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The Role of Remote Sensing in Monitoring Biofuel Feedstock and Land Use Changes

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WINROCK INTERNATIONAL

Winrock International aims to support the development of effective policies and voluntary standards for biofuels by increasing the evidence base and knowledge transfer for indirect land use change.

This paper assesses the potential to use Remote Sensing (RS) technologies and products to identify land use changes (direct and indirect) relating to the increased production of biofuel crops. Specifically the technical work is intended to assess indicators of LUC at different spatial scales for use within a monitoring framework (Winrock, forthcoming) and better define drivers and trends of LUC in different hotspots to contribute to better understanding of the biofuels and LUC discussion more broadly.

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1. EXECUTIVE SUMMARY

Agricultural lands dedicated to bioenergy crops are expanding globally, driven in large part by the belief that replacing petroleum-based fuels with biofuel will reduce greenhouse gas (GHG) emissions and will thereby reduce the detrimental effects of climate change. However, recent studies have shown that as the demand for bioenergy crops increases, subsequent land use changes could result in CO_2 emissions that greatly outweigh any GHG reduction benefits resulting from the substitution of traditional fuels with biofuels. Therefore, these land use changes must be monitored so that the full GHG and other environmental impacts of biofuel expansion can be evaluated.

The land use change (LUC) associated with biofuel expansion may occur directly (on the land converted to the biofuel crop) (dLUC) or indirectly (iLUC) as a result of the displacement of production activity through market effects. Research has turned increasingly to the use of spatially explicit remote sensing (RS) data to enable the identification of land cover types and land cover changes for land-use monitoring. While it is unlikely that remote sensing methods will be used to monitor iLUC on a global scale anytime in the near future, these methods are useful on a national or sub-national scale for monitoring simultaneous land cover changes in multiple locations. For example, if it can be shown that wheat crops are being replaced by corn crops due to demand for corn ethanol in one area (dLUC), and simultaneously (or within a short time-frame) in another areas grasslands are converted to wheat crops (iLUC), this evidence could be an indication of iLUC resulting from the increased demand for corn bioethanol.

The work summarized here forms part of a project that will identify a draft framework for monitoring biofuel sustainability. This paper explores technical issues associated with monitoring land use to help inform the development of the framework. Specifically the technical work is intended to assess indicators of LUC at different spatial scales for use within a monitoring framework and better define drivers and trends of LUC in different hotspots to contribute to better understanding of the biofuels and LUC discussion more broadly. The first part of this study assesses current literature related to biofuel driven dLUC and iLUC, the land cover classifications important for the monitoring of LUC from biofuels, and general methods and data sources that could be used for identifying the land cover and LUC. The second part performs an analysis on the state of North Dakota using the US National Agricultural Statistics Service Cropland Data Layer (NASS CDL) dataset to assess if and how it can be used for monitoring land use change associated with biofuels.

Global scale remote sensing research on monitoring LUC from biofuels has provided some important insight, but has generally concluded that the data and technology are currently insufficient. Research suggests that a multi-scale approach would be better for understanding the relationship between biofuels and LUC, using coarse-scale imagery to map hotspots where further in-depth remote sensing analysis could be conducted to accurately map direct and indirect land use change.

Recent concern about indirect land use change has been substantial and some believe that the increasing biofuel targets within the United States (US) will drive undesirable land use changes in the US and overseas. The biofuel industry in the US is well established for corn-based ethanol and soy-based biofuel and is now the largest producer of fuel ethanol in the world. As a substantial producer of biofuel and with publically available technical resources upon which to undertake analysis, we selected the US as a case study to assess the ability of available remote sensing data to enable monitoring of land use changes associated with biofuels (dLUC and iLUC). We focused our analysis on the state of North Dakota because this state experienced one of the largest increases in soy and corn crops over the past decade (2000-2010) and contains a mixed landscape of forests, native grasslands, rangelands, pastures and agricultural cropland that would likely interact and change as increased demand pushes the expansion of cropland. The US Cropland Data Layer provides information about both the location and distribution of crops over time and thus enabled an analysis of land cover change. By analyzing the changing distribution of croplands and other land cover types, we quantified the increase in biofuel crops types, identified the locations into which these crops expanded, and assessed whether the expansion had any effect on the distribution of other crop types.

Overall, the results showed that between 2002 and 2009, the net area of agricultural croplands in North Dakota increased by 6%, covering 41% of the state in 2002 and increasing to 47% of the state in 2009. Developed and forest/shrub lands also increased, with the net area of developed and barren land increasing from 2% to 6% of the state and forest /shrub land from 1% to 3% of the state. The net expansion of croplands was due overwhelmingly to the two crop types relevant for biofuels: corn and soy. However, this expansion occurred mainly through the replacement of other crop types (such as wheat); there was very little direct replacement of non-cropland land cover types (such as grassland) by corn or soy. Rather, corn and soy largely replaced other crop types, most notably wheat, during the time period analyzed. This did not result in the expansion of wheat into new areas; wheat production simply declined with respect to the total area planted. However, other crops such as barley, oats, peas, beans, hay, beets, and potatoes did appear to expand into and replace grassland/fallow land cover types. This ‘knock-on’ effect could provide indications that corn and soy have resulted in iLUC within North Dakota.

While it could be concluded that biofuels have driven land use change in North Dakota either directly through converting wheat to corn or indirectly through the displacement of other crops into other areas of the state, there are several other factors that complicate the issue and cause this conclusion to be much more uncertain. Wet weather and disease associated with crops, particularly wheat, have contributed to land use changes since the early 2000s as well as technological changes such as the availability of genetically modified soybeans and corn. A better net income for farmers switching to corn and soybeans as a result of the technological advances have contributed to the move away from wheat in which many fewer technological advances have been made. Land-based oil shale mining has increased significantly over recent years in North Dakota and is located in the region with the highest loss of grassland and could displace or replace crops. This could be considered an indirect impact of fossil fuels.

Based on the results from this case study, it is clear that the CDL can identify relatively detailed changes in land use on an annual basis and identify dLUC. Although there are correlations in the data that suggest potential iLUC, this issue warrants further ground-based investigation. The biggest limitation in using the CDL for monitoring land use change related to biofuels is its relatively poor classification of non-cropland land cover types and the inconsistencies in the classification before 2006. The ability to better classify grassland condition would be a significant improvement towards better monitoring as such broad categories limit the ability to conduct appropriate monitoring of land use change associated with biofuels. The most appropriate technique for identifying grassland condition for different countries or areas will need to be independently assessed and will be influenced by the climate, vegetation structure and availability of ground data.

2. INTRODUCTION

The aim of this study is to assess the potential to use Remote Sensing (RS) technologies and products to identify land use changes (direct and indirect) relating to the increased production of biofuel crops. The study assesses the strengths and weaknesses of the options available related to data availability, collection and analysis.

The study forms part of a project entitled ‘Developing a draft framework for monitoring biofuel sustainability’. It is intended to explore technical issues associated with monitoring land use to help inform the development of the framework. Specifically the technical work is intended to assess indicators of LUC at different spatial scales for use within a monitoring framework and better define drivers and trends of LUC in different hotspots to contribute to better understanding of the biofuels and LUC discussion more broadly.

This report focuses on the US and hotspots within North Dakota. Follow-up work is intended to address similar monitoring issues in regions of Indonesia and Brazil. **Section 3** explores the use of RS technology to monitor land use changes related to biofuel production. First, the topic of biofuel production in general is discussed as it relates to the three largest biofuel producing countries: USA, Brazil, and Indonesia. **Section 4** focuses more specifically on the state of North Dakota, USA, as a case study for assessing the utility of the US National Agricultural Statistics Service Cropland Data Layer (NASS CDL) dataset to provide information on how land use changes (LUC) in general, and indirect land use change (iLUC) associated with biofuels in particular, may be assessed or monitored. **Section 5** discusses the findings of the case study within the context of broader factors for land use change in North Dakota and conclusions and recommendations for further work are identified in **Section 6**.

3. OVERVIEW OF REMOTE SENSING (RS) APPLICATIONS FOR MONITORING LAND USE CHANGE

3.1 Background: What needs to be monitored and how can RS help?

Agricultural lands dedicated to bioenergy crops are expanding globally (Searchinger et al. 2008; Campbell et al. 2008). This expansion has been driven in large part by the belief that replacing petroleum-based fuels with biofuel will reduce greenhouse gas (GHG) emissions and will thereby reduce the detrimental effects of climate change. However, recent studies have shown that as the demand for bioenergy crops increases, subsequent land use changes could result in CO_2 emissions that greatly outweigh any GHG reduction benefits resulting from the substitution of traditional fuels with biofuels (Campbell et al. 2008; Searchinger et al. 2008). Therefore, these land use changes must be monitored so that the full GHG and other environmental impacts of biofuel expansion can be evaluated.

Emissions from land use change result when high biomass environments, such as forests, shrublands, or grasslands are converted to biofuel croplands that contain less biomass. Other environmental and social problems could also result from biofuel expansion such as the loss of biodiversity, increased erosion, water pollution, and increasing food costs that would affect food-insecure peoples worldwide (Naylor et al. 2007; Searchinger et al. 2008; Johansson & Azar 2007). However, the impacts of land use change are not always negative; the expansion of biofuels into degraded lands with low standing biomass could result in net sequestration of carbon from the atmosphere as well as a net GHG benefit from the replacement of fossil fuel with biofuel. If managed appropriately, the expansion of biofuels could provide sustainable agricultural development opportunities on otherwise unproductive land (Panichelli & Gnansounou 2008; Campbell et al. 2008).

The land use change (LUC) associated with biofuel expansion may occur directly (on the land converted to the biofuel crop) (dLUC) or indirectly (iLUC) as a result of the displacement of production activity through market effects (Tipper & Viergever 2009; Panichelli & Gnansounou 2008), (**also see box at left**). While dLUC can generally be monitored and has been addressed by bioenergy policy in Europe (CEC, 2009), iLUC is more difficult to monitor and has no clear policy protections (Tipper & Viergever 2009). Due to this discrepancy the European Commission and the US Environmental Protection Agency have independently commissioned research on the effects of iLUC (Tipper & Viergever 2009) and how to monitor them. Most of this research employs general equilibrium or trade simulation models such as GTAP[1] and FAPRI[2] (Panichelli & Gnansounou 2008). The results of these modeling exercises have sometimes been used with statistical information on land use changes to estimate GHG impacts (Edwards et al. 2010) and sometimes with spatially explicit information to estimate GHG impacts of land use changes (EPA 2010). Location-specific information is critical for identifying which specific ecosystems are being transformed directly and/or indirectly (and for estimating associated GHG fluxes and water impacts more precisely); providing locations where LUC can be verified or where assessments and interventions can be performed; and providing information on the potentially sustainable (low biomass, degraded environment) versus unsustainable (high biomass, native or diverse environment) expansion of biofuels (Tipper & Viergever 2009). Critical issues such as water availability are not adequately addressed without spatially explicit approaches.

Direct and Indirect Land Use Change

Indirect land use change is best understood as the “trickle down” effect that takes place when market forces create incentives for producers to convert land from one use to another. For example, if the market causes production to shift in one location from a food crop to a biofuel feedstock, land elsewhere will be converted to the original food crop to maintain supply. The conversion of land from food crop to biofuel feedstock is a direct land use change (dLUC). The conversion of land elsewhere to the food crop to fill the supply gap is an indirect land use change (iLUC). Biofuel policies use the term “land use change effect” (LUC) to refer to the sum of direct and indirect land use impacts of biofuel production.

Owing to the limitations of non-spatial biofuel land use change models, research has turned increasingly to the use of spatially explicit RS data to enable the identification of land cover types and land cover changes for land-use monitoring. Some of this research (e.g., Gao et al. 2010, Gibbs et al. 2010) has focused at the global scale while other research has focused at the regional scale e.g., Shao et al. (2009) in the USA, Rudorff et al. (2010) in Brazil and Tipper & Viergever (2009) in Argentina.

Remote sensing technology such as airborne (aerial) photographs and space-borne imagery collected from radar and satellite-based sensors can identify some types of land cover and thus the extent (area) and location of a given land cover type can be monitored. Because the imagery is georeferenced, it provides spatially-explicit information, including where the change occurred, what changes took place, and what the magnitudes of these changes were. When images collected at different points in time are compared, direct land cover changes can also be assessed. However, iLUC is a global, market-driven phenomenon that is, by definition, not directly observable. A direct

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[1]GTAP: Global Trade Analysis Project https://www.gtap.agecon.purdue.edu/.
[2]FAPRI: Food and Agriculture Policy Research Institute http://www.fapri.iastate.edu/.

change in land use in one location may result in an indirect change elsewhere, and this indirect change can occur in the next field or across the world. **It is not possible using remote sensing imagery to assign causation to the global changes observed**; remote sensing methods cannot separate LUC (e.g., grassland conversion for biofuel crops) from iLUC (e.g., grassland conversion for food crops as a result of displacement of food crops elsewhere by biofuel crops). In general, remote sensing cannot monitor biofuels specifically. What RS imagery can provide is information about where and what **land cover** types existed at a given time, rather than detecting whether a given land cover type (e.g. agricultural land) was produced for food, fuel or other purposes. Therefore, to attempt to derive **land use**, any RS analysis needs to be supplemented with statistical or empirical on the ground data.

Land Cover vs Land Use

Land cover and land use are significantly different terms that are important in a discussion of monitoring. Land cover refers to the physical appearance of the land (e.g. cropland or forest) and land use refers to the human interaction (e.g. agriculture or managed forest). Whereas remote sensing allows land cover to be mapped, land use is primarily reported through statistical information (e.g. agricultural surveys).

While it is unlikely that remote sensing methods will be used to monitor iLUC on a global scale anytime in the near future, these methods are useful on a national or sub-national scale for monitoring simultaneous land cover changes in multiple locations, which could provide insight to iLUC. (Gao et al. 2011). For example, if it can be shown that wheat crops are being replaced by corn crops due to demand for corn ethanol in one area (dLUC), and simultaneously (or within a short time-frame) in another areas grasslands are converted to wheat crops (iLUC), this evidence could be an indication of iLUC resulting from the increased demand for corn bioethanol.

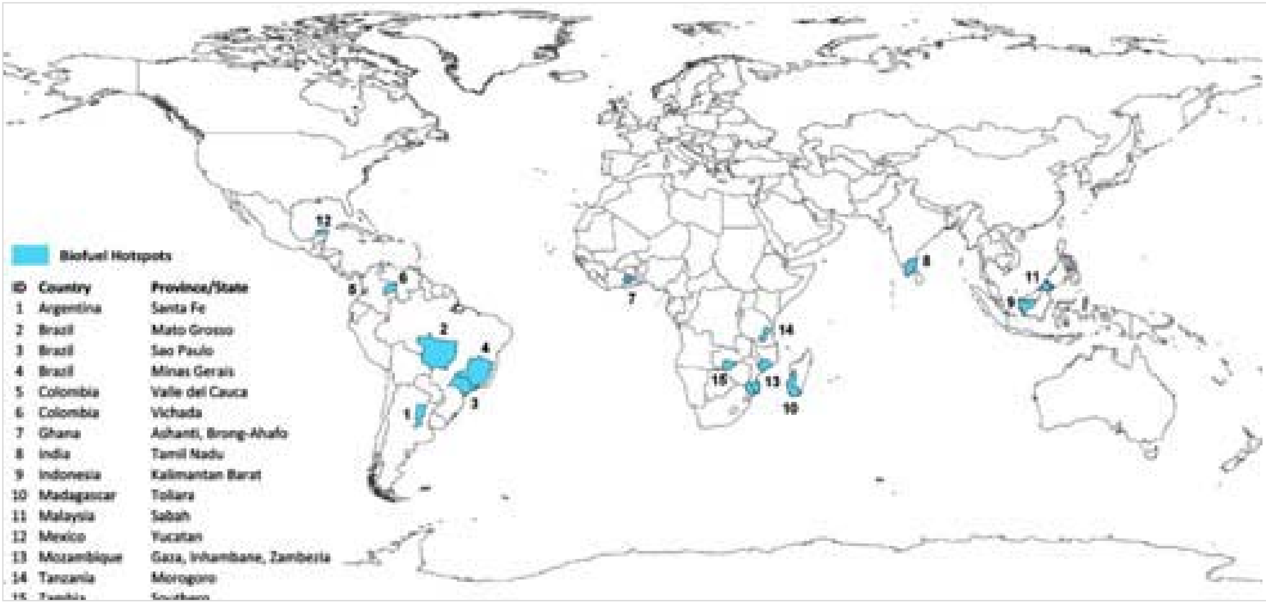
3.2 What research has been done using RS technology to monitor biofuel-related LUC?

