012 NRI, and the spatial analysis to measure change between the 2007 and 2012 CDL datasets (for states available in the 2007 CDL) (Figure 19). The relationship between 2007 and 2012 NRI and CDLs was lower ($r^{2=}$=0.4053) than the 2007 to 2015 comparison. The NRI has 5 states where cropland is estimated to have declined while the CDL has cropland increasing in all states in the study. This could be one contribution. Also, the CDL estimated much higher cropland increases. For instance, Kansas has an increase of over 3.4 million acres in cropland according the CDL, but an increase of only 228,000 cropland acres according to the NRI. Removing Kansas from the equation improves the $r^2$ to 0.5922.

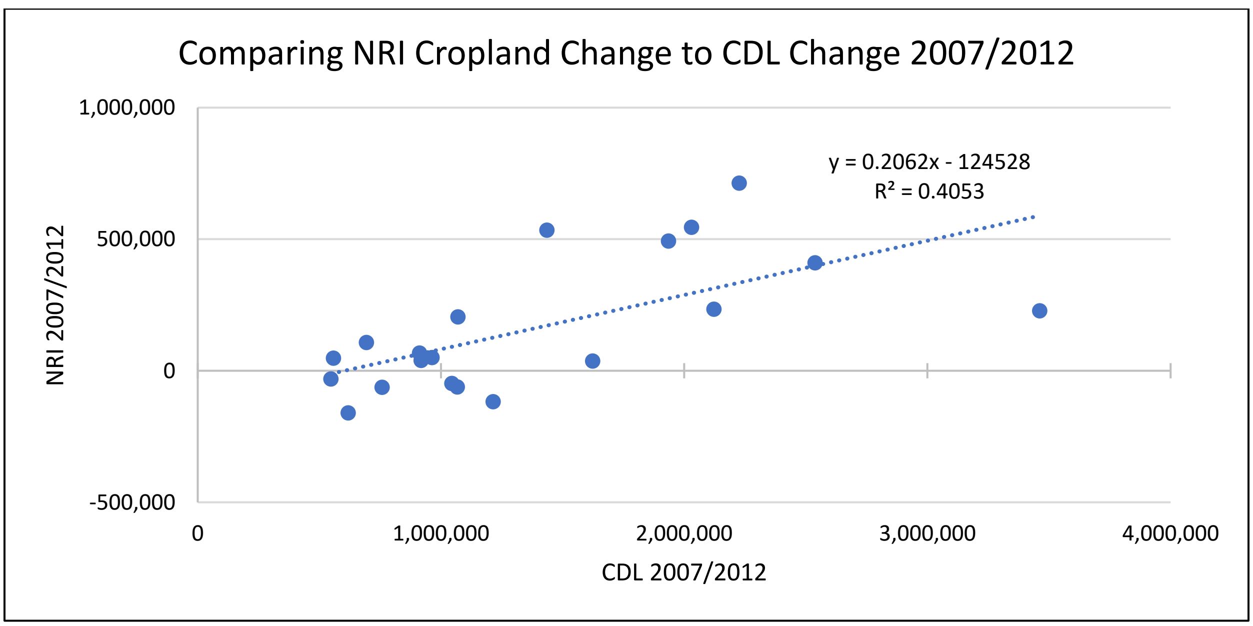



**Fig. 19**: Comparing NRI to CDL Change (2007 to 2012).

A comparison was also made between the two tabular datasets (selecting those states included in the CDL in 2007) to better understand similarities in their estimated changes in cropland (Figure 20) . The relationship appears less rigorous than those between the tabular datasets and the CDL with an $r^2$ of 0.1778. Similar to the CDL, the Census estimates increases in cropland for all states while the NRI, as previously stated, has some states declining in acreage from 2007 to 2012. The lower relationship, however, may come from the fact that sometimes, as with Kansas, the Census estimates almost 5 times as many acres being converted while in Missouri, the NRI estimates almost 4 times as many acres.

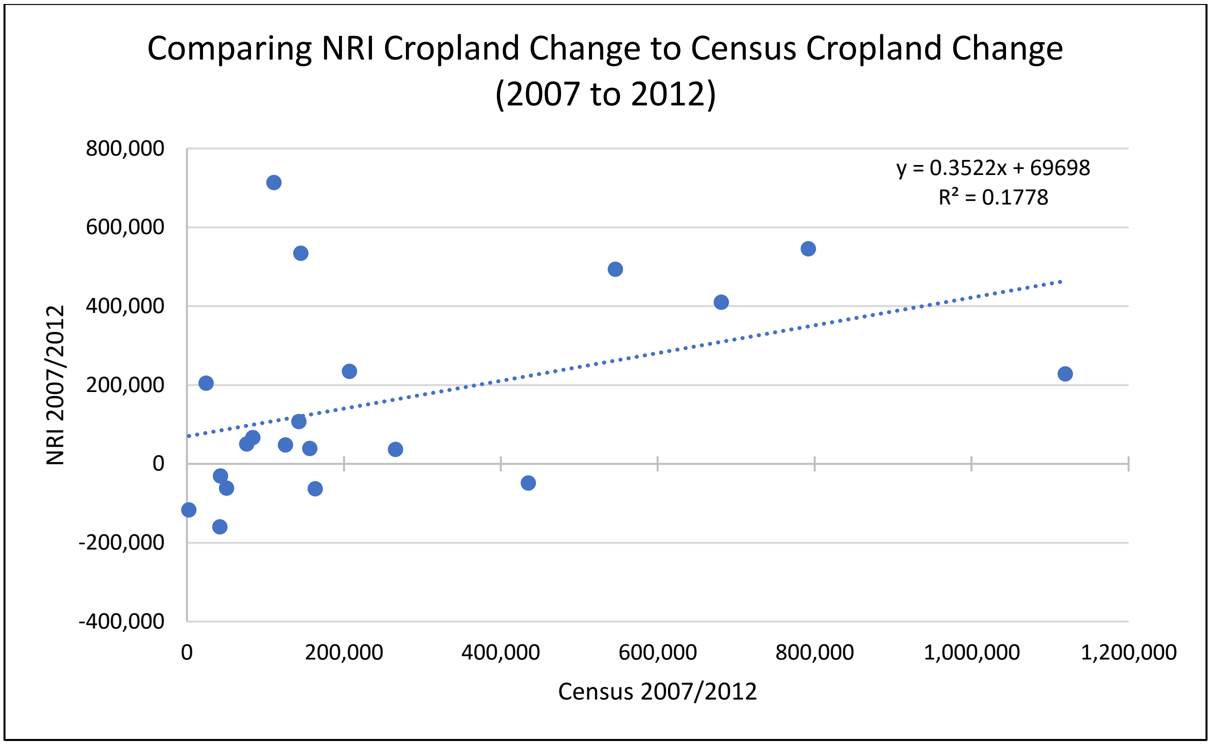



**Fig. 20**: Comparing NRI to Census Cropland Change (2007 to 2012).

Comparing the 2007/2012 CDL cropland change to the 2007/2012 Census change in cropland acres did result in a good relationship also ($R^2 = 0.5913$) (Figure 19). The comparison was between a change in Census cropland acres (no including cropland/pasture acres) and CDL net conversion (conversion to agriculture minus reversion to other land cover/uses).