Global scale RS research on monitoring LUC from biofuels has provided some important information, but has generally concluded that the data and technology are currently insufficient (Gao et al. 2011; Pittman et al. 2010). Gao et al. (2011) found that to monitor deforestation and biofuel production at a global level is “extremely difficult if not virtually impossible” due to reasons relating to data availability, data characteristics, and the way biofuels are produced. In essence, the scale (resolution) of global datasets is too coarse to accurately monitor land use change from biofuels, and the nature of biofuel crops as food, fodder or biofuel is too complex to untangle and associate with these datasets. Another report on global RS datasets by You et al. (2008) found the estimation of global croplands lacking, and that the **regions with the most severe errors were Latin America and Sub-Saharan Africa**. They also state that areas reported as croplands in the global datasets are primarily highly managed intensive agriculture and pastures, while rotational agriculture or extensive pastures are difficult to distinguish from natural grasslands and therefore are not identified.

Research by Gao et al. (2010) suggests that a multi-scale approach would be better for understanding the relationship between biofuels and LUC. The research goes on to use coarse-scale MODIS land cover data for Latin America, Africa and Asia along with biofuel production data to map hotspots where further in-depth RS analysis should be conducted (**Figure 1**). The results illustrate large potential hotspot areas where more detailed analysis is warranted in Brazil[3], parts of southern Africa and India as well as Indonesia.

[3]Note that there are some potentially surprising conclusions – Sao Paulo is identified as a deforestation hotspot but does not now contain large areas of intact forest.

Figure 1: Gao et al. 2010 Map of Potential Deforestation Hotspots from Biofuel Crop Expansion.



Due to the difficulties associated with monitoring at a global scale, monitoring land use changes with RS at a national or sub-national scale may result in higher accuracy. Some datasets, such as the US Cropland Data Layer, have recently been produced that map croplands and rangelands[4] at a national scale with accuracies of around 90%, but none have been produced for the sole purpose of biofuel monitoring. At the sub-national scale, we know of three published RS studies that have addressed the issue of monitoring land use change due to biofuel production, and only one of these studies addresses the issue of indirect land use change.

The first of these regional studies is by Shao et al. (2009), who attempt to map different crop types in the Great Lakes Basin of the USA (an area of 480,000km²). The justification for their study is that timely and reliable information about crop distribution is key for assessing biofuel impacts. However, they do not attempt to monitor land use change. The important aspect of this paper for the purposes of assessing the capabilities of remote sensing for biofuels monitoring is their use of coarse scale MODIS[5] 250m resolution 16-day NDVI[6] imagery to map the region's crops with a reported accuracy of 84%. This is important because such coarse scale data require fewer resources to produce maps for a given area than would the same analysis using data at finer resolutions. Their methodology includes the use of intra-annual time series data to track the cycle of crop rotations associated with

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[4]Rangelands are generally agricultural grazing land. They can be distinguished from pastures lands as pasture lands represent more intensively managed land, and rangelands are predominantly extensively managed lands.
[5]Moderate Resolution Imaging Spectroradiometer, an instrument onboard the Terra and Aqua satellites operated by the US National Aeronautics and Space Administration (NASA).
[6]NDVI Normalized Difference Vegetation Index is a ratio of the red and infrared spectrum (bands) that is commonly used to identify green live vegetation. In RS it isa simple numerical indicator that can be used to analyze remote sensing measurements and assess whether the target being observed contains live green vegetation or not.

different crop types (**see box at right**). To do this, Shao et al. (2008) used specific qualitative and quantitative data on a given year's crop cycles (green-up[7] date, harvest date, etc.) and associated these variables with MODIS NDVI data for that same date. Their analysis justifies further investigation into MODIS 16-day NDVI data for monitoring land use changes associated with biofuels. However, this study did not provide information on the potential for MODIS NDVI data to monitor non-cropland land cover types such as pasture and grasslands, and the potential for successful replication of this analysis in other regions (e.g., tropical areas) is unknown (You et al. 2008).

2008 MODIS NDVI Temporal Profile for Corn, Soy, Hay and Wheat

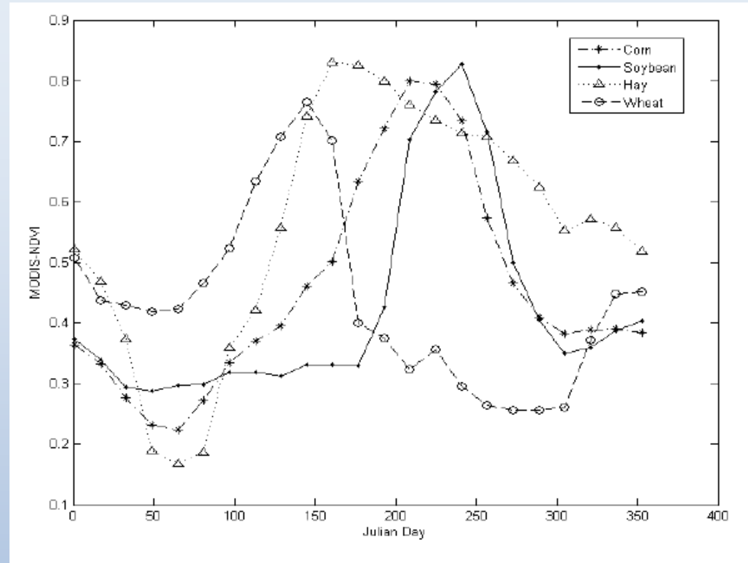

Figure from Shao et al. 2008 MODIS NDVI temporal profile for corn, soy, hay and wheat. This graph shows how NDVI varies throughout the year for select crops. Satellite imagery from only 1 or 2 points in time make the separation of different crops and grassland difficult. However with multiple images throughout the year different crops exhibit distinct temporal profiles that make classification possible.

A second regional-scale study by Rudorff et al. (2010) used higher resolution Landsat[8] imagery (30m) to map and monitor the expansion of sugarcane crops as a result of biofuel expansion between 2003 and 2008 in the state of Sao Paulo, Brazil. In 2003, flex-fuel cars started to enter the Brazilian market and caused an increased demand for sugarcane bioethanol. This demand was largely responsible for the expansion of sugarcane from 2.57 million ha in 2003 to 4.45 million ha in 2008. Between 2006 and 2008 alone, the cultivation of sugarcane in new areas (dLUC) reached 1.55 million ha with 57% of that expansion taking place on pasture land and 40% on other agricultural crops. Other land cover types (citrus, forest or natural vegetation and reforestation) accounted for around 3% of the newly converted area. The study uses inter-annual time series Landsat imagery along with other ancillary data, crop rotation dates for the years of study, and detailed crop statistics to estimate the amount of sugarcane used for food or fuel. Rudorff et al. (2010) conclude that Landsat imagery is highly suitable for mapping and evaluating the expansion of sugarcane, and therefore for monitoring dLUC change from biofuel crops. The report stops short of 1) estimating the actual GHG fluxes associated with these land use changes and 2) addressing iLUC, i.e., whether the 40% of land converted from other crops to sugarcane had been 'pushed' elsewhere in the region.

The third regional-scale study is by Tipper & Viergever (2009), who also used Landsat imagery to map a variety of important land cover classes, predominantly "soy," (assumed to be used for biofuel), non-biofuel crops "peanuts" and "other crops," and non-cropland land cover "grasslands" and "woodlands" across 2.1 million ha of Argentina. In this part of Argentina, the main RS technical

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[7]A period of time when crops are growing to maturity.

[8]The Landsat program is the longest running enterprise for acquisition of Earth imagery from space. It is operated by US government organizations.

challenge was to distinguish between crop types and grassland because these vegetation classes are spectrally very similar. This technical challenge was overcome (as in the other studies mentioned above) by analyzing inter-annual changes in spectral signatures associated with individual crop rotations. Further classification identified high biomass grassland from low biomass grassland. The maps achieved 68% to 70% accuracy. The study then associated biomass and carbon values with each land cover type, which made it possible to estimate GHG emissions due to land use change. The study also mapped other important crop types like peanuts in an attempt to monitor iLUC. The results of the analysis were that between 2002/03 and 2008/09, the conversion of grasslands to croplands resulted in 4.7 million t CO_2, of which 3.7 million t CO_2 were attributed to dLUC and the other 1 million t CO_2 were attributed to iLUC. The study is touted as more accurate and cost-effective than economic models, with a spatial dimension that the economic models cannot achieve. However, only a small portion of Argentina was analyzed and the real challenge for the accurate monitoring of land use change from biofuels will be the mobilization of these types of methods at much larger scales.

In conclusion:

- There is relatively little research into the potential for RS to monitor land use changes specifically, and iLUC in particular, associated with biofuels.
- Economic modeling has not been tied to sufficiently detailed modeling of land use and land cover to generate GHG emission forecasts.
- Currently, the most useful RS imagery for classifying and monitoring biofuel -related LUC is moderate resolution (30-60m) imagery at national to sub-national scales. However, coarser resolution (>60m) data have the potential to deliver some useful information and further investigation into MODIS 16-day NDVI data for monitoring land use should be conducted.
- Basic monitoring of biofuel land use change will require accurate and timely (yearly to every few years) mapping of specific biofuel crops, pastoral rangelands, natural grasslands, forests and other land cover types including developed lands, exposed ground, water, etc.
- Technical challenges exist in distinguishing between some land cover types such as different cropland types and grassland, but in many areas of the world these challenges can be mitigated by analyzing inter-annual changes in spectral signatures associated with individual crop rotations.

3.3 How can RS be used to map and monitor different crop types important for biofuels?

The ability to monitor biofuel dLUC and iLUC depends upon the ability of RS to accurately and consistently map the major biofuel crops and the land cover types into which biofuel crops and other displaced crop types will expand. To do this, three important steps must be followed:

a. Define the land cover classes necessary for monitoring biofuel LUC.

b. Select the appropriate RS data source.

c. Develop methodology for interpreting the RS data to produce land cover maps of acceptable accuracy (e.g. >80%) within a relatively short time frame (annually to bi-annually).

a. Define the appropriate land cover classes for biofuel LUC monitoring

Before any RS analysis begins, a thorough assessment is needed of the objective to be achieved and of the relevant land cover types to be defined. **Table 1** provides an overview of the land 'types' discussed in studies and events related to sustainable biofuel production.

Table 1: Land cover classes that have been deemed relevant in the biofuels LUC assessment.

Land 'Type'	Why Relevant?	Comment
1. Cropland	Must identify changes in the extent of cropland compared to other categories. The mapping of specific crop types could prove very valuable for assessing iLUC. Other crops that should be monitored would be those that are 1) major crop types for the region of interest and 2) that are likely to interact with biofuel expansion.	Cropland as a general category is present even in coarse scale (e.g., 1-km) RS products. However, accurate mapping of individual crop types is challenging and often requires the assessment of multiple intra and inter-annual images. The basis for a biofuel LUC RS assessment will be the mapping of individual biofuel crops vs. other croplands. It is likely that the mapping of other key crop types that would interact with biofuel crop expansion will be important. While the mapping of all crop types could prove valuable for many different purposes, the effort is substantial and may not be necessary for monitoring impacts of biofuels.
2. Grassland/ rangeland	Grasslands may be affected by cropland expansion. Identification of high vs. low biomass grasslands would prove important for understanding LUC emissions and sustainability of biofuel expansion issues. This includes degraded rangelands (*see #4*).	A broad category often defined in RS products. For iLUC will likely be important that further sub-division is required e.g. native grassland vs. pasture lands and high biomass grasslands vs. low biomass grasslands. The accurate mapping of different grassland/rangeland environments, (e.g. degraded to lush) is one of the most difficult challenges in RS.
3. Forested land	Encroachment of biofuel crops into forest land can cause substantial GHG emissions. Harvest of biomass residues from forested land can avoid iLUC.	This land cover type is well established in RS products and is often broken down into specific categories (i.e. forest types). However, challenges exist in determining different forest types or plantation forest vs. native forest when using coarse scale imagery.
4. Degraded land	Promoted as land that should be used for bioenergy to avoid iLUC.	Not a specific land classification in RS products, but some characteristics can be mapped with varying degrees of accuracy (e.g. recently deforested, exposed ground/ % vegetation cover). There is no agreed definition of degraded land within biofuel sustainability discussions.
5. Idle cropland	This category is missing from many current modeling estimates of iLUC and has often been identified as grassland. It is usually the 'buffer' capacity before cropland expansion onto native vegetation becomes relevant.	Not a specific land classification in RS products but some characteristics can me mapped- e.g. land that is consistently changing between rangeland/ grassland and cropland.
6. Marginal land	Promoted as land that should be used for bioenergy to avoid iLUC.	Not a specific land classification in RS products but some characteristics can me mapped e.g. exposed ground/ % vegetation cover, moderate and steep slope, frequently flooded agricultural areas. There is no

	Land 'Type'	Why Relevant?	Comment
			agreed definition of marginal land within biofuel sustainability discussions.
7.	**Managed and unmanaged pastures**	Crop expansion into managed or unmanaged pastures will have different impacts on carbon stocks, biodiversity, GHG emissions (fertilizer), and water resources.	RS **cannot** identify causation. RS **can** identify managed or unmanaged if these land cover types have some unique spectral information. For example RS can map irrigated fields (managed) vs. non-irrigated (unmanaged) with a good degree of accuracy as one is often very green and the other is senescent and brown.
8.	**Unmanaged vegetation**	*See #7 above*	*See #7 above*
9.	**Managed vegetation ("semi-natural"): Extensively managed forest or non-forest lands**	*See #7 above*	RS **cannot** identify causation. RS **can** identify extensive or intensive if these land cover types have some unique spectral information. For example RS can identify with varying degrees of accuracy changes in grassland as they go from lush to degraded, often associated with intensive vs. extensive as they often go from 100% green cover to 75, 50 and 25% green vegetation cover. Other RS data such as Lidar and Radar may prove useful in assisting in these land cover types.
10.	**Managed vegetation ("semi-natural"): Intensively managed semi-natural forest and non-forest lands**	*See #7 above*	*See #9 above*
11.	**Vegetation comprising native species, exotic species, and short-rotation woody crops**	Lignocellulosic crops such as perennial grasses and short rotation woody crops are expected to play an increasing part in the future of the biofuel industry.	As stated in #7 and #9, a unique spectral characteristic identifying native or exotic would need to be identified. Being able to identify changes from natural through semi-natural to intensively managed land enables qualitative (sometimes quantitative) assessments of impacts

Our ability to map developed areas, exposed ground, forests, grasslands and generic croplands using RS is well established. Some types of imagery are routinely classified at regular intervals using the same methodology to provide maps with such classifications. Products such as the MODIS Global Land Cover Type Yearly maps are generated for individual years (2001-2009) by interpreting imagery collected at regular (16-day) intervals throughout the year at 500-m and 1-km spatial resolution (1 pixel on the map = 25 or 100 ha, respectively). Other imagery, such as that collected by Landsat and SPOT[9] sensors, has much higher spatial resolution (~30-m resolution, or 0.1 ha pixels), but one image covers a much smaller area and thus the volume of data that must be captured, stored and processed for national- and global-scale applications is significant. Substantial challenges remain with respect to how the raw data – i.e., the signal transmitted by the satellite sensor – should

[9]Satellite pour l'Observation de la Terre, a French-operated high resolution imaging satellite system developed and funded by Centre National d'Etudes Spatiales (CNES).

be interpreted into detailed land classification schemes that are meaningful for the analysis under consideration. In the case of generating classification schemes for biofuels monitoring, the separation of a general ‘cropland’ category into specific crop types (e.g., corn, soy, wheat, etc.) is challenging due to the fact that many crops have very similar spectral signatures during certain periods of the year, while at other points of the year the crops have been harvested and are impossible to identify using RS data alone. To solve that challenge, many researchers have relied on multiple intra-annual datasets, correlated with different crop types and their planting and harvest times.