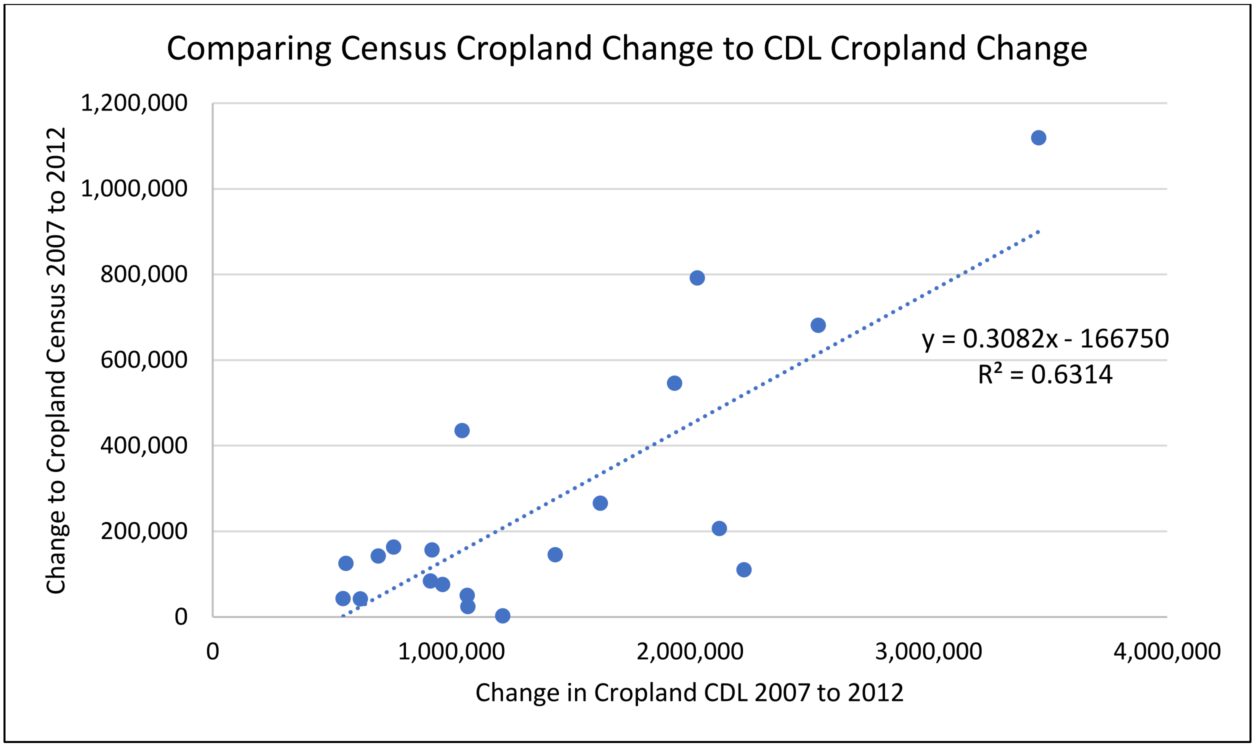



**Fig. 21**: Comparing Census to CDL Change (2007 to 2012).

Previous research by Lark et al. (2015) and others has used changes in the CDL between 2008 and 2012 to attempt to estimate conversions to cropland (Lark et al. 2015). To see how well, the 2008 to 2012 data might compare with the 2007 to 2012 Census, a correlation was performed between estimated conversion to cropland from the 2008 to 2012 CDL and changes to cropland estimated from the 2007 to the 2012 Census at the state level using the same methods from the year by year analysis above (Figure 20). The results showed a relationship did exist but not as strong as the annual comparisons ($R^2$ = .3869). The CDL consistently measured net conversion to cropland (increases in cropland) while the Census had some states that indicated a decline in cropland (net reversion).

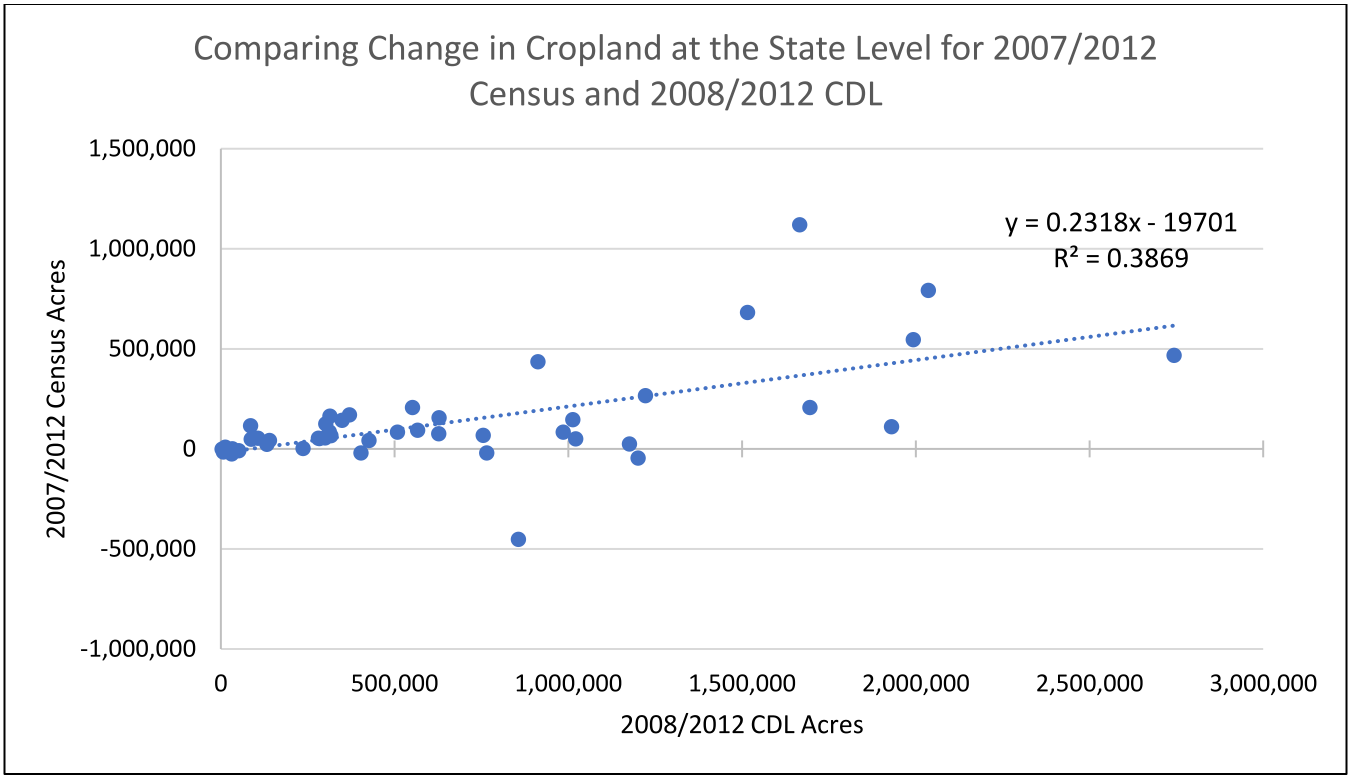



**Fig. 22**: Comparing Census to CDL Change (2007/2012 to 2008/2012).

Comparing a 2008/2015 CDL estimated net cropland conversion to a 2007/2015 NRI change in total cropland, unlike the Census, indicates a relationship does exist with an $R^2$ = 0.5016 despite the difference in the years (Figure 21).