Possibly one of the most difficult land use transitions to distinguish using RS technology is the transition of different types of grasslands, such as fallow, pasture or unmanaged natural grasslands, that vary from high to low biomass and native to introduced. Grasslands are hard to distinguish because, like agricultural crops, they often have a very similar spectral signature, but they don’t have a defined rotational cycle like crops do (Pittman et al. 2010). This is especially important for the monitoring of biofuel expansion because grasslands and pasture environments are often the most likely to be converted into agricultural land due to the fact that it is less labor intensive and costly than clearing forest or developed land. The conversion of grasslands into cropland is also important from an emissions and/or environmental stand point because the conversion, for example, of high biomass native grasslands to lower biomass croplands would result in LUC emissions (source of GHG) and environmental degradation such as a decline in biodiversity, while a previously degraded low biomass pasture or abandoned land could enhance biomass carbon stocks and result in net sequestration of CO2 from the atmosphere.

b. Select the appropriate RS data source

Satellites that collect remote sensing data operate at different spatial, spectral and temporal scales (**Table 2**). For accurate monitoring, the most important factors to consider when choosing a remote sensing tool are the size of the project to be monitored (national vs. local scale), the pixel size of the chosen medium of remote sensing (ranging between 5km and <1m), the frequency of observation (i.e. daily / weekly), and available budget. **Table 2** provides examples of remote sensing sources and applications organized by both spatial and temporal scales of resolution.

Table 2: An illustration of remote sensing sources and applications. Scale is broken into 3 groups based on the pixel resolution (m), sensor is the name of the satellite, swath width is the horizontal length of each individual scene (image) taken by the sensor, frequency is the relative time period between which two images of the same place can be taken, and spectral resolution are the number of bands in the electromagnetic spectrum that are recoded.

Scale (Resolution)	Sensor	Swath Width	Frequency of Passes	Spectral Resolution	Comment
Large (>60m)					
1000m	SPOT Vegetation*	2,250km	10 days	4 bands	**Useful mapping scale: global. General scale for identifying land cover: 100-1000ha. This imagery has been used to map large area croplands and cropland types. It can be used to identify broad forest categories such as broadleaf and conifer, but likely high error with other woody land cover like shrub lands. Able to map large grassland areas but has very limited ability to determine grassland conditions.**
250-500m	MODIS*	2,330km	8-16 day	7 bands	
Medium (10-60m)					
56m	IRS AwiFS	796km	8-16 days	8 bands	Useful mapping scale: national. General scale for identifying land cover: 1-5ha. This imagery has routinely been used to map crop types across regional areas and more recently has reached national scales for countries as large as the US. Has been used to identify different forest types but is relatively limited. Has been used to determine grassland conditions in numerous studies with varying degrees of accuracy.
30m	Landsat*	185km	16 days	8 bands	
15-60m	ASTER	60km	16 days	15 bands	
Small (>10m)					
2.5-5m	SPOT-5	60km	5 days**	5 bands	Useful mapping scale: sub-national. General scale for identifying land cover: 2-50m. This imagery can be used to map cropland types. More often high resolution is used for identifying crop conditions for purposes such as determining irrigation or fertilization deficits. Can be used to map different forest types grassland conditions and other detailed land cover dynamics.
1-4m	Ikonos	11.3km	5 days**	4 bands	
0.5-2m	WorldView-2	16.4km	3 days**	8 bands	

*Freely available.
**This temporal frequency is theoretically possible if the satellite is ordered to focus on a specific location.

c. Methods for interpreting RS data to produce land cover maps

There are numerous methods for the classification of imagery; possibly the most common are “supervised” and “unsupervised,” but many other methods exist and no single method is specific for one type of classification. Therefore the choice of which method to employ should be made on a case by case basis by the RS expert responsible for the classification. Below is a brief explanation of some RS classification methods.

Supervised Classification

In a supervised classification, the analyst identifies homogeneous representative samples of different land cover categories (e.g. forest, water, agriculture, etc.) from the image. These samples are referred to as ‘training sites’. The selection of appropriate training sites is based on the image analysts’ familiarity with the geographical area and their knowledge of the actual cover categories present on the ground or/and on the availability of ground truth data to support the analyst’s interpretation of the land cover categories. The information in all spectral bands for the pixels comprising these training sites are used to ‘train’ the computer to recognize spectrally similar areas for each land cover class. Signature characteristics are first determined for each of the training site categories using specialized software (Idrisi, ERDAS Imagine, etc). Then, each pixel in the image is compared to the signature characteristics for each of the training sites to determine the land cover category the pixels belongs to.

Unsupervised Classification

In an unsupervised classification the number of classes (discrete clusters) is defined by the user and any individual pixel is compared to the mean value of each class to see which one it is closest to. In other words, the image analyst does not provide specific information on what is presented in the scene prior the classification; the software separates the pixels in defined classes based on statistical characteristics. After classification, the classes must be interpreted (labeled) by the image analyst as to what they represent in the reality on the ground. This requires some level of image classification experience or personal familiarity with the area. If the result from the unsupervised classification is not satisfactory to the user, the number of classes can be adjusted or some classes could be aggregated to represent broader category (e.g. three clusters (classes) representing three different types of forest can be aggregated into one category of forest). Different unsupervised techniques are commonly used to perform unsupervised classification (i.e. Cluster, K-mean, Paralepiped, ISODATA, etc.).

Other Image Classification Techniques

Object oriented Image segmentation is another classification technique that uses an automated process in which the pixels are aggregated based on similarity of color and texture. The result of the image segmentation is a set of segments covering the image. More precisely, image segmentation is the process of assigning a label to groups of contiguous pixels in the image such that all pixels with the same label share certain visual characteristics. This type of object oriented classification is most useful for higher resolution imagery (e.g. 1-5m resolution).

Other land cover classification techniques exist including visual interpretation which is manually performed by the user through a process called digitization. Although easy to implement, this approach is time consuming and image interpreter biased.

4. CASE STUDY ON LAND-USE CHANGE: NORTH DAKOTA, USA.

4.1 Background

The biofuel industry in the United States (US) is well established for corn-based ethanol and soy-based biofuel and is now the largest producer of fuel ethanol in the world. In the United States from 2005 to 2009, corn ethanol production increased almost three times, from 3.9 to 10.75 billion gallons[10]. Recent policies and incentives have driven this production. In early 2007, US President Bush announced the "Twenty-in-Ten" initiative, a plan to reduce gasoline consumption by 20% in 10 years. A major element of the plan was a request that Congress mandate an increase in domestic renewable and alternative fuels production to 35 billion gallons. Congress responded in December 2007 by passing a Renewable Fuel Standard (RFS) as part of the Energy Independence and Security Act (EISA) of 2007 (Biomass Research & Development Board, 2008). The second version of this standard, the RFS2, went into effect in July 2010. The RFS2 requires consumption of 36 billion gallons per year of biofuels by 2022 (up from the target of 4 billion gallons for 2005) and includes specific provisions for advanced biofuels, such as cellulosic ethanol and biomass-based diesel. By 2022, 21 billion gallons must come from cellulosic biofuel or advanced biofuels derived from feedstocks other than cornstarch and must meet a 50% to 60% GHG reduction target compared to their fossil equivalent[11]. USDA estimates that this will require 27 million acres of cropland, 6.5% of the total 406.4 million acres of cropland as reported in the 2007 Census of Agriculture (COA)[12].

Data Available in the US for Land Use Change Measurements

In the US the US Geological Survey produces nation-wide land cover information through aerial photography and satellite imagery. Complimentary data is collected by the US Department of Agriculture, which conducts surveys of all aspects of US agriculture, including agricultural production, prices, labor statistics, chemical use, imports and exports.

As a substantial producer of biofuel and with publically available technical resources upon which to undertake analysis, we have selected the US as a case study to assess the ability of available RS data to enable monitoring of land use changes associated with biofuels (dLUC and iLUC). The US Department of Agriculture (USDA) produces a national cropland data layer (CDL) that maps the distribution of different crops (as well as and other land cover types) for multiple years (circa 2000 to 2009). The CDL results from the combination of RS imagery and agricultural statistics, so it is able to provide information about **both the location and distribution of crops over time** and thus enables an analysis of land cover change. By analyzing the changing distribution of croplands and other land cover types, we can quantify the increase in biofuel crops types, identify the locations into which these crops expanded, and assess whether the expansion had any effect on the distribution of other crop types.

The analysis of the CDL provides a unique opportunity to assess the potential for RS to monitor biofuel dLUC and iLUC, and will provide important insights into its benefits and limitations. These insights will help guide further RS analysis of biofuel monitoring, such as:

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[10] http://www.usda.gov/documents/USDA_Biofuels_Report_6232010.pdf and http://www.eia.doe.gov/oiaf/analysispaper/biomass.html.
[11] http://www.usda.gov/documents/USDA_Biofuels_Report_6232010.pdf.
[12] http://www.usda.gov/documents/USDA_Biofuels_Report_6232010.pdf.

- The effectiveness and limitations of the CDL in monitoring biofuels, given the spatial and temporal resolution.

- How the classification systems could be improved to facilitate monitoring LUC associated with biofuels.

- Potential for expanding the CDL methods to other countries for monitoring biofuel-related LUC.

4.2 Methods

Location

North Dakota is in the United States along the Canadian border between 45° and 49° North latitude. The western half of the state consists mostly of hilly Drift Prairie Grasslands, the northwest is dominated by the rugged Badlands, and the eastern portion of the state consists of the Red River Valley. The Red River Valley supports the majority of the agricultural industry. The North Dakota climate is considered semi-arid, with cold winters (average January temperature 7°F (-14°C), warm summers (average July temperature 69°F (21°C), and an average annual precipitation of 14-22 inches (360-560mm).

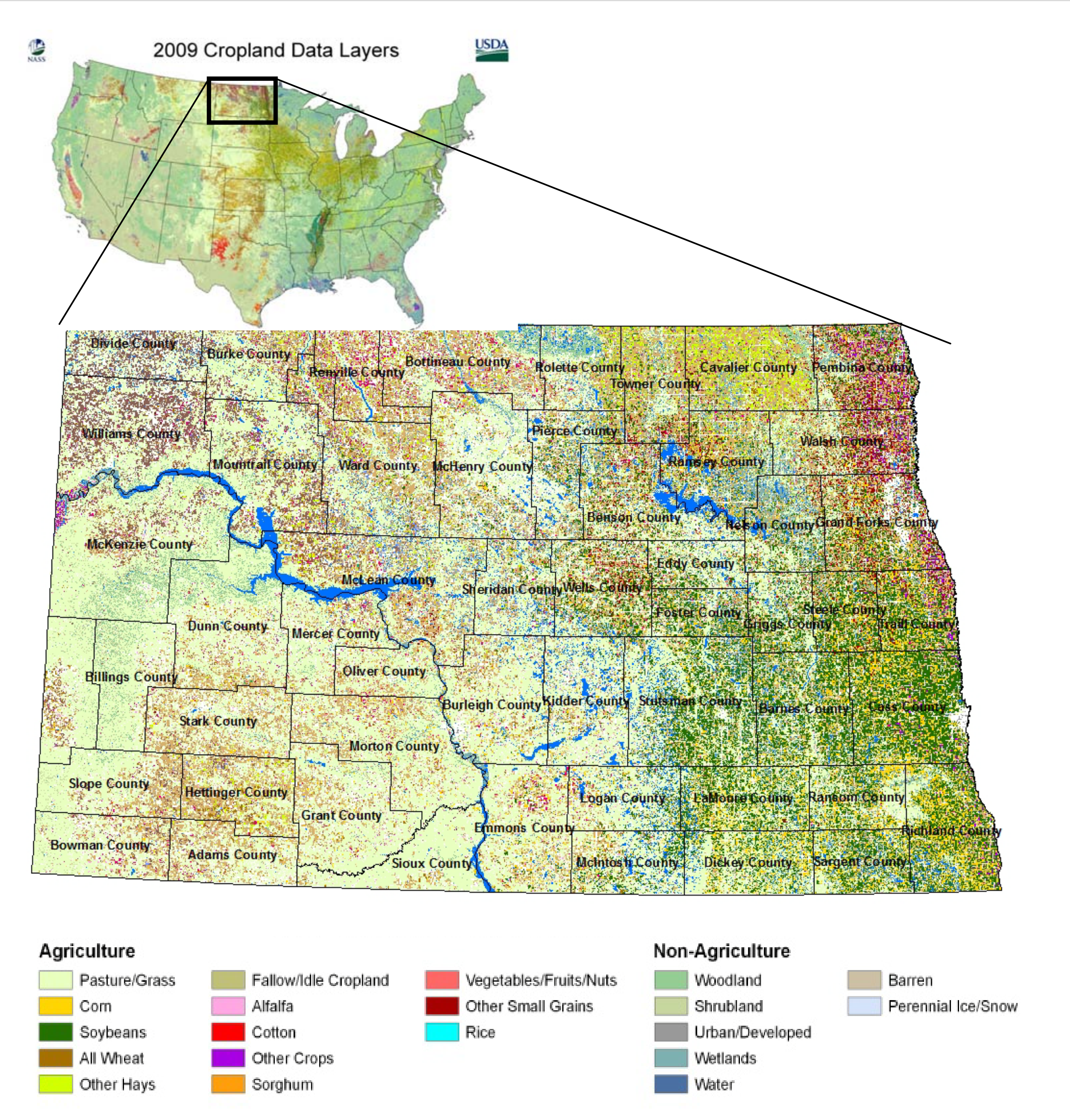
The rationale for focusing our analysis on the state of North Dakota (**Figure 2**) within the US is as follows:

- North Dakota had one of the largest increases in soy and corn crops over the past decade (2000-2010).

- North Dakota contains a mixed landscape of forests, native grasslands, rangelands, pastures and agricultural cropland that would likely interact and change as increased demand pushes the expansion of cropland.

- The CDL for North Dakota is available for every year back to 1999.

Figure 2: The CDL for North Dakota in 2009. The classification has been generalized for viewing purposes.



Agricultural Status

Table 3 illustrates that wheat, soybeans and corn in North Dakota are significant to the agricultural industry with the largest percentage of total farm receipts. North Dakota is ranked second in exports of wheat among US states (**Table** 4). Wheat comprises spring wheat, durum wheat and winter wheat. The subsequent analysis using the CDL combines these three varieties into a single 'wheat' category.

Table 3: Top 5 agricultural commodities in North Dakota, 2009.

	Percent of Total Farm Receipts in North Dakota	Percent of US Value
Wheat	**29**	**17**
Soybeans	**16**	**3**
Corn	**13**	**2**
Cattle & calves	**9**	**1**
Barley	**6**	**36**

Source: http://www.ers.usda.gov/statefacts/ND.HTM

Table 4: Top 5 agricultural export estimates, 2009.