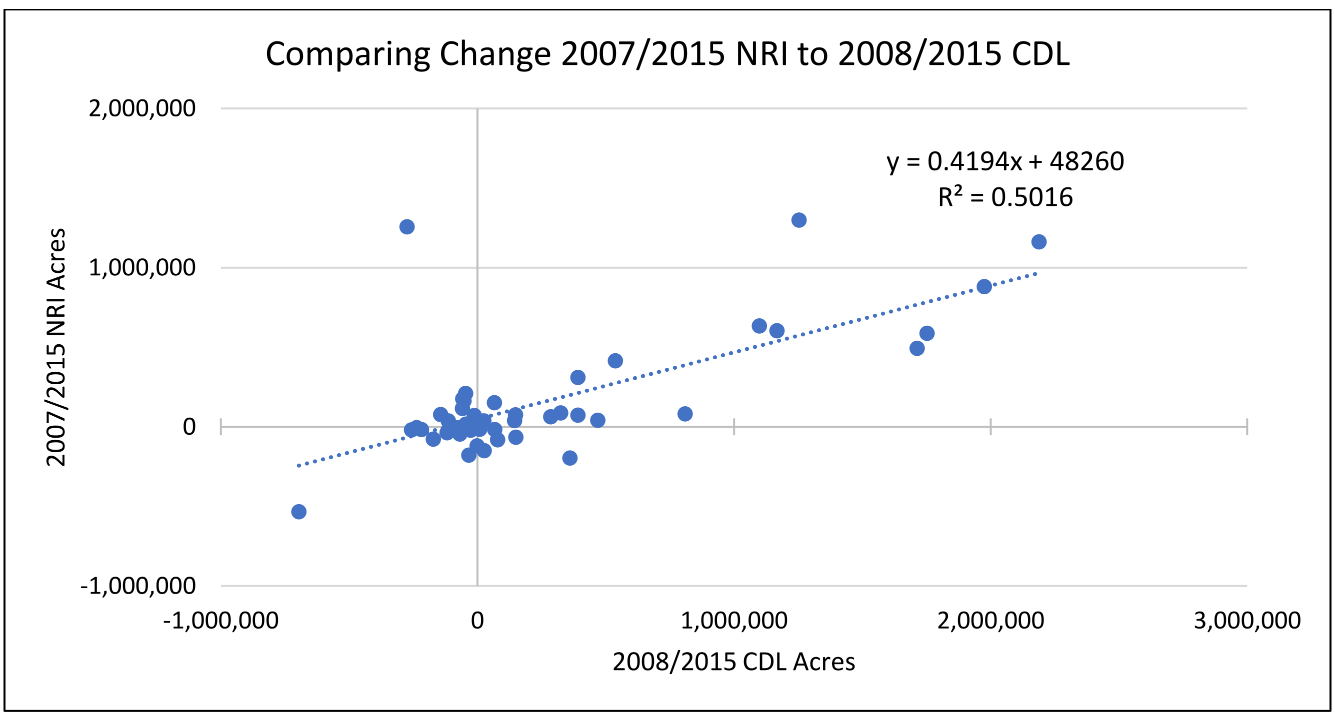



**Fig. 23**: Comparing NRI (2007 to 2015) to CDL Change (2008 to 2015).

The good relationships between the 2007/2015 NRI and 2007/2012 Census to the CDL estimated changes in cropland for the same years do show that the CDL does estimate change trends similar to the two tabular datasets but total change is much higher in the CDL (56+ million acres when performing a direct comparison between CDL crop acres in 2007 and CDL crop acres in 2012 without any steps to remove potential error compared to 7+ million for the Census and 3+ million for the NRI). This discrepancy is too large to ignore. As mentioned, Lark et al. (2015) and others have performed image processing techniques to lower these acreage change numbers, but it is unclear if these techniques just remove pixels or actually improve the accuracy of the estimation. Additional analysis will focus on testing these vetting methods and will focus on the 2007 to 2012 Census, NRI and CDL since these have a good relationship and closely match the years (2008/2012) used in the previous research. To better understand the effectiveness of these methods, each technique was replicated on the 2007/2012 CDL and then compared to the 2007/2012 Census and 2007/2012 NRI estimated cropland changes to see if the relationship between the datasets is improved.

In a first step, a 3x3 majority filter was applied to the CDL 2007/2012 dataset. This analysis is intended to remove single pixels and smaller pixel groupings by choosing the majority value in a 3x3 pixel window. A correlation analysis between the 2007/2012 Census and NRI with the 2007/2012 CDL was then performed (Figures 22 and 23). This did not improve the relationship, as a matter of fact, the relationship with the Census declined from an $R^2$ = 0.6885 to an $R^2$ = 0.6314, and the relationship between the CDL and NRI declined from 0.76 to 0.74.

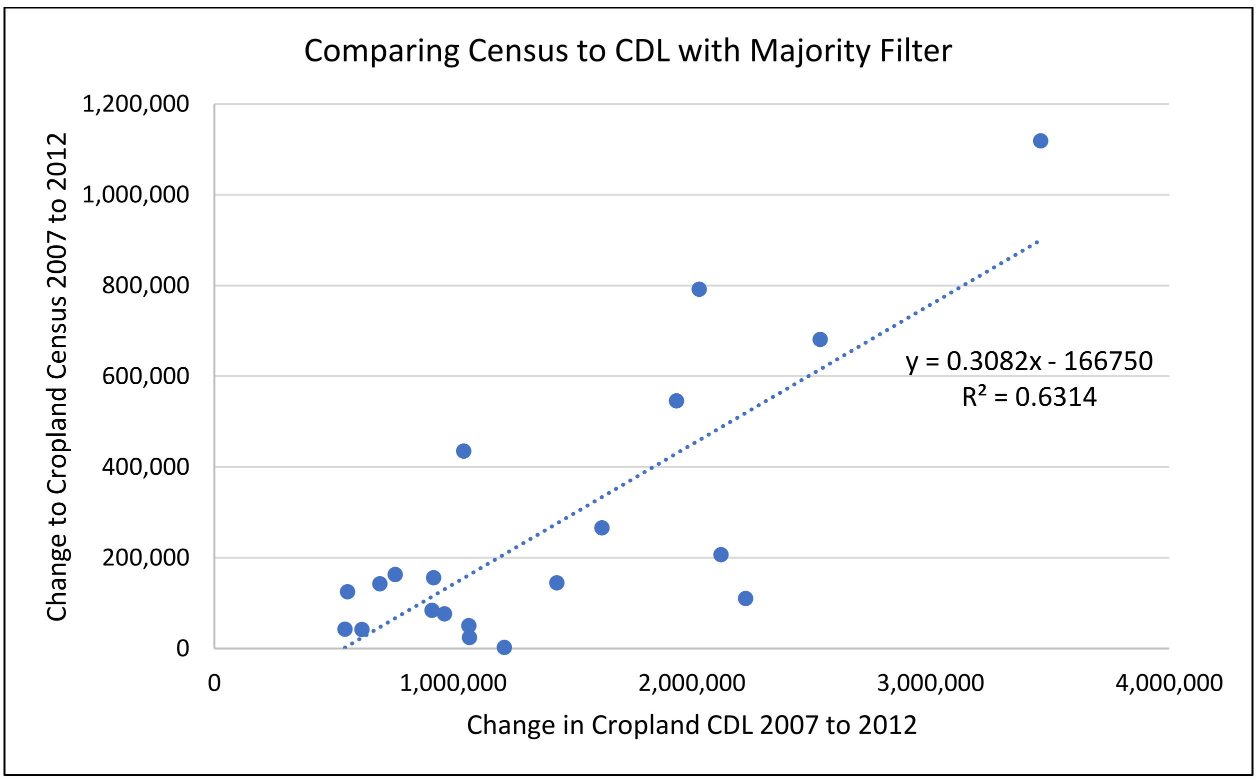



**Fig. 24**: Relationship between 2007/2012 CDL and 2007/2012 Census crop change after a majority filter was applied.

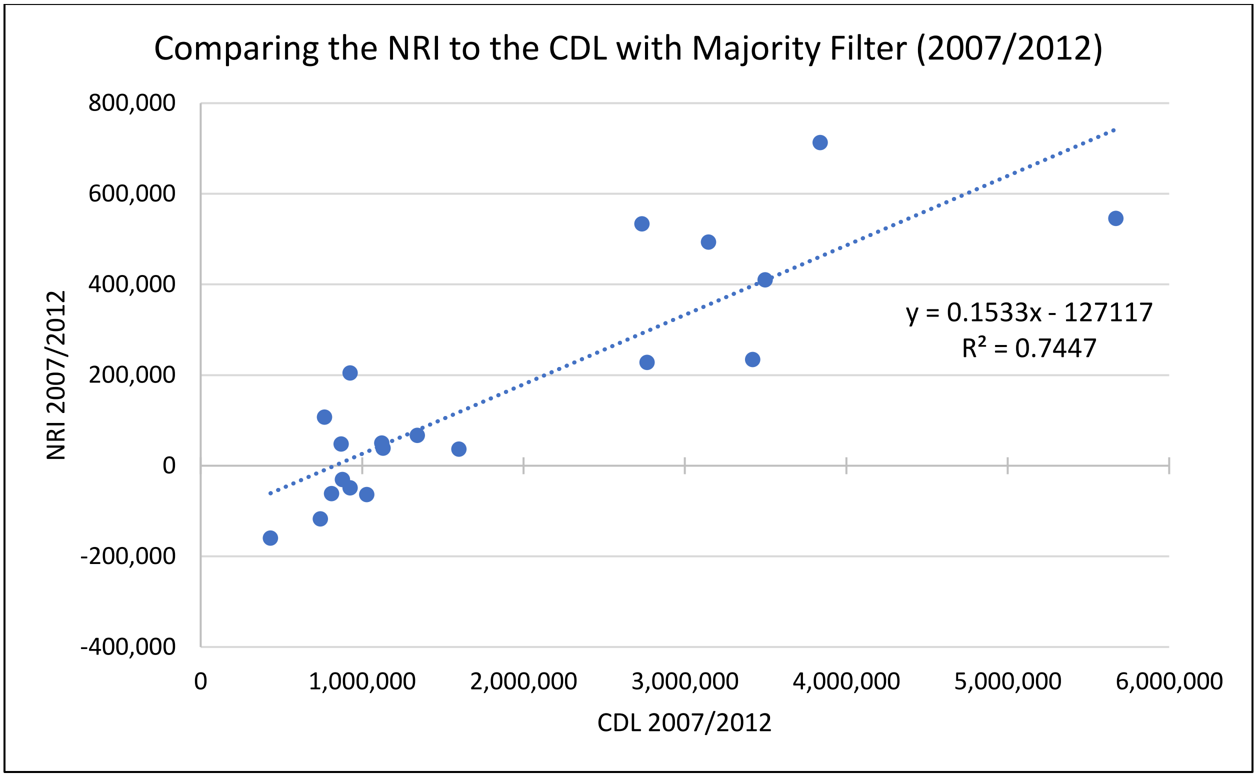



**Fig. 25**: Relationship between 2007/2012 CDL and 2007/2012 NRI crop change after a majority filter was applied.

- Applying a majority filter to the CDL did not improve a relationship with Census or NRI cropland change.

The next step, based on the Lark et al. (2015) methodology, was to remove clusters of the same land cover/use change that were less than 15 acres in size. This also was intended to remove noise in the dataset by removing smaller areas of estimated change that may represent areas within fields and not actual change. Here also, the $R^2$ did not improve, declining from 0.5727 to 0.3052 for the Census and from 0.7447 to 0.2498 with the NRI (Figures 24 and 25).

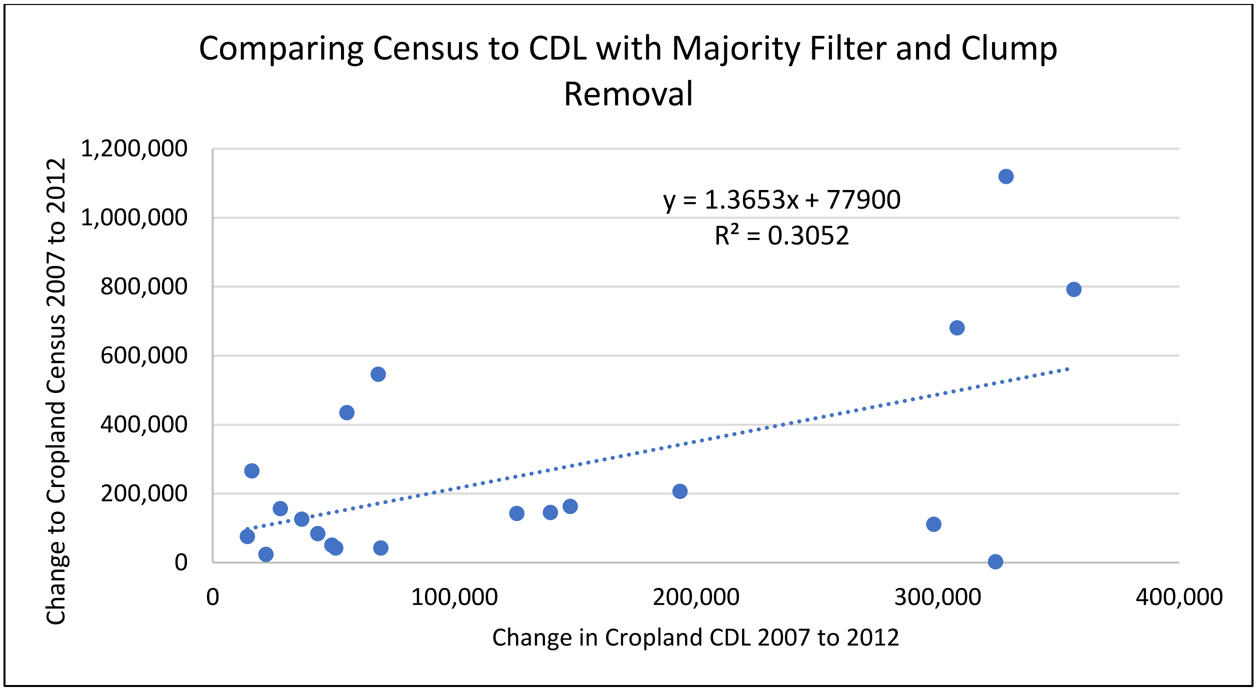



**Fig. 26**: Relationship between 2007/2012 CDL and 2007/2012 Census crop change after a majority filter was applied and clusters smaller than 15 acres were removed.

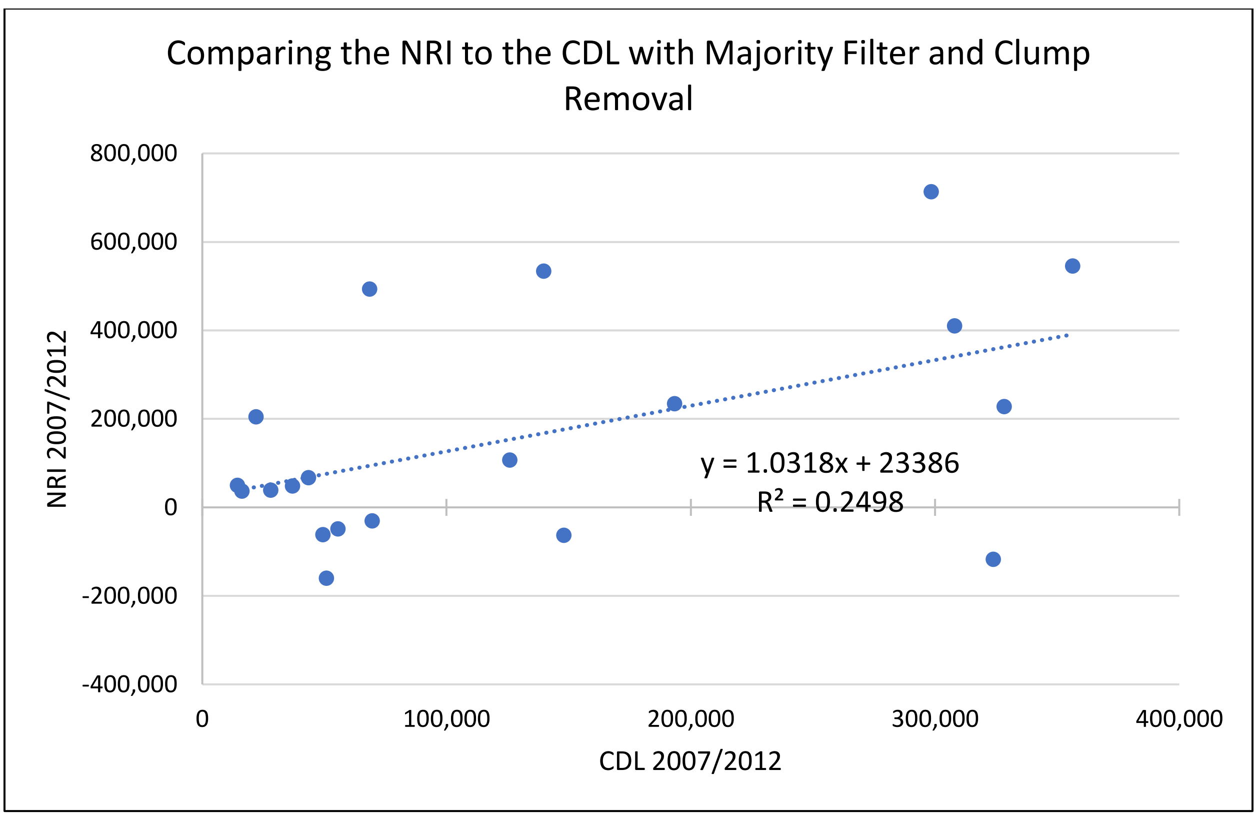



**Fig. 27**: Relationship between 2007/2012 CDL and 2007/2012 Census crop change after a majority filter was applied and clusters less than 15 acres were removed.

- Removing land cover/use change clusters smaller than 15 acres in size reduced the apparent relationship between change to cropland in the CDL and change in cropland in the Census and NRI.

Finally, the CDLs from 2008 thru 2011 were combined with the 2007 and 2012 CDL, and pixels which did not maintain a consistent trajectory (moved in and out of different land cover/use classes), were removed. Also, lands that were defined as cultivated cropland in the 2001 and 2006 National Land Cover Dataset (NLCD) were removed from 2007 non-agricultural classes to further ensure locations identified as non-agriculture in 2007 had not been in agriculture in 2001 or 2006. Despite these efforts, the relationship between the CDL values and the NRI remained well below the raw comparison ($R^2$ = 0.2823), and the relationship between the Census and CDL did not improve ($R^2$ = 0.3761) (Figures 26 and 27).