	North Dakota Rank Among States
Wheat and products	**2**
Soybean and products	**11**
Feeds & fodders	**2**
Vegetables & preparations	**4**
Feed grains & products	**12**

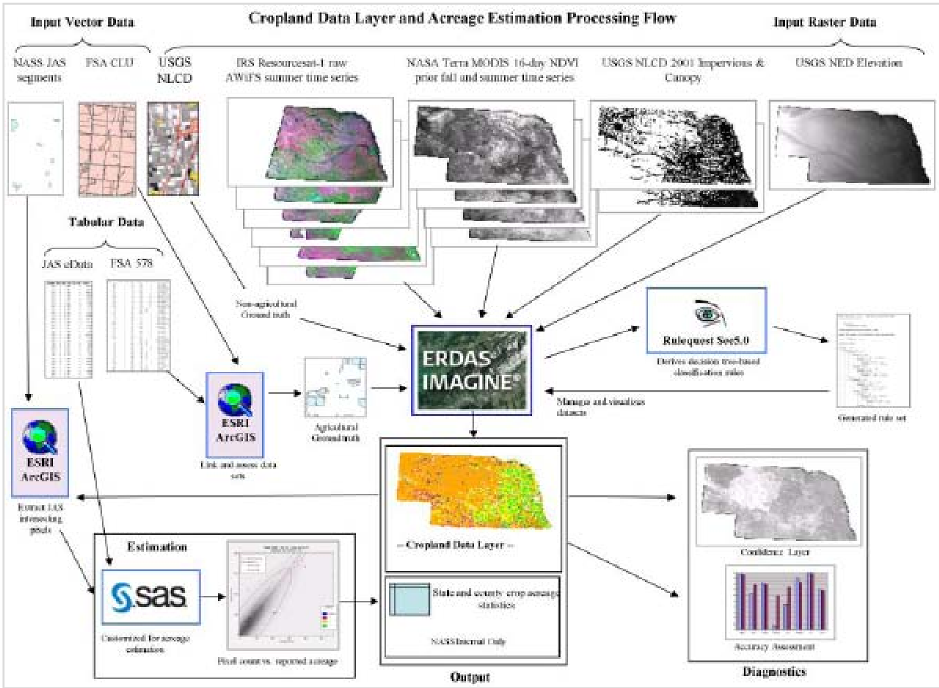
Source: http://www.ers.usda.gov/statefacts/ND.HTM

Data Description

The CDL was produced by United States Department of Agriculture's National Agricultural Statistics Service (NASS) (**Figure 2**). The completed US cropland data layer was released in 2009 at 56 meter resolution. The CDL utilizes a comprehensive and robust archive of Indian Remote Sensing Advanced Wide Field Sensor (AWiFS) satellite imagery from the US Foreign Agricultural Service (FAS) along with ground truth data provided by the US Farm Service Agency. Where AWiFS imagery was not available, Landsat was used. AWiFS is hyperspectral (contains 8 bands of information from blue to infrared) and is collected at 56 meter resolution (pixel size = ~0.3 ha). In addition to the AWiFS/Landsat imagery, NASS included supplemental datasets of MODIS 16-day NDVI, the 2001 National Land Cover Dataset (NLD) and the USGS National Elevation Dataset. The combination of these data sources was used to produce a land cover classification with 46 classes, 29 of which are cropland and 17 are non-cropland (**see Appendix 1**). The data and methods used to develop the CDL are shown in **Figure 3.**

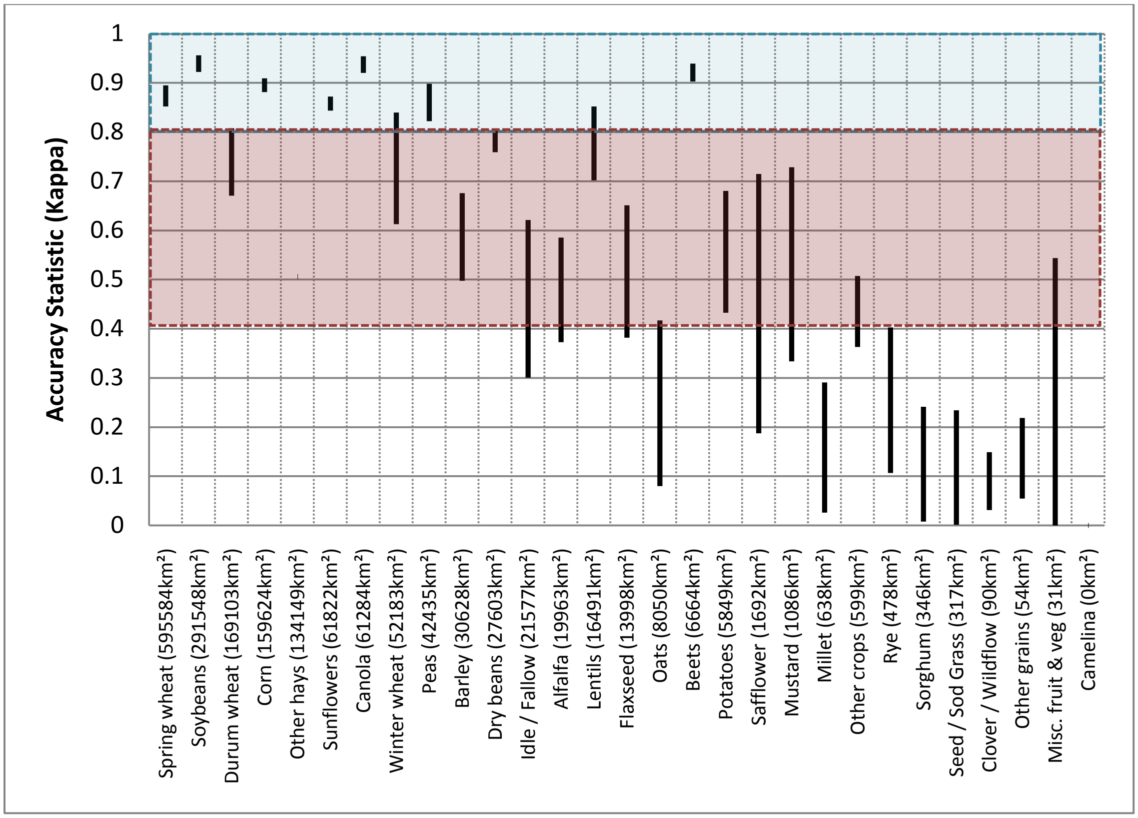
The training sites used to distinguish among different crop types (and to validate the CDL) were based on NASS's June Agricultural Survey (JAS), which compiles georeferenced data from 41,000 farmers across the US and reports acreage and crops planted.

Figure 3: Data and Methods Used to Create the US Cropland Data Layer.



It is critical for any RS analysis to contain information about the accuracy of the RS data products used. This will become particularly important as individuals, industry, and policy makers begin using RS technology to answer complex questions such as evaluating the impacts of biofuels on LUC. The CDL provides detailed accuracy statistics for each cropland class back to 2006 but does not provide these statistics for years before 2006. **Figure 4** shows the range of accuracies for each class in North Dakota listed in order from the largest area of land to the smallest area (left to right). Corn, soy and spring wheat have good accuracies. By grouping spring, durum and winter wheat together and all others into ‘other crops’ we improve the accuracy from the reported accuracy of individual categories shown in Figure 4.

Figure 4: Accuracy Statistics for the North Dakota CDL 2006-2009. Bars represent the range of kappa values obtained over three years. Land cover types are arranged in order of decreasing area (left to right) with area reported in the label. The blue shaded area (0.8-1.0) is considered good classification accuracy, the red shaded area (0.4-0.8) moderate accuracy, and below 0.4 is poor accuracy.

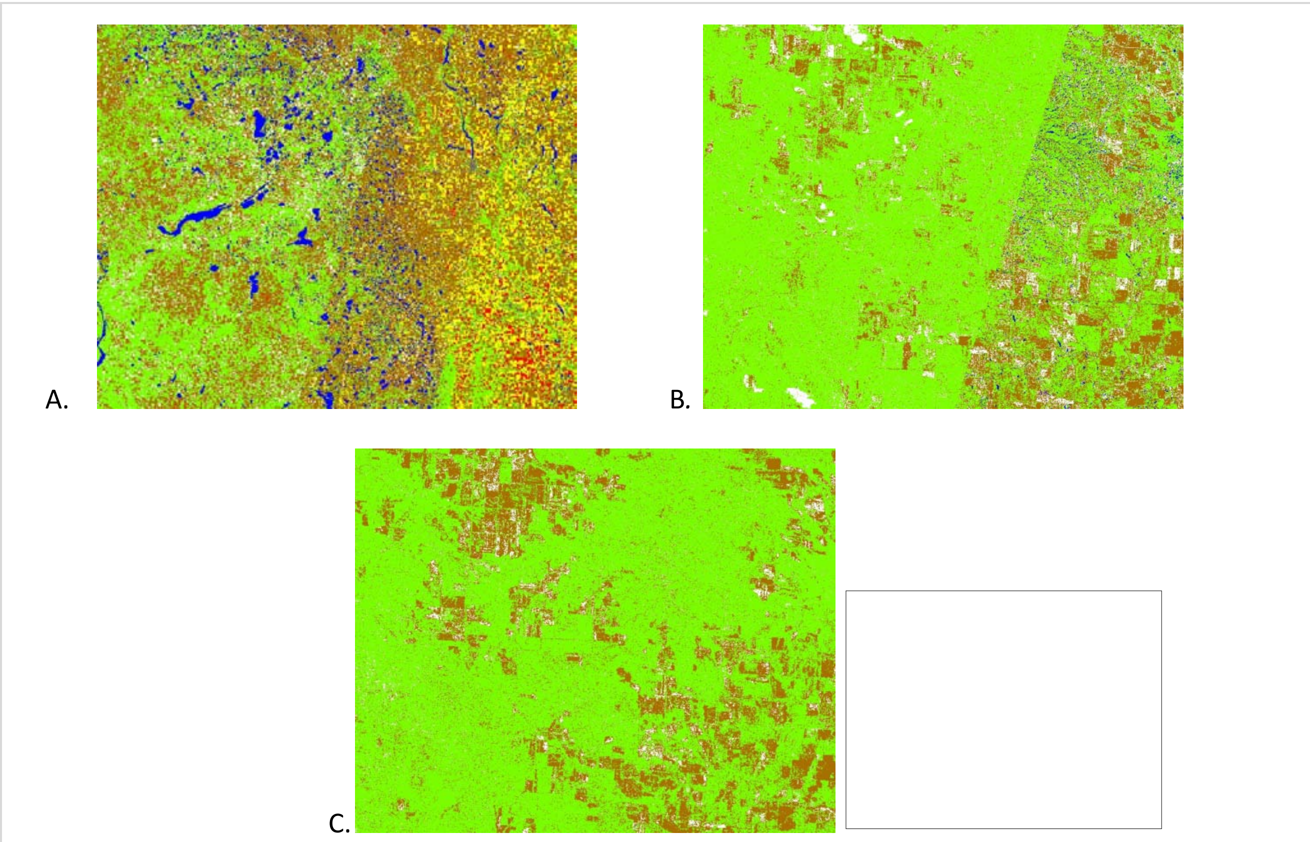


The Kappa coefficient (on the vertical axis in Figure 4) ranges from scale 0 and 1, where the latter indicates complete agreement with ground truthing data, and the former indicates no agreement. The Kappa statistic is often multiplied by 100 to give a percentage measure of classification accuracy. Kappa values are also characterized into 3 groupings: a value greater than 0.80 (80%) represents strong agreement, a value between 0.40 and 0.80 (40% to 80%) represents moderate agreement, and a value below 0.40 (40%) represents poor agreement.

The accuracy of the CDL before 2006 is reported to be 85% to 90%, but these accuracy statistics are not verified and the datasets show significant errors (**Figure 5**). Despite these errors, the CDL is acknowledged to be well ahead of most large scale annual RS datasets in accuracy statistics[13].

[13] Accuracy statistics are reported in the metadata for the CDL (http://www.nass.usda.gov/research/Cropland/metadata/meta.htm).

Figure 5: Examples of RS Error in the CDL Dataset Prior to 2006. (A) Cloud shadows are misclassified as lakes, as indicated by the blue polygons; (B) Land cover changes appear to be associated with the path of the satellite, as indicated by the vertical line distinguishing between two separate images; and (C) "Salt and pepper" effect with pixels of cropland scattered throughout the rangeland.



The classification of land cover types was not consistent between early and late versions of the CDL, which caused problems for classes such as wetlands that were first classified in 2004, but not again until 2006. With such inconsistencies, it is uncertain whether wetlands were incorporated into forest, grasslands or other land cover types in the intervening period. In 2006, the CDL incorporated the National Land Cover Dataset (NLCD)[14] into its analysis, which caused changes in the classification and subsequently the area of some of the land cover classes. At this point, considerable effort was employed to reduce errors associated with inconsistent land cover classes, including expert review by NASS RS staff.

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[14]The National Land Cover Dataset was developed by the USGS in 2001 classifying major land cover types (not specific to croplands) in the USA (http://www.mrlc.gov/).

Land Cover Change Analysis

We selected an analysis period of 2002 to 2009 to investigate changes in land cover in North Dakota using the CDL. This time period was chosen after an assessment of the data indicated that before 2002, some important crop types (most notably wheat) were excluded from the CDL dataset. Between 2002 and 2005, the CDL contains significant classification errors, such as unclassified pixels for areas covered in clouds, misclassification of water for different years, and inconsistencies in other land cover classes. Although the accuracy for this time period is assumed to be 85% to 90%, this value was not derived from ground verification but rather on more recent CDL accuracy results. The CDL for years after 2006 (2006-2009) produce much more consistent results, with virtually no unclassified areas and detailed accuracy statistics for each cropland class. Acknowledging these potential errors, we selected the time period 2002-2009 as a reasonable compromise between length of time considered and potential interannual inconsistencies in accuracy information.

The CDL categories were reclassified to highlight major biofuel crops as well as the land cover types into which biofuel crops and other displaced crop types are likely to expand. The important biofuel crops in North Dakota were identified as soybean and canola for biodiesel and corn for bioethanol. Canola was excluded in this analysis for two reasons: first, canola oil represented a relatively minor component of biofuel production compared to soy and corn, and second, the canola crop category was not mapped consistently in the CDL until 2006. Of the non-biofuel crop types, wheat was identified as the most important crop to monitor because it represents almost half of the total cropland in North Dakota. All other croplands were combined into a class called “other cropland” that included crops such as alfalfa, oats, sugar beets and potatoes. For a detailed list of the CDL cases and how they were reclassified, see **Appendix 1**.

It is important to note that **the CDL was not designed to map non-cropland land cover**; therefore there are no accuracy assessments performed on these classes, introducing room for unreported errors. After 2006, the CDL incorporated the NLCD to improve the non-cropland land cover accuracy. For the purposes of this analysis, non-cropland was first merged into five classes: forest/shrub land, developed/barren, grassland/pasture (includes native grassland, hay, rangeland and pasture), fallow/idle, wetland and water. Wetlands were not consistently mapped so they had to be merged with grassland classes or, in the case of “woody wetland”, with the forest class.

Fallow/idle land is identified as a useful land category to monitor because it likely ‘absorbs’ increases in crop expansion before expansion into native vegetation occurs. However, initial results from this study showed that between 2002 and 2006, nearly 6 million acres of fallow/idle land were lost, but nearly the same area (5.5 million acres) were gained in the grassland/pasture category. It is therefore possible that this is a result of errors due to the fact that pasture/grassland and fallow/idle land classes are spectrally very similar (both land cover types are unmanaged and are generally perennial grasslands). These large fluctuations between grassland/pasture and fallow/idle led to inconsistent results for both classes. To reduce the potential for errors in this study, the fallow/idle and grassland/pasture classes were merged together into one class called “grassland/fallow.” This new class covers a broad range from degraded to lush grasslands including fallow/idle, pasture, hay, rangeland and native grassland.

The CDL was analyzed with IDRISI software, utilizing cross-tabulation and the Land Change Modeler tools to assess LUC. ArcGIS 10 was used for the analysis of LUC at the county scale and for other general GIS analyses. Excel pivot tables were used to analyze the data.

4.3 Results

Overall, the results show that between 2002 and 2009, the net area of agricultural croplands in North Dakota expanded by 6%, covering 41% of the state in 2002 and increasing to 47% of the state in 2009. Developed and forest/shrub lands also increased, with developed and barren areas increasing from 2% to 6% of the state and forest /shrub land from 1% to 3% of the state.

The expansion of croplands was due overwhelmingly to the two crop types relevant for biofuels: corn and soy. However, this expansion of corn and soy occurred mainly through the replacement of other crop types (such as wheat); there was very little direct replacement of non-cropland land cover types (such as grassland) by corn or soy. Rather, corn and soy largely replaced other crop types, most notably wheat, during the time period analyzed. This did not result in the expansion of wheat into new areas; wheat production simply declined with respect to the total area planted. However, other crops such as barley, oats, peas, beans, hay, beets and potatoes did expand into and replace grassland/fallow land cover types[15]. This 'knock-on' effect could provide indications that corn and soy have resulted in iLUC within North Dakota. Most cropland areas that experienced a shift in crop type to soy or corn were located in the southeastern portion of the state. The crop types that were displaced by corn and soy in the southeast shifted and expanded into the northwestern portion of the state, replacing mainly grassland/pasture and fallow environments in McKenzie, Dunn, Williams, McHenry and Billings counties, with expansion of 419,600ac (22% of the county), 165,000ac (12%), 151,941ac (11%), 134,400ac (11%), 123,500ac (17%) respectively, all in the west of the state.

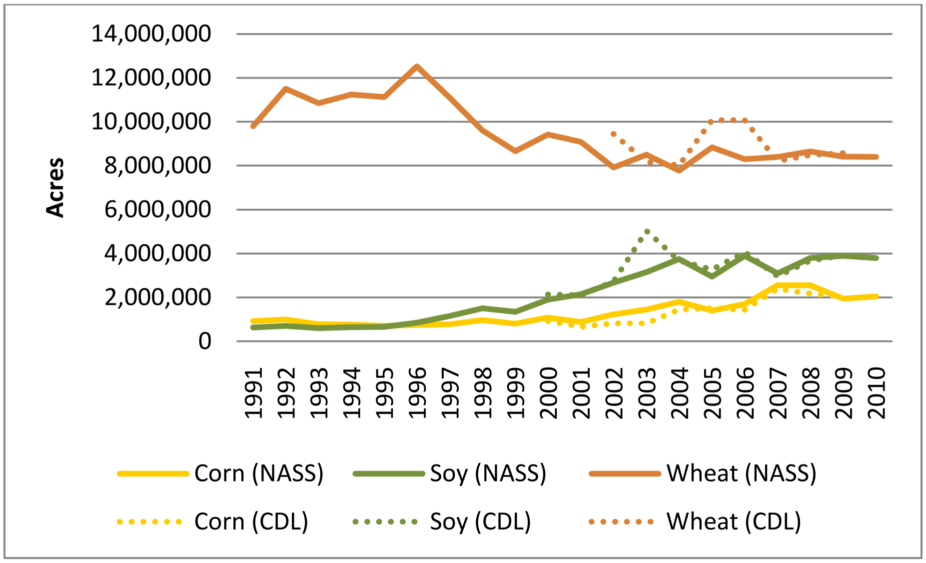
Comparison of the CDL with NASS Statistics

Statistics such as the National Agricultural Statistics Service (NASS) database are useful for providing insight into LUC because they provide detailed information about what crops are grown, over what area and at what production levels. Unlike RS data, national agricultural statistics are generally available even in many developing countries, and they extend back several years or decades. Combining agricultural statistics with spatially-explicit land cover data – such as was done to produce the CDL - can provide better insights into land use at a spatial level such that trends in cropland statistics can be illustrated geographically over the landscape.

A comparison of the CDL from 2000 to 2009 with the NASS statistics for North Dakota indicates broad consistency between the two data sources (**Figure 6**), although some outliers are apparent and should be investigated further. These datasets indicate that the area under wheat production has declined steadily in North Dakota over the past 20 years (24% in 1990 to 19% in 2009) while corn and soy have increased (1% to 8% of the state for soy and 2% to 5% of the state for corn).

[15] As discussed in the previous section, the CDL data layer does not enable identification of idled croplands distinct from grasslands.

Figure 6: Total Acres Planted for Corn, Soy and Wheat in North Dakota According to NASS Agricultural Statistics 1990-2010 (solid lines) and the CDL 2000-2009 (dashed lines).



Extent of Land Cover Change in North Dakota, 2002 to 2009

In 2002, most of North Dakota was covered by cropland (41%) and grassland/fallow land (42%). Between 2002 and 2009, North Dakota experienced an overall net increase in cropland, forests, and developed areas (**Table 5**).

By 2009 total cropland area had increased to 47% of the state (an increase of 2.5 million acres) while grassland/fallow had decreased to 39% of the state (472,000ac).

Developed and forest land increased from 1% to 3% and 2% to 5% of the state, respectively. In percentage terms these numbers are small but represent large areas; the total increase of both land cover types was 3.1 million acres.

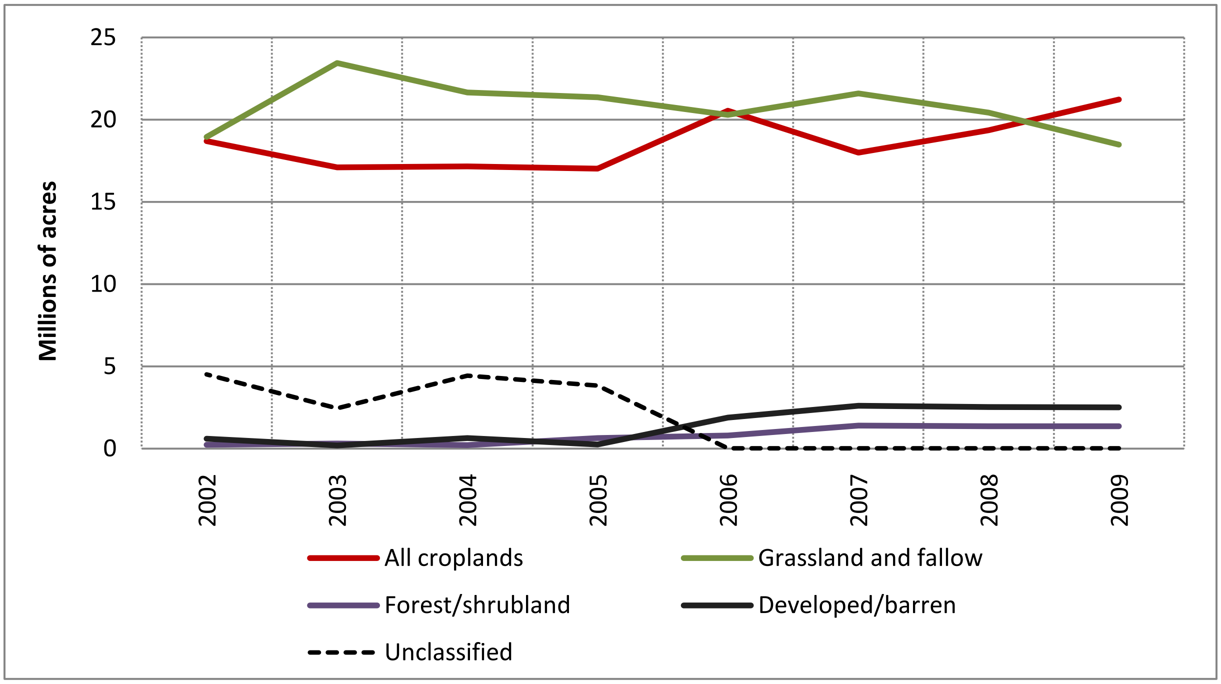
These increases were offset by decreases in unclassified and grassland/fallow land. Unclassified land represents a significant error in interpreting these results.

Table 5: Land cover area statistics according to the Cropland Data Layer for the state of North Dakota, US.

	Total Area 2002 (ac)	Change in Area (ac)	% Change 2002
Grassland/fallow	18,955,149	-471,984	-2%
All cropland	18,697,030	2,537,373	14%
Developed	593,478	1,921,766	324%
Forest/shrub land	232,544	1,128,445	485%
Unclassified	4,520,470	-4,510,229	-100%

Changes in land cover types were not linear during the period 2002-2009; **Figure 7** shows annual trends in land cover between 2002 and 2009, and indicates that in general, the area in croplands vs. grasslands are inversely correlated (when cropland goes up, grassland goes down and vice versa).

Figure 7: Land Cover Change in North Dakota, 2002-2009.



A more detailed analysis of the distribution of specific crop types in North Dakota (soy, corn, wheat and "other crops" which includes all other crop types combined[16]) allows insights into LUC dynamics among the biofuel crop types (soy and corn), wheat, other crops and non-cropland land cover. **Table 6** indicates that between 2002 and 2009, the area planted in corn more than doubled, and the area planted in soy increased by nearly 50%. Although wheat is the most extensive crop planted in North Dakota (9.5 million acres in 2002), the area planted in wheat declined by 5%, or by almost 0.5 million acres, between 2002 and 2009 (Table 6).

Table 6: Crop area statistics according to the Cropland Data Layer for the state of North Dakota, US.

Crop	Total Area 2002 (ac)	Change in Area (ac) to 2009	% Change in Area 2002-2009
Wheat	9,532,817	-492,227	-5%
Other crops	5,610,766	636,094	11%
Soy	2,729,769	1,182,718	43%
Corn	823,601	1,210,788	147%

Note: 1 acre = 0.4 hectares

[16]See Appendix 1.

The advantage of the spatial nature of the CDL is its ability to provide information about which land cover types are replacing, and are being replaced by, other land cover types. For the period 2002 to 2009 in North Dakota, soy was replaced primarily by corn and developed land, but during the same interval, soy was replacing wheat and other crops (**Figure 8** – **Soy**). Nearly all cropland in corn in 2002 stayed in corn between 2002 and 2009, with additional areas of corn expansion into wheat, soy, and other croplands with a small amount of expansion into grassland/fallow land (**Figure 8** – **Corn**). There was virtually no expansion of wheat in North Dakota between 2002 and 2009 (with the exception of wheat into 'unclassified areas', which is an artifact of the processing of the CDL data layer). Rather, wheat was replaced by corn, soy, other crops and developed land (**Figure 8**– **Wheat**). **Figure 8** – **Other Crops** indicates significant expansion of other crops into grassland/fallow areas; much more so than was the case for corn, soy or wheat.

A 'developed lands' class was also included in this analysis as it was a major contributor to LUC in North Dakota. Developed land displaced almost every major land cover type, with grassland losing the most area to developed land, followed by the other cropland category. This may be an indication that development is relatively indiscriminate in it expansion. A visual assessment of the expansion of developed areas in North Dakota shows that, excluding roads, the expansion is generally concentrated around existing city centers.

Figure 8: Soy, Corn, Wheat, Other Crops and Developed Land Gains and Losses in Thousands of Acres, 2002-2009, in North Dakota, US. Positive numbers indicate expansion of the crop into a land class and negative numbers indicate replacement of the crop by a land class.

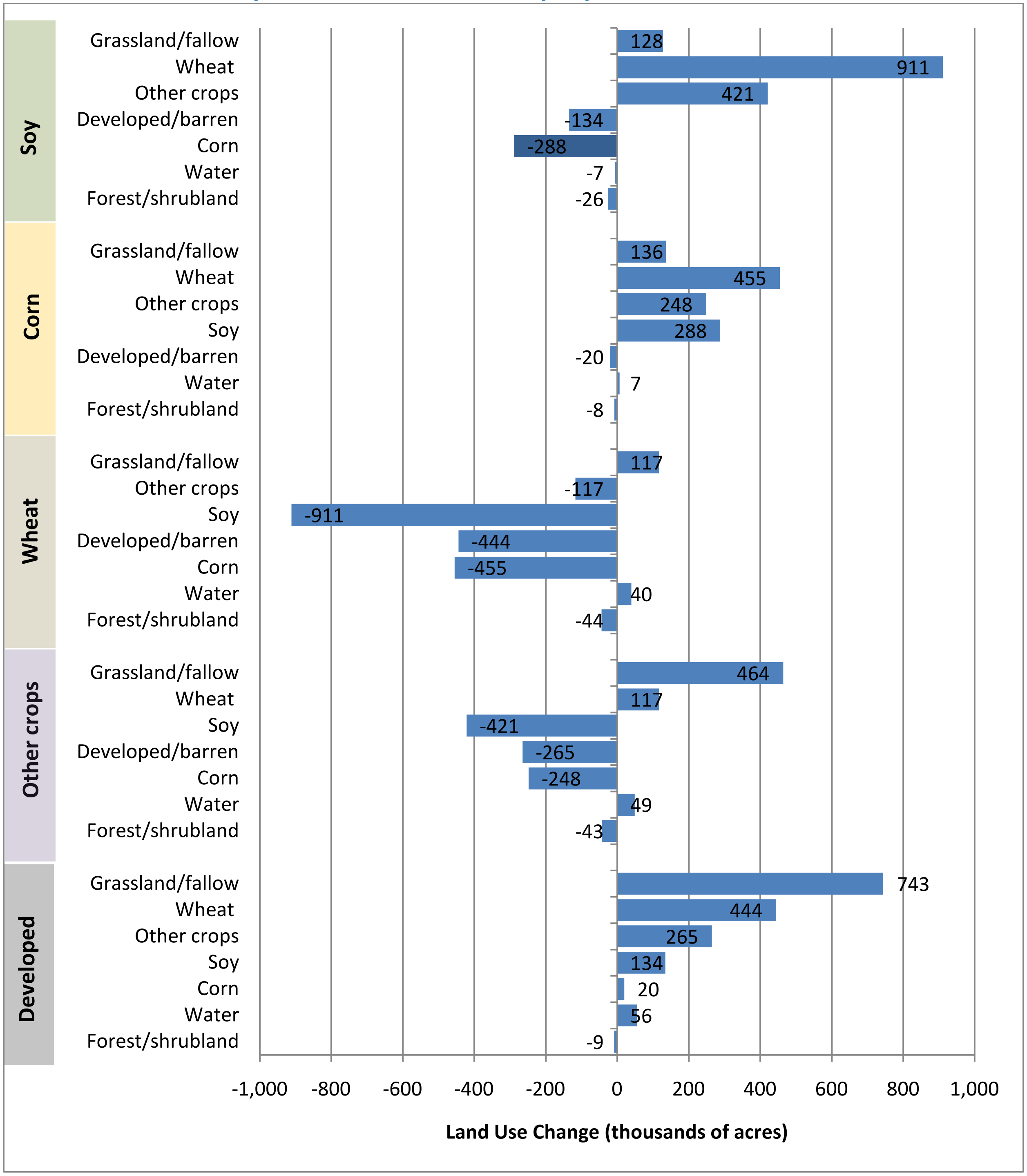
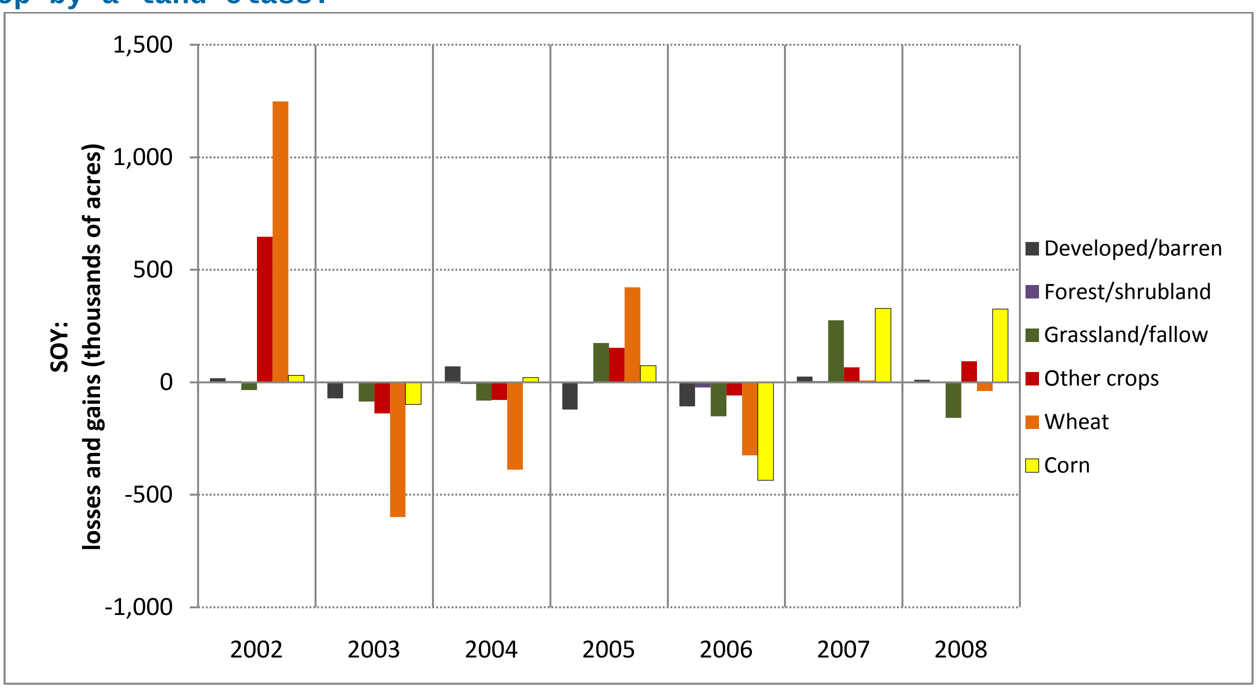


Figure 8 (previous page) shows the net area changes among different crop types and land cover classes over the time interval 2002 to 2009, but because the CDL is available by year, it was also possible to examine interannual variability. **Figure 9** shows gains and losses in soy, corn, wheat and other crops on an annual basis.