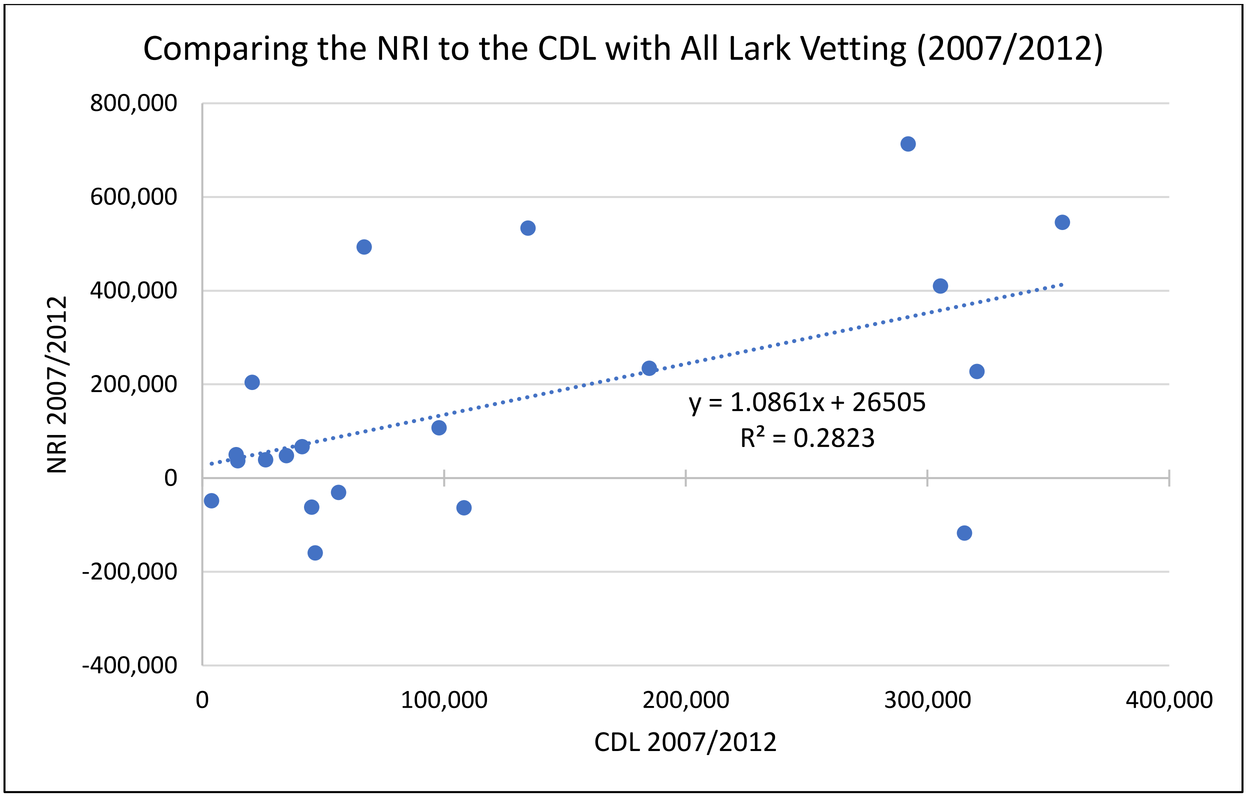



**Fig. 28**: Comparing the state-level NRI Changes in total cropland to state-level land cover/use changes in the CDL for 2007 to 2012 with multiple vetting methods applied to the CDL.

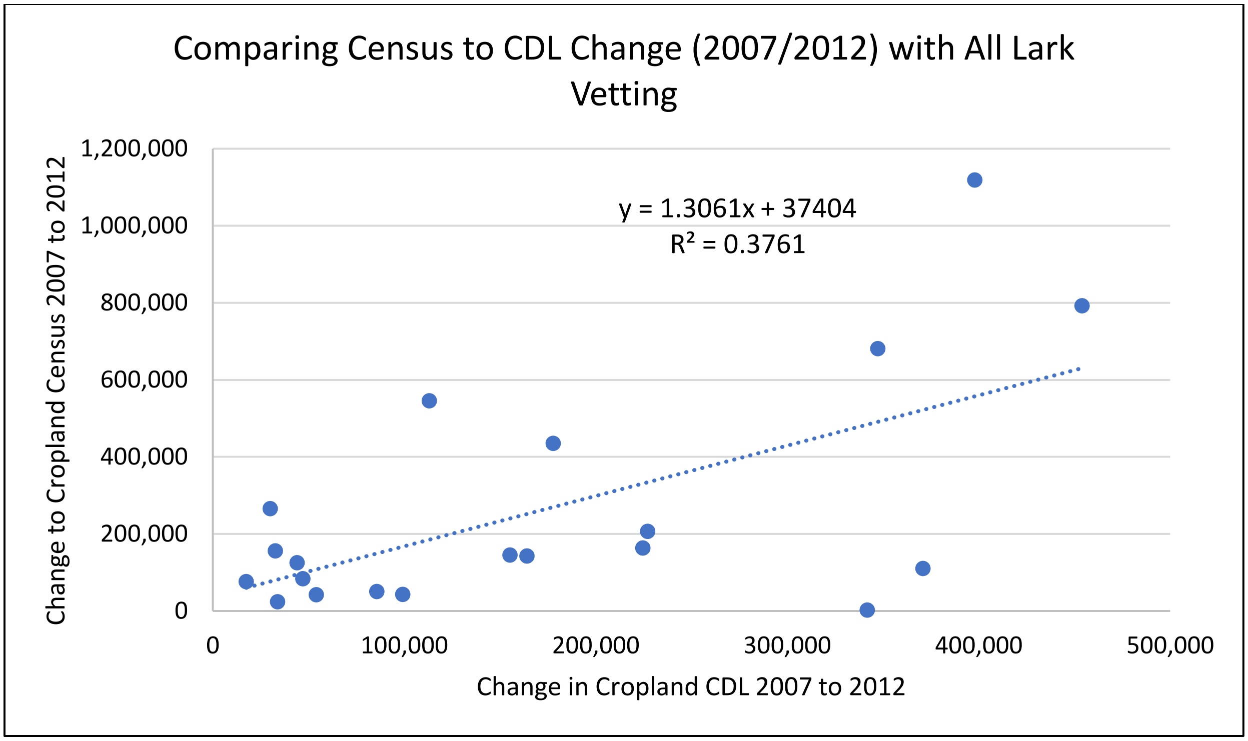



**Fig. 29**: Comparing the state-level Census Changes in total cropland to state-level land cover/use changes in the CDL for 2007 to 2012 with multiple vetting methods applied to the CDL.

- Removing transition classes and other land cover/uses that were crop in the 2001 or 2006 NLCD did not improve the relationship between change to cropland in the CDL and change in cropland in the Census and NRI.

## Conclusion

Comparing the USDA Census and NRI tabular datasets to the geospatial CDL at the state level for the same timeframes may offer some insights into the relationship and accuracy of each. If each shows similar trends, total acres and changes in acres, it would indicate that different datasets obtained using different methodologies are reporting similar results and offer verification to each. However, if different trends or different total changes are shown, there could be an indication of inconsistency in at least one of the datasets. In our analysis, there was a strong relationship between the NRI, the Census and the CDL when comparing total cropland during the same year although crop totals varied. There was also a good relationship between the different datasets when comparing change between 2007 and 2012 (the years for which the datasets were developed) except the CDL had much higher change acreage (10-fold). The relationship declined when moving the CDL up a year to 2008 in order to include more states that did not have a CDL layer in 2007. While vetting methods, such as those proposed by Lark et al. (2015), lower change acres for the CDL, the relationship between the CDL and the NRI and Census actually declined (Table 3). This, combined with the previous research we have provided on CDL accuracies, should provide a very strong caution for using the CDL data as a source for estimating changes in cropland.

| Vetting | Census Change | NRI Change | CDL Change | Census to CDL $R^2$ | NRI to CDL $R^2$ |
|---|---|---|---|---|---|
| **Raw** | 7,013,421 | 3,229,700 | 56,522,844 | 0.6314 | 0.7613 |
| **Majority** | 7,013,421 | 3,229,700 | 37,640,744 | 0.6314 | 0.7447 |
| **Majority and Clump** | 7,013,421 | 3,229,700 | 2,676,819 | 0.3052 | 0.2498 |
| **All Vetting** | 7,013,421 | 3,229,700 | 2,485,543 | 0.3761 | 0.2823 |

**Table 3**: CDL with each stage of vetting compared with NRI and Census.

## Section 3: National Demand Model Results

In response to the Energy Independence and Security Act (EISA) of 2007 EPA conducted extensive life cycle modeling runs to evaluate the future impact of biofuels use encouraged by the act including the effects on land use. EPA used two different models: the Forestry and Agriculture Sector Optimization Model (FASOM) which simulated changes in domestic crop prices in response to a biofuels policy, agricultural land-use and crop export volumes. FASOM then was coupled with the integrated Food and Agriculture Policy and Research Institute (FAPRI) model which assessed international land use change. FASOM and FAPRI are considered partial equilibrium models for the agricultural sector. During the same time the California Air Resources Board (CARB) was developing the Low Carbon Fuel Standard (LCFS). In its assessment of the land use impact from biofuels production CARB relied on Purdue's Global Trade Analysis Project (GTAP) model which is a general equilibrium model that was refined to cover biofuels in more detail. For corn ethanol both multi-year modeling exercises relied on forward projections of crop yields, ethanol plant efficiencies and distillers dried grains with solubles (DDGS) production and the products' feedback within the fuel, feed, land, and other market sectors. While economic models have the benefit of considering economic feedbacks the parameters that establish the economic linkages and substitution effects have also been shown to be subject to considerable uncertainties.[1,2]

In this section we employ a simplified, static model to assess the impact of crop yield and DDGS production on land demand. While the static model does not include economic feedbacks from, for example, increased DDGS production like GTAP or FASOM did back in 2008 we now have the benefit of documenting the actual, realized yield increases and DDGS production efficiencies and DDGS substitution effects in the market place.