Results presented in Figure 9 are somewhat difficult to interpret, because changes from one year to the next could represent actual shifts in land use or simply crop rotation patterns. However, larger or sustained increases may represent more than just crop rotation. For example, a large increase of soy occurred in 2002 over wheat and other crops, and wheat, along with grassland/fallow, appear to be the main land cover types with which soy interacts (**Figure 9A**). In general, land use change trends to and from corn are much less clear than for soy, wheat and other cropland. In the case of corn, small increases over wheat, other crops and sometimes grassland occurred, except for 2004 and 2005 when very little change occurred (**Figure 9B**). In contrast, wheat showed substantial fluctuations, largely in and out of grassland, soy and other crops (**Figure 9C**). In 2005, wheat expanded only onto grassland and lost land to soy and other crops. In 2006, however, land that had been wheat in 2005 was now largely grassland again. After 2005, the extent of expansion of other croplands onto wheat started to decline and by 2007 the trend had reversed entirely, with wheat beginning to replace other cropland. Although other cropland replaced wheat initially, in later years other crops moved into and replaced grassland areas, with a large increase over grasslands in 2008 (**Figure 9C & 9D**).

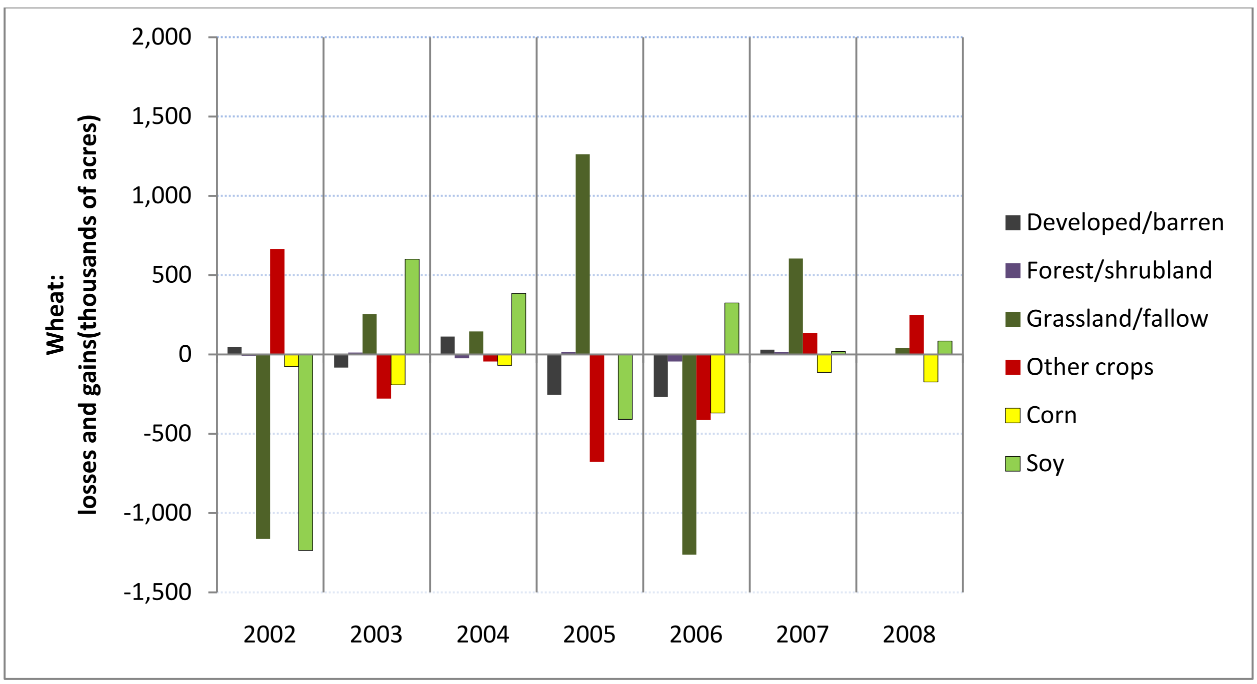
Figure 9: Gains and Losses of (A) Soy; (B) Corn; (C) Wheat; and (D) Other Crops in North Dakota, US, Between 2002 and 2009, as Estimated Using the US Cropland Data Layer (CDL). Positive numbers indicate expansion of the crop into a land class and negative numbers indicate replacement of the crop by a land class.



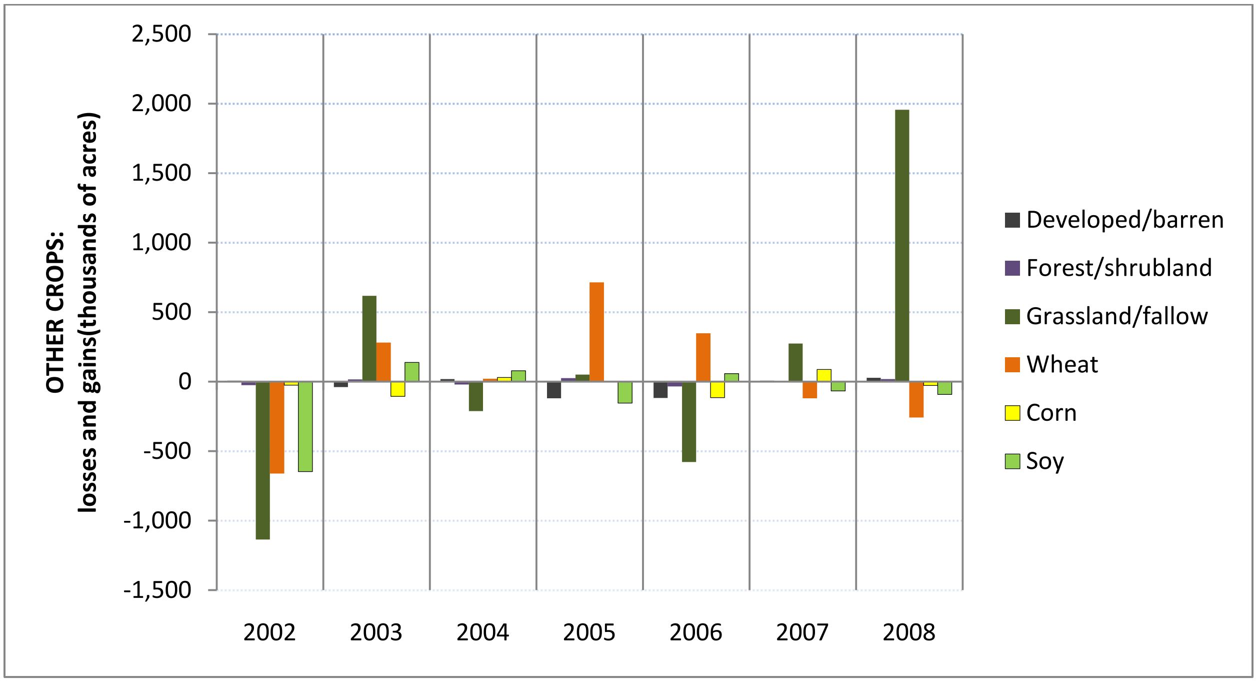
9A.


1,500
1,000
500
0
-500
-1,000
CORN:
losses and gains(thousands of acres)
2002
2003
2004
2005
2006
2007
2008
Developed/barren
Forest/shrubland
Grassland/fallow
Other crops
Wheat
Soy

9B.


2,000
1,500
1,000
500
0
-500
-1,000
-1,500
Wheat:
losses and gains(thousands of acres)
2002
2003
2004
2005
2006
2007
2008
Developed/barren
Forest/shrubland
Grassland/fallow
Other crops
Corn
Soy

9C.



9D.

Location of Land Cover Change in North Dakota, 2002-2009

A spatial analysis of the trends in land cover by county indicates that other crops are being replaced by corn and soy in the southeast of the state (**Figure 10A & 10B**), and these other crops are expanding into the northwest (**Figure 10C**) (**see Appendix 1.B, Figure 18,** for a map of county names). During the same time that other crops were expanding into the western part of the state, grasslands showed some correlated decreases (**Figure 11**).

This possible iLUC could be further investigated in the counties with the highest conversion of grassland McKenzie, Dunn, Williams, McHenry and Billings, with 419,600ac (22% of the county), 165,000ac (12%), 151,941ac (11%), 134,400ac (11%), 123,500ac (17%) respectively, all in the west of the state.

Figure 10: North Dakota County Gains in (A) Corn, (B) Soy, and (C) Other Crops by Counties 2002-2009.

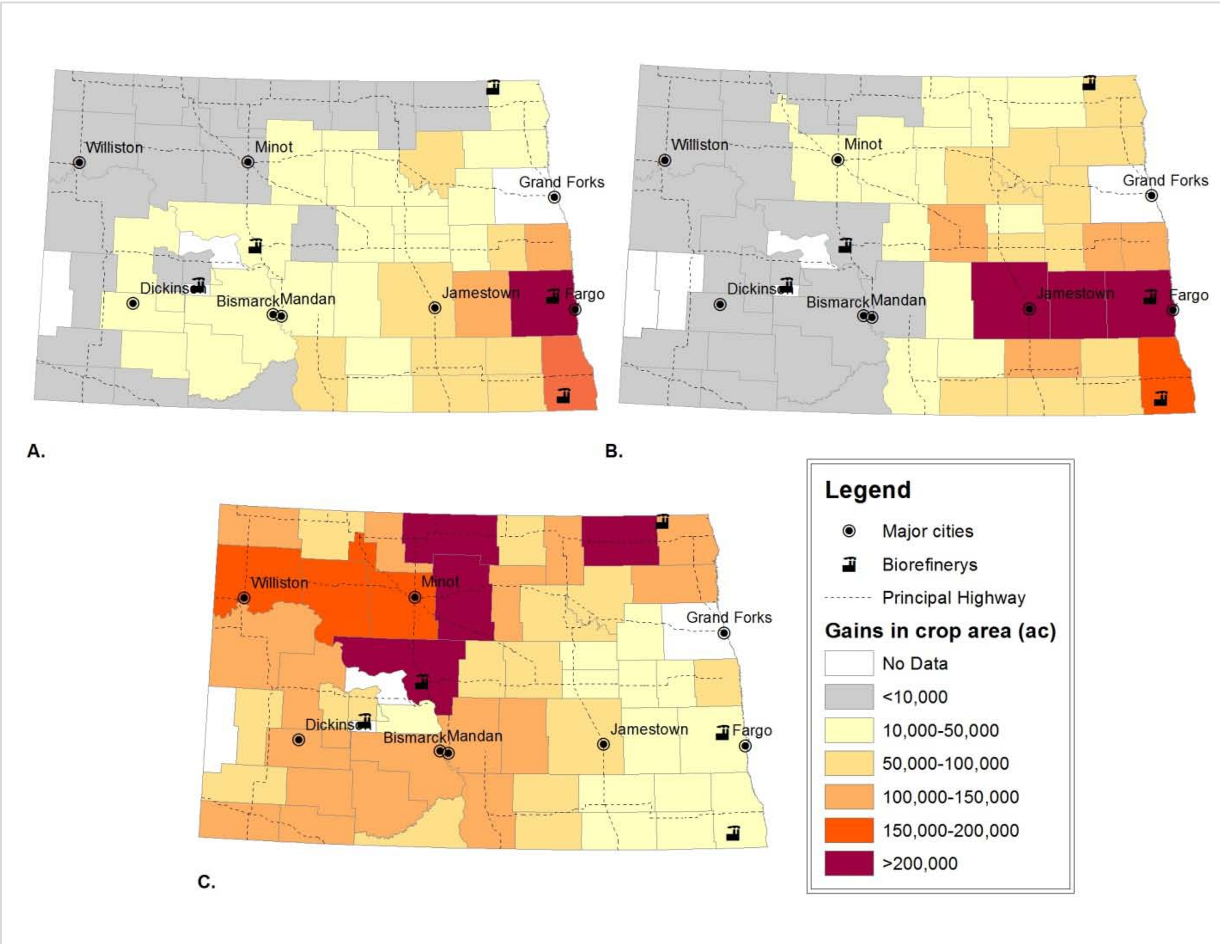
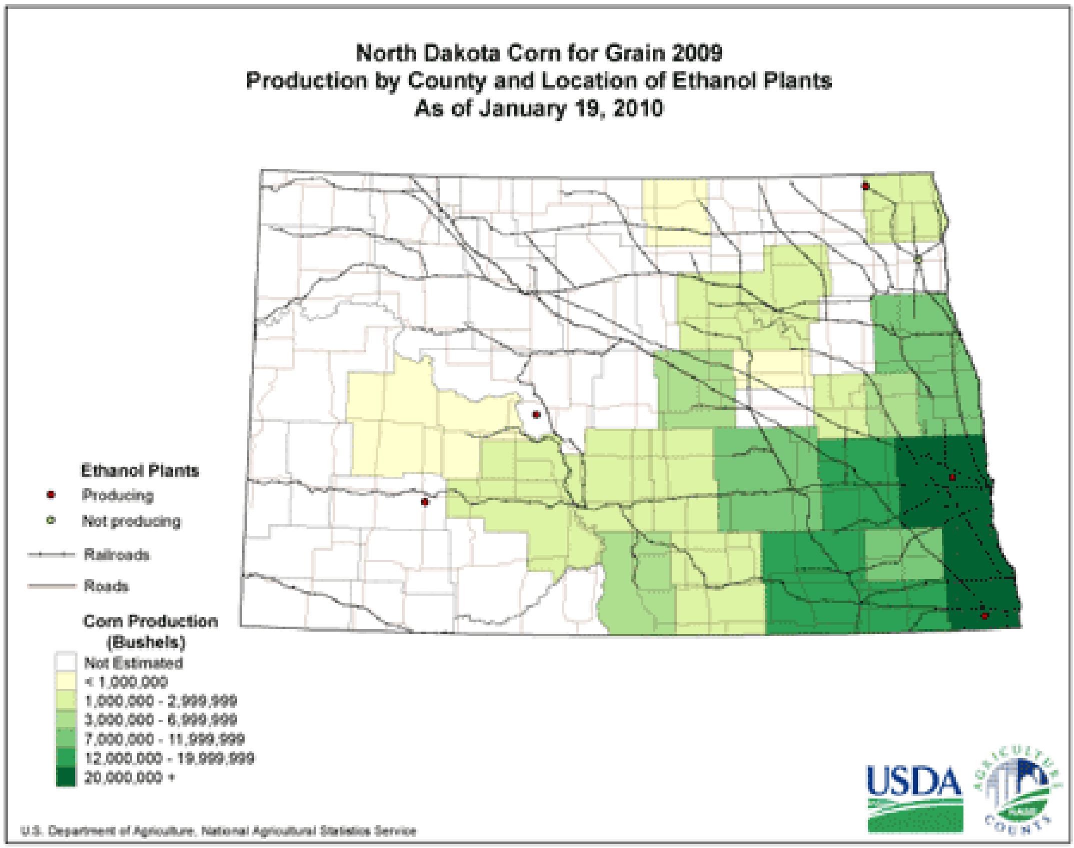


Figure 11: North Dakota County Losses in Grassland/Fallow 2002-2009.

Largest losses to corn illustrated in **Figure 10A** are correlated broadly with the locations of ethanol plants illustrated in **Figure 12**.

Figure 12: Locations of Ethanol Plants in North Dakota and Volumes of Corn Production.



Source: http://www.nass.usda.gov/Charts_and_Maps/Ethanol_Plants/North_Dakota/index.asp

5. DISCUSSION

The overall goal of this study was to assess the potential to use Remote Sensing (RS) technologies and products to identify land use changes (direct and indirect) relating to the increased production of biofuel crops. The case study of North Dakota enabled an assessment of the strengths and weaknesses of the CDL as a data source for identification and an analysis of how it could be improved for biofuel LUC monitoring. The case study was not intended to provide a comprehensive analysis of biofuel-induced land use change, which would require further investigation to attempt to derive conclusions of causality.

Much of North Dakota is not "ripe" for agricultural development due to its cold winters and semi-arid climate. The west and north of the state is most suitable for extensive rangelands consisting of drift prairie and the Missouri Plateau (The US Great Plains) with the rugged Badlands in the north. In contrast, the eastern border of the state is where the majority of the fertile croplands are, fed by the Red River that flows into Lake Winnipeg on the border of Canada. This is the region where the expansion of corn and soy between 2002 and 2009 largely replaced wheat and other crops. Much of the arable land in North Dakota has long been under production and while there are opportunities for agricultural expansion, they are limited. Rainfall and soil type has provided geographic limitations to land use changes – the southern half of the state is very suitable for soybeans (and the north not so) whereas the east of the state is more suitable for corn (and not so in the west of the state). This is related to rainfall availability and temperature which influences growth and maturity dates (Dagman, *pers comm*).

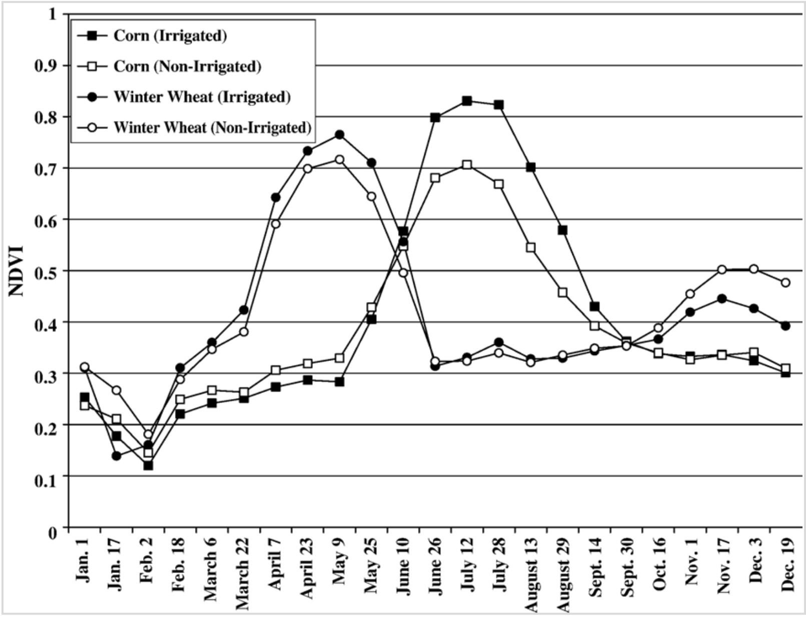
5.1 What does the CDL tell us about dLUC and iLUC due in North Dakota?

Based on the results from this case study, it is clear that the CDL can identify changes in broad number of land cover classes on an annual basis across North Dakota. This suggests that the CDL can identify dLUC. However, it is hard to determine the scale of accuracy for the CDL. Based on comparisons with agricultural statistics, it certainly appears accurate at the state and county level. Based on visual assessments, accuracy may be good down to the square mile, but at an individual farm level and below, the accuracy undoubtedly decreases. It is also clear that accuracy for different crops are related to total area, and that crops with small areas, both individual units (e.g., a farm) and in total area have lower accuracy. Based on the result of this analysis, there are correlations in the data that suggest potential iLUC (i.e., as corn and soy replace wheat, and as wheat replaces other cropland, other cropland is replacing grassland), this issue warrants further ground based investigation. The biggest limitation in using the CDL for monitoring land use change related to biofuels is its relatively poor classification of non-cropland land cover types and the inconsistencies in the classification before 2006.

For the RS of croplands and other land cover types it is important to assess intra-annual as well as inter-annual time steps. **Figure 13** illustrate the significance of monitoring intra-annual changes in land use rather than drawing conclusions from a single time period developed using only a comparison between the start and end year. It shows how NDVI[17] for corn and winter wheat can vary throughout the year, and an image taken in late July may indicate very little corn (as most of it has already been harvested) while identifying considerable winter wheat. Another example could be an assessment between July of year 1 and April of year 2 and would indicate that expansion of corn over winter wheat implying a substantial land use changes that would be overestimated. In reality, there is considerable fluctuation between land uses, including cropland moving in and out of grassland/fallow. The more time steps available, both inter-annual and intra-annual the clearer the RS analysis can interpret the agricultural fluctuations throughout the year and between years thereby differentiate different crops and crop cycles.

[17]NDVI: Normalized Difference Vegetation Index is a ratio of the red and infrared spectrum (bands) that is commonly used to identify green live vegetation. In RS it is a simple numerical indicator that can be used to analyze remote sensing measurements and assess whether the target being observed contains live green vegetation or not.

Figure 13 From Wardlow and Egbert 2008. NDVI values over one growing season for irrigated and unirrigated corn and winter wheat. RS imagery from only one point in time could misclassify either one of the classes depending if the imagery was taken in April or August.



Between 2002 and 2009, the most significant LUC in North Dakota was the interaction between croplands and grasslands, with more than 6% of the state undergoing LUC between grassland/fallow and cropland categories. This LUC is important, in part, because of the associated emissions related to the conversion of these non-cropland areas. The analysis also shows that after 2006, there is a trend of cropland expansion into grasslands/fallow, which correlates with the 2005 increased national demand from biofuels[18]. The two crops primarily responsible for this expansion are the major biofuel crops of corn and soy[19], which expanded primarily into wheat and other croplands by approximately 2.4 million acres accounting for 83% of its total expansion. The remaining 17% of expansion took place over grassland/fallow land and some unclassified land. The large expansion of corn and soy into wheat and other croplands suggests that either wheat or other croplands were replaced and did not expand into other areas, resulting in a net decrease in their area, or they continued to expand and therefore were displaced to other areas, indicating potential iLUC. The results show that between 2002 and 2009, wheat did decline in area by about 2 million acres. In contrast, other crops continued to expand at a relatively moderate rate of 0.6 million acres over the same period. Approximately 60% of that expansion occurred onto grassland/fallow areas, and the remaining expansion occurred on unclassified land and wheat. The county-by-county spatial analysis indicates that other crops were replaced by corn and soy in the more fertile east of the state, and in turn these other crops expanded into grassland/fallow areas in the west and north of the state. The largest expansion of other crops into grassland/fallow land occurred in the western counties of McKenzie,

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[18]In the United States from 2005-2009 corn ethanol production increased almost three times from 3.9 to 10.75 billion gallons due to domestic and international policies (http://www.usda.gov/documents/USDA_Biofuels_Report_6232010.pdf and http://www.eia.doe.gov/oiaf/analysispaper/biomass.html).

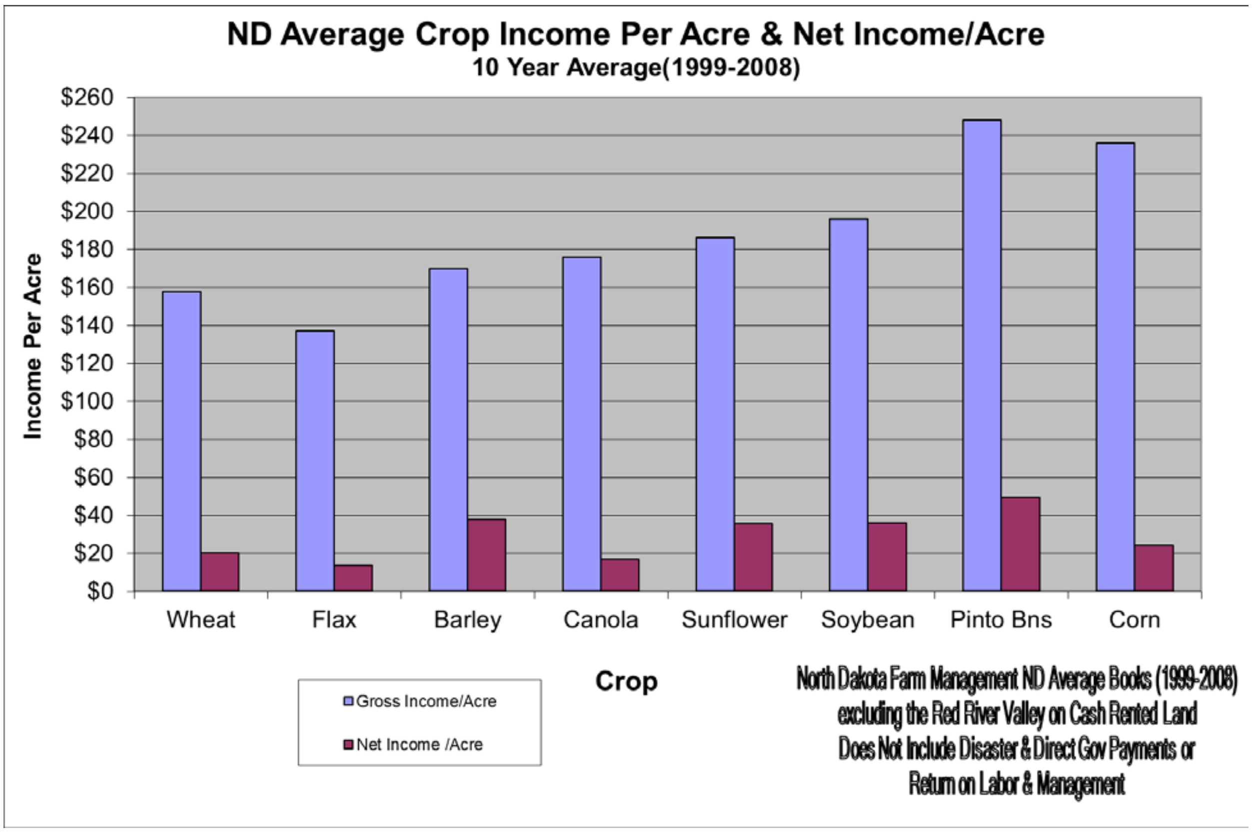
[19]Soy is a major biofuel crop on an international basis though not specifically in North Dakota.

Dunn, Williams, McHenry and Billings, with 419,600ac (22% of the county), 165,000ac (12%), 151,941ac (11%), 134,400ac (11%), 123,500ac (17%) respectively, all in the west of the state.

5.2 Potential explanations for observed land use trends

iLUC from increasing corn demand for biofuels is one potential conclusion that may be drawn from our analysis. Higher prices for corn driven partly by demand from biofuels are influencing planting decisions (Dagman, *pers comm*). **Figure 14** illustrates that the net income per acre for corn and soybeans and wheat over the last 10 years has not been sufficient to ascribe all changes in land use to changes in net income alone. Average data over 3 years (2006-2008 inclusive) from the same source draws the same conclusion.

Figure 14: Crop Income per Acre and Net Income per Acre: 10 Year Average in North Dakota.



Source: North Dakota Farm Management (2010).

There are several factors that complicate the issue and cause conclusions on iLUC and its magnitude due to biofuels alone to be much more uncertain. These factors are explained in more detail below:

Fluctuations in Market Conditions and Natural Weather Events

While spatial analysis can provide indications of iLUC associated with biofuels, it cannot provide the relevant context which is critical in understanding causality and attributing changes to biofuels alone.

During the early 2000's North Dakota experienced particularly wet weather that led to disease to a large extent in wheat and also in barley. This substantially affected yields and prices and led production away from wheat (Dagman, *pers comm*).

Events such as flooding may be a significant factor in expansion of soy over wheat areas. For example, the North Dakota Wheat Commission was expecting wheat plantings from North Dakota to drop sharply in 2009 due to lower expected wheat prices. However, in 2009, North Dakota suffered from flooding in parts of the state, an event which was expected to compound reductions in spring wheat plantings (wheat planting in North Dakota generally needs to start by mid-April, while soybean seeding (or sunflowers and dry beans) can wait an extra month)[20]. Therefore, more soybeans or crops other than wheat may have been planted in 2009 in certain areas due to reasons other than biofuel expansion.

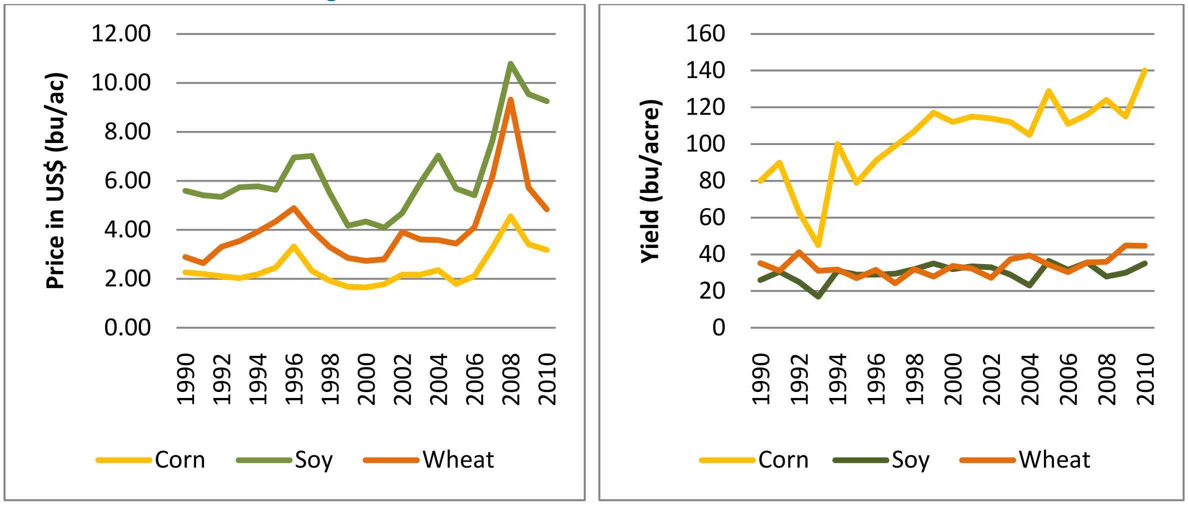
There are a wide variety of drivers for planting decisions. Energy costs are one of these, and while they account for roughly half of operating costs for crops such as wheat and corn and sorghum, they account for less than one-quarter of operating costs for soybeans. Rising energy prices (alone) may induce a switch from energy-intensive crops such as corn to less energy-intensive crops like soybeans (USDOE & USDA, 2009).