Our spreadsheet-based model assesses the magnitude of land use pressure from increased corn demand for the observed increase in ethanol production volume from 2000 to 2018. The spreadsheet model considers the portion of corn that is diverted into ethanol production, and the demand offsets provided by substantial corn yield increases and the relatively high animal feeding value of DDGS. Due to the nexus between corn, soybeans and other principal crops competing for land area, land use for and the productivity trend in these crops were included in the analysis.

The following data were used for the analysis:

- U.S. harvested acreage and yields for corn, soybeans, wheat and hay (USDA 2019b).
- U.S. historic ethanol production (Renewable Fuels Association 2019).
- Average DDGS production efficiency of ethanol plants selected from the EPA-led cluster analysis.
- GREET DDGS Displacement Ratios (Wang et al. 2014) and published soybean processing yields of 79.2% for soybean meal, 17.8% for soybean oil and 3% for waste (Lusas 2004).

While the time horizon of this analysis was from 2000 to 2018, two base years for the analysis were used. The first base year was 2000 to capture total land use pressure from substantially all ethanol

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[1] Taheripour, Farzad et al. "The impact of considering land intensification and updated data on biofuels land use change and emissions estimates." Biotechnology for biofuels vol. 10 191. 20 Jul. 2017, doi:10.1186/s13068-017-0877-y

[2] Mueller, Steffen, Stefan Unnasch, Wallace E Tyner, Jennifer Pont, and Jane M-F Johnson. "Handling of co-products in life cycle analysis in an evolving co-product market: A case study with corn stover removal" Advances in applied agricultural science 3, no. 5 (2015): 8-2

production since the early days of the industry. The second base year was 2008 which is the relevant first year under the RFS' existing agricultural land definition[3]. The analysis was performed at the national level.

## Approach

The incremental gallons of ethanol produced and the mass of incremental DDGS produced relative to the base years were calculated for each subsequent year using the average ethanol and DDGS production efficiencies (or yields).

The gross corn acres needed to meet the incremental ethanol demand over the base years were then computed for each subsequent year. This was calculated by dividing the incremental gallons of ethanol produced by the national corn yield for the respective year. Tables 4 and 5 shows the results of the calculations. For example, 13.3 million gross acres of corn were needed in 2018 to produce the additional 6.8 million gallons of ethanol from the 2008 base year.

**Table 4**: Gross Acres for Ethanol Production for Base Year 2000.

| | | **Incremental Production over Base Year of 2000** | | |
|---|---|---|---|---|
| **Year** | **Annual Ethanol Production (MM gallons)** | **Ethanol (MM Gallons)** | **DDGS (Thou Tons)** | **Corn (Gross Thou Acres)** |
| 2000 | 1,622 | - | - | - |
| 2001 | 1,765 | 143 | 395 | 364 |
| 2002 | 2,140 | 518 | 1,430 | 1,409 |
| 2003 | 2,810 | 1,188 | 3,281 | 2,938 |
| 2004 | 3,404 | 1,782 | 4,921 | 3,909 |
| 2005 | 3,904 | 2,282 | 6,302 | 5,426 |
| 2006 | 4,884 | 3,262 | 9,008 | 7,694 |
| 2007 | 6,521 | 4,899 | 13,528 | 11,432 |
| 2008 | 9,309 | 7,687 | 21,227 | 17,634 |
| 2009 | 10,938 | 9,316 | 25,725 | 19,928 |
| 2010 | 13,298 | 11,676 | 32,242 | 26,908 |
| 2011 | 13,929 | 12,307 | 33,985 | 29,482 |
| 2012 | 13,218 | 11,596 | 32,021 | 33,127 |
| 2013 | 13,293 | 11,671 | 32,228 | 25,961 |
| 2014 | 14,313 | 12,691 | 35,045 | 26,100 |
| 2015 | 14,807 | 13,185 | 36,409 | 27,534 |
| 2016 | 15,413 | 13,791 | 38,082 | 27,777 |
| 2017 | 15,845 | 14,223 | 39,275 | 28,323 |
| 2018 | 16,100 | 14,478 | 39,980 | 28,460 |

[3] Subpart M. Renewable Fuel Standard Section 80.1401. Definitions. https://www.law.cornell.edu/cfr/text/40/80.1401. "Existing agricultural land is cropland, pastureland, and land enrolled in the Conservation Reserve Program (administered by the U.S. Department of Agriculture's Farm Service Agency) that was cleared or cultivated prior to December 19, 2007."

**Table 5**: Gross Acres for Ethanol Production for Base Year 2008.

| | | Incremental Production over Base Year of 2008 | | |
|---|---|---|---|---|
| **Year** | **Annual Ethanol Production (MM gallons)** | **Ethanol (MM Gallons)** | **DDGS (Thou Tons)** | **Corn (Gross Thou Acres)** |
| 2000 | 1,622 | - | - | - |
| 2001 | 1,765 | - | - | - |
| 2002 | 2,140 | - | - | - |
| 2003 | 2,810 | - | - | - |
| 2004 | 3,404 | - | - | - |
| 2005 | 3,904 | - | - | - |
| 2006 | 4,884 | - | - | - |
| 2007 | 6,521 | - | - | - |
| 2008 | 9,309 | - | - | - |
| 2009 | 10,938 | 1,629 | 4,498 | 3,485 |
| 2010 | 13,298 | 3,989 | 11,015 | 9,193 |
| 2011 | 13,929 | 4,620 | 12,758 | 11,068 |
| 2012 | 13,218 | 3,909 | 10,794 | 11,167 |
| 2013 | 13,293 | 3,984 | 11,001 | 8,862 |
| 2014 | 14,313 | 5,004 | 13,818 | 10,291 |
| 2015 | 14,807 | 5,498 | 15,182 | 11,482 |
| 2016 | 15,413 | 6,104 | 16,856 | 12,294 |
| 2017 | 15,845 | 6,536 | 18,049 | 13,015 |
| 2018 | 16,100 | 6,791 | 18,753 | 13,349 |

The mass of DDGS production was converted into total acres needed to produce equivalent amounts of livestock and poultry feed (at 2018 yields) and the results of these calculations are shown in Table 6. The resulting acreage that is offset by the incremental DDGS production from ethanol plants that started operating since the base year 2008 totals 6.75 million acres and the acreage offset for all plants that started operating since 2000 is 14.4 million acres.

**Table 6**: Acreage Offset from DDGS Production.

| | Base Year | |
|---|---|---|
| | **2000** | **2008** |
| DDGS Production (Thou Tons) | 39,980 | 18,753 |
| GREET DDGS Corn Displacement Rate | 0.763 | 0.763 |
| GREET DDGS Soy Meal Displacement Rate | 0.313 | 0.313 |
| DDGS Corn Equivalent - Area Harvested Credit (Thou Acres) | 6,090 | 2,856 |
| DDGS Soybean Equivalent - Area Harvested Credit (Thou Acres) | 8,309 | 3,898 |
| Total Credit from DDGS (Thou Acres) | 14,399 | 6,754 |

The 2018 corn yield was applied to each base year's corn acres and compared to the base year's actual corn production. The incremental bushels produced with the higher 2018 yields and the base years' corn acres represent corn production that would not necessarily create additional pressure on land use. The incremental bushels were then converted to corn acres spared at 2018's corn yield. For example, the 2018 acres yielded 2.0 billion bushels more (at 178.9 vs 153.3 bu/acre) which spared 11.2 million acres (Table 7). These corn acres are referred to as "spared acres." The land credit from the DDGS production and the land area spared from the corn yield increases were totaled for each year.

**Table 7**: Acreage Offset from Corn Yield Increase.

| | Year | | |
|---|---|---|---|
| | **2018** | **2000** | **2008** |
| Corn Harvested Acres (Thou) | 81,767 | 72,440 | 78,570 |
| Corn Yield (Bu/Ac) | 178.9 | 136.9 | 153.3 |
| Corn Production (Thou Bu) | 14,628,116 | 9,917,036 | 12,044,781 |
| Corn Production with 2018 Yields on Base Year Acreage Mask (Thou Bu) | | 12,959,516 | 14,056,173 |
| Corn Production on Base Year Acreage Mask from Increased Yields (Thou Bu) | | 3,042,480 | 2,011,392 |
| Land Area Spared from Corn Yield Increases (Thou Acres) | | 17,007 | 11,243 |

The 2018 soybean yield was also applied to each base year's soybean acres and compared to the base year's actual soybean production. The incremental bushels produced with the higher 2018 yields and the base years' soybean acres represent crop production that does not generate additional pressure on land use. The incremental bushels were then converted to soybean acres spared at 2018's soybean yield. Table 8 illustrates how the yield increase in soybean farming since the 2000 and 2008 base years produce significantly more soybeans today than in the past (3.9 billion bushels in 2018 as opposed to 3.0 billion bushels in the year 2008). Soybean acreage has also increased.

**Table 8**: Acreage Offset from Soybean Yield Increase.

| | **Year** | | |
|---|---|---|---|
| | **2018** | **2000** | **2008** |
| Soybean Harvested Acres (Thou) | 88,343 | 72,408 | 74,681 |
| Soybean Yield (Bu/Ac) | 52.1 | 38.1 | 39.7 |
| Soybean Production (Thou Bu) | 4,602,670 | 2,758,745 | 2,964,836 |
| Soybean Production with 2018 Yields on Base Year Acreage Mask (Thou Bu) | | 3,772,457 | 3,890,880 |
| Soybean Production on Base Year Acreage Mask from Increased Yields (Thou Bu) | | 1,013,712 | 926,044 |
| Land Area Spared from Soybean Yield Increases (Thou Acres) | | 19,457 | 17,774 |

## Results and Conclusion

Table 9 summarizes the national-level results. Our analysis shows that (without ethanol production) yield increases since 2000 would have reduced base year 2000 corn acres by 17 million acres and yield increases since 2008 would have reduced base year 2008 corn acres by 11.2 million acres. However, incremental ethanol production demanded a gross acreage of 28.5 million acres relative to the 2000 base year and 13.3 million acres relative to 2008 which is higher than the land spared from yield increases. But, taking the acreage offset from DDGS production into account of 14.4 million acres relative to base year 2000 and 6.8 million acres relative to base year 2008 results in net acres needed with ethanol production of 14 million (base year 2000) and 6.6 million (base year 2008) which would still result in an overall land area spared on base year corn acres: As pointed out above the yield increases without ethanol over the years would have reduced base year 2000 corn acres by 17 million acres. Now with ethanol the reductions would have still been 2.9 million acres. The yield increases without ethanol over the years would have reduced base year 2008 corn acres by 11.2 million acres and with ethanol the reductions would have still been 4.6 million acres. We conclude that based on the present model ethanol production would not be expected to increase the studied based years’ corn acreage totals.

**Table 9**: Summary of National-Level Results.

| | **Thousand Acres** | |
|---|---|---|
| **Base Year** | **2000** | **2008** |
| Land area spared from corn yield increases on Base Year corn acres (no ethanol production) | 17,007 | 11,243 |
| **Gross Acres for Ethanol Needed** | **28,460** | **13,349** |
| Land area spared from DDG production | 14,399 | 6,754 |
| Net Acres for Ethanol = Gross Acres for Ethanol Needed Minus Acres Spared from DDGS Production | 14,061 | 6,595 |
| Land area spared from corn yield increases on Base Year corn acres (with ethanol production) | 2,946 | 4,648 |

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## Appendix 1: National Resources Inventory (2015) Glossary of Selected Terms

*Terms in italics within a definition refer to terms defined elsewhere in this glossary.*

**Barren land.** A *land cover/use* category used to classify lands with limited capacity to support life and having less than 5 percent vegetative cover. Vegetation, if present, is widely spaced. Typically, the surface of barren land is sand, rock, exposed subsoil, or salt-affected soils. Subcategories include salt flats*; sand dunes; mud flats; beaches*; bare exposed rock; quarries, strip *mines*, gravel pits, and borrow pits; *riverwash*; oil wasteland; mixed barren lands; and other barren land.

**Beach.** A *barren land* subcategory. Includes the area adjacent to the shore of an ocean, sea, large river, or lake that is washed by the tide or waves.

**Built-up land.** See *urban and built-up areas*.

**Close-grown crops.** Crops that are generally drill-seeded or broadcast, such as wheat, oats, rice, barley, and flax.

**Conservation Reserve Program (CRP).** A Federal program established under the Food Security Act of 1985 to assist private landowners to convert highly erodible cropland to vegetative cover for 10 years.

**CRP continuous sign-up.** Continuous CRP was introduced in the 1996 Farm Bill. Eligible lands must be suitable to serve as one of a number of conservation practices, such as a wetland restoration, filterstrip, riparian buffer, or field windbreak. Landowners and operators with eligible lands may enroll the high priority conservation practices at any time during the year without competition. For NRI, land enrolled in the continuous CRP is included in its respective *land cover/use* (i.e.: cropland, grassland, forest, marsh, etc.).

**CRP general sign-up.** General CRP was introduced in the 1985 Farm Bill. Eligible lands must be highly erodible or in a State or National conservation priority area. Landowners and operators with eligible lands compete nationally for acceptance based on an environmental benefits index (EBI) during specified enrollment periods.

**CRP land use.** For NRI, only acres that have been enrolled in *CRP general sign-up* are included in the CRP *land cover/use* category. It does not include acres enrolled under *CRP continuous sign-ups*.

**Cropland.** A *Land cover/use* category that includes areas used for the production of adapted crops for harvest. Two subcategories of cropland are recognized: cultivated and noncultivated. Cultivated cropland comprises land in *row crops* or *close-grown crops* and also other cultivated cropland, for example, hayland or pastureland that is in a rotation with row or close-grown crops. Noncultivated cropland includes permanent *hayland* and *horticultural cropland*.

**Cropping history.** A record of the crop that was on the land during each of the 3 years preceding the current inventory year. These data are recorded on *cropland*, *pastureland,* and CRP land cover/uses only. Data are used to determine some of the values used to calculate water and wind erosion rates.

**Cultivated cropland.** See *cropland*.

**Developed land.** A combination of land cover/use categories, *large urban and built-up areas, small built-up areas*, and *rural transportation land*.

**Farmsteads and ranch headquarters.** A *land cover/use* category that includes dwellings, outbuildings, barns, pens, corrals and feedlots next to buildings, farmstead or feedlot windbreaks, and family gardens associated with operating farms and ranches. (Commercial feedlots, greenhouses, poultry facilities, overnight pastures for livestock, and field windbreaks are not considered part of farmsteads.)

**Federal land.** See *ownership*.

**Field.** A cultivated area of land that is marked out for a particular crop or cropping sequence.

**Forest land.** A *Land cover/use* category that is at least 10 percent stocked by single-stemmed woody species of any size that will be at least 4 meters (13 feet) tall at maturity. Also included is land bearing evidence of natural regeneration of tree cover (cut over forest or abandoned farmland) and not currently developed for non-forest use. Ten percent stocked, when viewed from a vertical direction, equates to an areal canopy cover of leaves and branches of 25 percent or greater. The minimum area for classification as forest land is 1 acre, and the area must be at least 100 feet wide.

**Hayland.** A subcategory of *cropland* managed for the production of forage crops that are machine harvested. The crop may be grasses, legumes, or a combination of both. Hayland also includes land in set-aside or other short-term agricultural programs.

**Horticultural cropland.** A subcategory of *cropland* used for growing fruit, nut, berry, vineyard, and other bush fruit and similar crops. Nurseries and other ornamental plantings are included.

**Lake.** A natural inland body of water, fresh or salt, extending over 40 acres or more and occupying a basin or hollow on the earth's surface, which may or may not have a current or single direction of flow.

**Land cover/use.** A term that includes categories of land cover and categories of land use. Land cover is the vegetation or other kind of material that covers the land surface. Land use is the purpose of human activity on the land; it is usually, but not always, related to land cover. The NRI uses the term land cover/use to identify categories that account for all the surface area of the United States.

**Large urban and built-up areas.** A *land cover/use* category composed of developed tracts of at least 10 acres—meeting the definition of *urban and built-up areas*.

**Margins of Error.** Margins of error are reported for each NRI estimate. The margin of error is used to construct the 95 percent confidence interval for the estimate. The lower bound of the interval is obtained by subtracting the margin of error from the estimate; the upper bound is obtained by adding the margin of error to the estimate. Confidence intervals can be created for various levels of significance which is a measure of how certain we are that the interval contains the true value we are estimating. A 95 percent confidence interval means that in repeated samples from the same population, 95 percent of the time the true underlying population parameter will be contained within the lower and upper bounds of the interval.

**Marshland.** A subcategory of the *land cover/use* category Other rural land, described as a non-forested area of land partly or intermittently covered with water and usually characterized by the presence of such monocotyledons as sedges and rushes. These areas are usually in a wetland class and are not placed in another NRI land cover/use category, such as *rangeland* or *pastureland*.

**Mines, quarries, and pits.** Uses of land for extraction of ores, minerals, and rock materials; a subcategory of the *land cover/use* category *barren land*.

**Mud flat.** A *land cover/use* subcategory under *barren land*. A mud area with less than 5 percent vegetative cover.

**Noncultivated cropland.** See *cropland*.

**Other rural land.** A *land cover/use* category that includes farmsteads and other farm structures, field windbreaks, *barren land*, and *marshland*.

**Ownership.** The separation of Federal and non-Federal lands and the distinction between administrative units of land. Water areas are not classified according to ownership. The six categories of ownership are:

> **Private.** A type of ownership pertaining to land belonging to an individual person or persons, a partnership, or a corporation (all of which are persons in the legal sense), as opposed to the public or the government; private property.
>
> **Municipal.** A type of ownership pertaining to land belonging to the local government of a town or city.
>
> **County** or **parish.** A type of ownership pertaining to land belonging to an administrative subdivision of a State in the United States, which is identified as a county or an equivalent administrative unit in areas where counties do not exist; examples are parishes in Louisiana and boroughs in Alaska.
>
> **State.** A type of ownership pertaining to land belonging to one of the States, commonwealths, or territories of the United States of America.
>
> **Federal land.** A land ownership category designating land that is owned by the Federal Government. It does not include, for example, trust lands administered by the Bureau of Indian Affairs or Tennessee Valley Authority (TVA) land. No data are collected for any year that land is in this ownership.
>
> **Indian tribal** and **individual Indian trust lands.** A type of ownership of land administered by officially constituted Indian tribal or individual Indian trust entities.

**Pastureland.** A *land cover/use* category of land managed primarily for the production of introduced forage plants for livestock grazing. Pastureland cover may consist of a single species in a pure stand, a grass mixture, or a grass-legume mixture. Management usually consists of cultural treatments: fertilization, weed control, reseeding or renovation, and control of grazing. For the NRI, includes land that has a vegetative cover of grasses, legumes, and/or forbs, regardless of whether or not it is being grazed by livestock.

**Prime farmland.** Land that has the best combination of physical and chemical characteristics for producing food, feed, forage, fiber, and oilseed crops and is also available for these uses.

**Railroads.** A category of *rural transportation* areas that includes all operational rail systems and their rights-of-way. Abandoned railroad beds are not included as railroad areas.

**Rangeland.** A *land cover/use* category on which the climax or potential plant cover is composed principally of native grasses, grasslike plants, forbs or shrubs suitable for grazing and browsing, and introduced forage species that are managed like rangeland. This would include areas where introduced hardy and persistent grasses, such as crested wheatgrass, are planted and such practices as deferred grazing, burning, chaining, and rotational grazing are used, with little or no chemicals or fertilizer being applied. Grasslands, savannas, many wetlands, some deserts, and tundra are considered to be rangeland. Certain communities of low forbs and shrubs, such as mesquite, chaparral, mountain shrub, and pinyon-juniper, are also included as rangeland.

**Remote sensing.** The science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation.

**Riverwash.** A subcategory of *barren land.* Barren alluvial areas, usually coarse-textured, exposed along streams at low water and subject to shifting during normal high water.

**Row crops.** A subset of the *land cover/use* category *cropland* (subcategory, cultivated) comprising land in row crops, such as corn, soybeans, peanuts, potatoes, sorghum, sugar beets, sunflowers, tobacco, vegetables, and cotton.

**Rural transportation land.** A *land cover/use* category which consists of all highways, roads, railroads and associated right-of-ways outside *urban and built-up areas*; also includes private roads to *farmsteads or ranch headquarters*, logging roads, and other private roads (field lanes are not included).

**Sand dunes.** A *land cover/use* subcategory under *barren land*. A sand area with less than 5 percent *vegetative cover*. An accumulation of loose sand heaped by the wind, commonly found along low-lying seashores above high-tide level, more rarely on the border of large lakes or river valleys, as well as in various desert regions, where there is abundant dry surface sand during some part of the year.

**Small built-up areas.** A *land cover/use* category consisting of developed land units of 0.25 to 10 acres, which meet the definition of *urban and built-up areas*.

**Stream.** A flow of water in a channel or bed, as a brook, rivulet, or small river.

**Urban and built-up areas.** A *land cover/use* category consisting of residential, industrial, commercial, and institutional land; construction sites; public administrative sites; railroad yards; cemeteries; airports; golf courses; sanitary landfills; sewage treatment plants; water control structures and spillways; other land used for such purposes; small parks (less than 10 acres) within urban and built-up areas; and highways, *railroads*, and other transportation facilities if they are surrounded by urban areas. Also included are tracts of less than 10 acres that do not meet the above definition but are completely surrounded by urban and built-up land. Two size categories are recognized in the NRI: areas of 0.25 acre to 10 acres, and areas of at least 10 acres.

**Water areas.** A *land cover/use* category comprising water bodies and streams that are permanent water.

## Appendix 2: CDL Class Changes to Represent Crop and Other Non-Crop Classes

| Original CDL Class Name | Recoded Name | Original CDL Class Name | Recoded Name | Original CDL Class Name | Recoded Name |
|---|---|---|---|---|---|
| Background | Blank | Tomatoes | Crop | Asparagus | Crop |
| Corn | Crop | Caneberries | Crop | Garlic | Crop |
| Cotton | Crop | Hops | Crop | Cantaloupes | Crop |
| Rice | Crop | Herbs | Crop | Prunes | Crop |
| Sorghum | Crop | Clover/Wildflowers | Other | Olives | Crop |
| Soybeans | Crop | Sod/Grass Seed | Crop | Oranges | Crop |
| Sunflower | Crop | Switchgrass | Crop | Honeydew Melons | Crop |
| Peanuts | Crop | Fallow/Idle Cropland | Fallow Cropland | Broccoli | Crop |
| Tobacco | Crop | Forest | Forest | Peppers | Crop |
| Sweet Corn | Crop | Shrubland | Other | Pomegranates | Crop |
| Popcorn Corn | Crop | Barren | Other | Nectarines | Crop |
| Mint | Crop | Cherries | Crop | Greens | Crop |
| Barley | Crop | Peaches | Crop | Plums | Crop |
| Durum Wheat | Crop | Apples | Crop | Strawberries | Crop |
| Spring Wheat | Crop | Grapes | Crop | Squash | Crop |
| Winter Wheat | Crop | Christmas Trees | Crop | Apricots | Crop |
| Other Small Grains | Crop | Other Tree Crops | Crop | Vetch | Crop |
| Dbl Crop WinWht/Soybeans | Crop | Citrus | Crop | Dbl Crop WinWht/Corn | Crop |
| Rye | Crop | Pecans | Crop | Dbl Crop Oats/Corn | Crop |
| Oats | Crop | Almonds | Crop | Lettuce | Crop |
| Millet | Crop | Walnuts | Crop | Pumpkins | Crop |
| Speltz | Crop | Pears | Crop | Dbl Crop Lettuce/Durum Wht | Crop |
| Canola | Crop | Clouds/No Data | Blank | Dbl Crop Lettuce/Cantaloupe | Crop |
| Flaxseed | Crop | Developed | Other | Dbl Crop Lettuce/Cotton | Crop |
| Safflower | Crop | Water | Other | Dbl Crop Lettuce/Barley | Crop |
| Rape Seed | Crop | Wetlands | Other | Dbl Crop Durum Wht/Sorghum | Crop |
| Mustard | Crop | Nonag/Undefined | Other | Dbl Crop Barley/Sorghum | Crop |
| Alfalfa | Crop | Aquaculture | Other | Dbl Crop WinWht/Sorghum | Crop |
| Other Hay/Non Alfalfa | Crop | Perennial Ice/Snow | Other | Dbl Crop Barley/Corn | Crop |
| Camelina | Crop | Developed/Open Space | Other | Dbl Crop WinWht/Cotton | Crop |
| Buckwheat | Crop | Developed/Low Intensity | Other | Dbl Crop Soybeans/Cotton | Crop |
| Sugarbeets | Crop | Developed/Med Intensity | Other | Dbl Crop Soybeans/Oats | Crop |
| Dry Beans | Crop | Developed/High Intensity | Other | Dbl Crop Corn/Soybeans | Crop |
| Potatoes | Crop | Barren | Other | Blueberries | Crop |
| Other Crops | Crop | Deciduous Forest | Forest | Cabbage | Crop |
| Sugarcane | Crop | Evergreen Forest | Forest | Cauliflower | Crop |
| Sweet Potatoes | Crop | Mixed Forest | Forest | Celery | Crop |
| Misc Vegs & Fruits | Crop | Shrubland | Other | Radishes | Crop |
| Watermelons | Crop | Grass/Pasture | Grassland | Turnips | Crop |
| Onions | Crop | Woody Wetlands | Other | Eggplants | Crop |
| Cucumbers | Crop | Herbaceous Wetlands | Other | Gourds | Crop |
| Chick Peas | Crop | Pistachios | Crop | Cranberries | Crop |
| Lentils | Crop | Triticale | Crop | Dbl Crop Barley/Soybeans | Crop |
| Peas | Crop | Carrots | Crop | | |