New Technology

New technology may be encouraging a move away from wheat production towards corn and soybeans and also a conversion of grassland to crop production. **Figure 15A** shows that while prices for corn, wheat and soy have mirrored each other, the price for corn has remained below soy and wheat. Despite this, **Figure 15B** shows that the yield trend for corn from 1990 to 2010 is a more substantial increase than soy and wheat, which have remained relatively stable over the same period. Genetically modified herbicide-tolerant varieties of corn and soybean have been rapidly adopted and save time in the busy planting season. New varieties of corn and soy may be relaxing labor constraints that limited cropland acres. Technological advances in wheat by comparison have been substantially less and resulted in better profits from corn and soy (Dagman, *pers comm*).

[20] http://www.reuters.com/article/2009/03/26/us-usa-flood-idUSTRE52P6KA20090326?pageNumber=1.

Figure 15: (A) Price per Bushel for Corn, Soy and Wheat According to NASS Data for North Dakota, 1990-2010. (B) Yields for Corn, Soy and Wheat for North Dakota According to NASS Data from 1990-2010.



New technology for corn has contributed to substantially better yield growth (which has provided good net returns per acre) and has enabled adoption of no-till production for soybeans, which may reduce spring-time labor requirements and make it easier to convert highly erodible grassland without risking the loss of farm program payments under the US sodbuster provision[21] (Claasan, 2010).

Other Land Use Pressures beyond Corn and Soy: Oil Exploration

Our analysis provides evidence that land use pressures do not result solely from corn and soy expansion. While RS analyses cannot assign causation of all land use changes to biofuel expansion, they can identify land use pressures and assist in providing better context in which to assess land use changes associated with biofuels. In this analysis, while soy and corn have expanded by 50% to 150% between 2002 and 2009 (by a total of ~2.4 million acres), developed areas and forest land have also increased substantially, from 2% to 6% of the state totaling 3.1 million acres. These comparisons show that there are comparable pressures on land use change from other drivers as those from corn and soy expansion.

The details of what is classed under developed land are uncertain – huge rates of urbanization appear unlikely (Dagman, *per comm*). However, the west and northwest region of North Dakota has undergone rapid development in recent years owing to the presence of a substantial oil shale formation (the Bakken Shale oil field) which could be related to direct land use changes in this region[22]. The west and northwest of North Dakota is the area with the highest proportion of losses of grassland (**Figure 11**).

[21]Applies to highly erodible land that was not farmed between 1981 and 1985 and requires the adoption of a conservation system that reduces erosion to a level above which long-term soil productivity may be depleted.
[22]http://www.bloomberg.com/apps/news?sid=ayj1uo_gdNI4&pid=newsarchive.

Expiring Conservation Reserve Program (CRP) Contracts

The conversion of CRP land back into production is another possibility that could explain the loss of grasslands to other crops in the west and north of the state. The CRP was initiated by the US Government between 1986 and 1995. It provided agricultural producers with government payments to retire poorly producing or ecologically sensitive land and establish long-term, resource-conserving covers to improve the quality of water, control soil erosion, and enhance wildlife habitat. The program created one of the largest land use/land cover conversions in US history, with approximately 36.5 million acres of cropland converted back into grassland, woodland and other conservation uses (Egbert et al. 2002). In much of the Midwest, native grassland habitats showed significant increases as private land owners retired their land into the CRP (Egbert et al. 2002). USDA data confirm that considerable CRP land contracts were coming due in North Dakota between 2005 and 2009, with North Dakota showing the second highest area of CRP land set to retire during this time period in the US (**Table 7**).

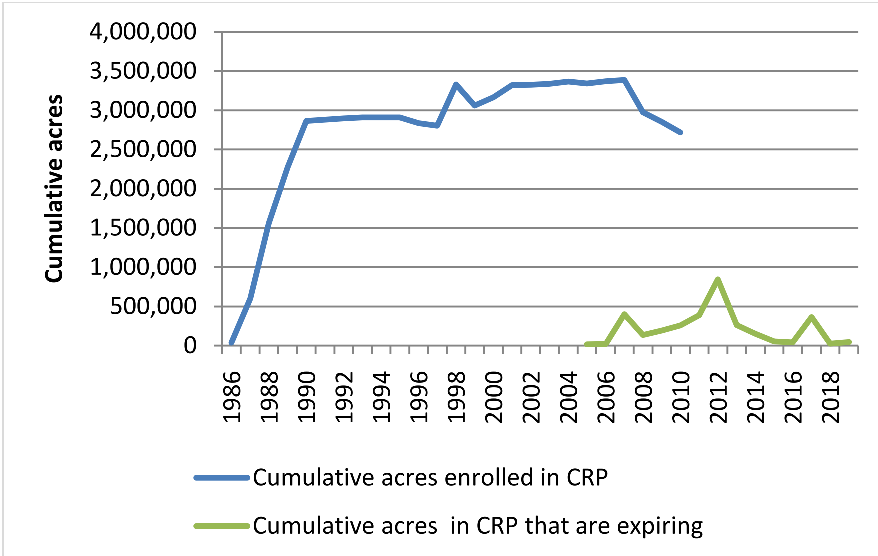
Table 7: Top 10 US states for CRP area contract expirations 2005-2009 (acres).

	2005	2006	2007	2008	2009	Total
TEXAS	23,989	20,928	151,718	109,082	561,493	867,210
NORTH DAKOTA	***17,275***	***21,147***	***400,828***	***134,905***	***191,777***	***765,931***
SOUTH DAKOTA	6,957	5,599	301,794	118,663	183,719	616,732
MONTANA	27,107	37,618	257,631	81,680	138,388	542,425
KANSAS	4,289	8,963	130,079	43,010	331,165	517,506
COLORADO	996	1,444	41,460	23,390	409,399	476,689
IOWA	38,574	19,139	145,804	143,779	99,843	447,139
MISSOURI	25,292	16,405	146,649	48,873	32,620	269,838
NEBRASKA	6,870	5,478	89,936	45,373	116,621	264,278
MINNESOTA	11,226	5,307	78,676	107,119	57,216	259,544

In North Dakota between 2005 and 2009 CRP land set to expire ranged from 17,000 to 500,000 acres per year. Between 2009 and 2019, CRP land set to expire in North Dakota ranges from 23,000 to 850,000 acres per year (**Figure 16**). The extent to which CRP land that is due to 'expire' is converted back to cropland depends on the relative economics of the rental payments of the program versus the economic returns of cropping. Given current market prices for corn and other commodities, a higher proportion of land retired from the CRP at present may go back into crop production[23].

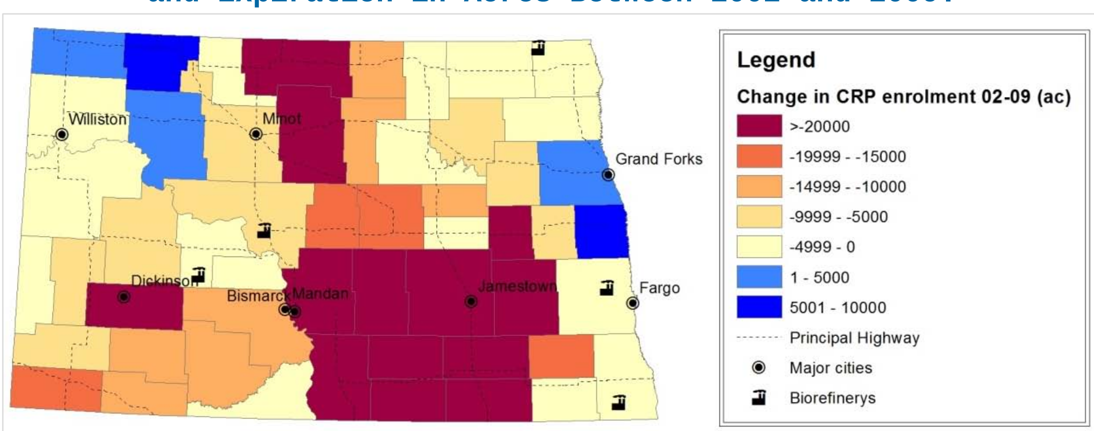
[23] http://www.ers.usda.gov/AmberWaves/February08/Findings/LandRetirement.htm.

Figure 16 North Dakota CRP Contract Enrollment (Cumulative) and Expiration, 2009-2019.



The expiration and enrolment of CRP land in North Dakota is shown by county in **Figure 17.** This indicates that the southern central part of the state has had the most CRP land expiring between 2002 and 2009. This does not appear highly correlated with the highest losses to grassland which **Figure 11** illustrates is in the west of the state (although the loss of grasslands occurs throughout the state) but the loss of CRP in northern central counties does appear to correlate with the largest increase in 'other crops' (**Figure 10C**) within the state.

Figure 17: North Dakota CRP Contracts Enrollment and Expiration in Acres Between 2002 and 2009.



Agricultural Policy

Subsidies in the agriculture sector can help protect crop farmers from very low prices and yields, which enable farmers to maintain the production of certain crops even when market prices alone would suggest a switch to a different crop or a different land use altogether. Support payments also influence whether yields are increased or new land is brought into production. For example, producers in the US can increase their eligibility for certain programs, and therefore subsidy payments, by converting grassland to crop production. While breaking ground on native grasslands requires special permits that would be recorded by local USDA (under the sodbuster provision[24]), cultivation of such grasslands may be allowed in certain circumstances (such as the use of no-till cultivation techniques).

Demographics of Farming Population

Many of North Dakota's livestock (beef) farmers are ageing. The work is demanding and some are converting pasture to grow crops to make production life less physically demanding (Dagman, *pers comm)*.

Distinguishing Land Use Change from Rotation Patterns

Pasture and hay are often grown in long term rotation with cultivated crops, leading to a much more active margin with cultivated cropland when compared with the cropland-rangeland margin (Claasen, 2010). As the grassland/fallow category does not distinguish between pasture and hay and rangeland these long term rotations with grassland will not be distinguished from land use changes.

5.3 Limitations of the CDL for monitoring purposes

The CDL has enabled the identification of croplands expanding into the 'grassland/fallow' category. The 'grassland/fallow' category includes:

- Idled/fallow cropland. This is land that is temporarily uncultivated due to the underlying rotation cycle or because it is uneconomic to cultivate the land at the present time. While the CDL identifies an individual 'fallow' category, low accuracy in early datasets (discussed below) suggest that this category is unable to be distinguished on its own in this analysis along with other important grassland types/conditions (e.g. low to high biomass) that are critical in understanding the impacts of land use changes.

- Conservation Reserve Program (CRP)[25] land. This is also idled/fallow land, but has been enrolled in the CRP program and will remain idle for the length of the CRP contract.

- Pasture and rangeland. Major differences between rangelands and pastures are the kind of vegetation and level of management that each land area receives. In most cases, rangeland supports native vegetation that is extensively managed through the control of livestock rather than by agronomy practices, such as fertilization, mowing, and irrigation. Rangeland also

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[24]The sodbuster provision was introduced in the 1985 Food Security Act for the purposes of conservation of highly erodible lands (HEL). Anyone cultivating these lands must adopt a basic conservation system that reduces erosion to a specified level.

[25]USDA Farm Service Agency's (FSA) Conservation Reserve Program (CRP) is a voluntary program available to agricultural producers to help them safeguard environmentally sensitive land. Producers enrolled in the CRP establish long-term, resource-conserving vegetation cover to improve the quality of water, control soil erosion, and enhance wildlife habitat. In return, FSA provides participants with rental payments and cost-share assistance. Contract duration is between 10 and 15 years.

includes areas that have been seeded to introduced species (e.g., crested wheatgrass), but which are extensively managed like native range. Pastures are represented by those lands that have been seeded, usually to introduced species (e.g., tall fescue) or in some cases to native plants (e.g., switchgrass), and which are intensively managed using agronomy practices and control of livestock.[26]

- Native vegetation that ranges from high biomass to low biomass grasslands. Existing data on US land use does not identify grasslands as native or non-native (Claasen, 2010).

The distinction of grassland categories is significant for several reasons. First, fallow/idle land is a useful land category to monitor because it likely 'absorbs' increases in crop expansion before expansion occurs into native vegetation. It is possible that the land has been idled for a relatively short period of time and therefore there has not had sufficient time for soil fertility to be restored. Second, grassland may be intact or degraded. If degraded, the land will have little vegetation cover and infertile, eroded soils. In contrast, grassland that has remained intact for a long period of time is likely to have higher carbon stocks and may also have established habitats that may be severely impacted by changes to cultivated land. Therefore, the GHG and other environmental impacts of conversion of degraded vs. intact grassland will differ significantly, and these impacts cannot be evaluated until separate land use categories are able to be distinguished.

Idled/Fallow Cropland

Fallow/idle versus grassland and pasture land is identified in the CDL but we found considerable inconsistencies between these two classes, and discussions with NASS CDL experts suggest that this was likely due to confusion between the two classes (as both are spectrally very similar, unmanaged perennial grassland type environments). This is not reported by the CDL, because the CDL is not focused on mapping non-cropland land cover.

Fallow/idle and grassland/pasture had to be merged for this analysis. The combined class that includes rangeland, hay, pasture and native vegetation as well as fallow land. For a proper RS analysis of biofuel LUC, maintaining a fallow/idle land cover class separate from grassland/pasture would be important. It is possible that methods could be developed to identify fallow land using annual (or semi-annual) land cover data sets that were available for multiple years. These data sets together could be used to identify locations and areas of land moving in and out of cropland to grassland that that could be identified as "fallow" (Campbell et al. 2008).

High/Low Biomass Grasslands

A distinction between different perennial grasslands environments as it relates to low to high biomass would also be important for the monitoring of biofuels and their associated LUC emissions. As reported by Tipper & Viergever (2009) and Pittman et al. (2010), using RS to distinguish between grassland high and low biomass and specific croplands is probably the most difficult to detect due to the fact that vegetation cover like cereal grains versus tall grass prairie are spectrally similar. Despite these difficulties many studies (including the CDL) have reported success in distinguishing different croplands from grasslands using multiple inter-annual datasets that can be used to assess different crops (or non-crops) cycles of green-up and harvest (Panichelli & Gnansounou 2008; Pittman et al. 2010; Shao et al. 2010; Tipper & Viergever 2009; Wardlow & Egbert 2008b; Thenkabail et al. 2004).

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[26] http://www.epa.gov/oecaagct/anprgidx.html.

The ability to use RS for distinguishing grassland condition is challenging, and no single solution fits all areas or countries. Identifying low biomass grasslands for example could be an indication of degraded land, which is a term much discussed in the context of biofuel sustainability. In the tropics, identification of degraded pasture land has been undertaken through the correlation of the biophysical properties of pasture and grazing impact with RS signatures like Non-Photosynthetic Vegetation index (NPV) and shade ratios (GV) (Numata et al. 2007). A Normalized Differential Vegetation Index (NDVI) for estimating live and dead vegetation in pasture areas (Asner et al. 1999) has also been utilized. In more arid environments, RS studies have found pasture degradation to be correlated with a higher ratio of exposed ground to photosynthetic vegetation (Asner et al. 2003). The most appropriate technique for different countries or areas will need to be independently assessed and will be influenced by the climate, vegetation structure and availability of ground data.

6. CONCLUSION

Land use changes associated with biofuels are significant because they can negate the benefits that biofuels are intended to deliver. While direct land use changes can be measured, indirect land use changes cannot and must be inferred from information on the type and magnitude of land use changes as well as broader contextual information.

Accurately monitoring land use changes is the foundation for assessing the sustainability of biofuels. This analysis provides evidence that RS can be used as a cost-effective tool for monitoring land *cover* changes associated with biofuels and, when combined with ancillary data, land *use* changes. A more detailed categorization of land use changes than broad categories such as grassland and cropland is beneficial because it provides insight into land use dynamics and provides more detailed information on which to better assess impacts on carbon stocks.

Basic monitoring of land use change requires accurate and timely (yearly to every few years) mapping of specific biofuel crops, pastoral rangelands, natural grasslands, forests and other land cover types including developed lands, exposed ground, water, etc. Imagery such as MODIS has, to date, not been used for detailed mapping owing to its coarse scale, but recent research shows that MODIS 250m resolution 16-day NDVI imagery has been used to map crops within the Great Lakes region of the USA with a reported accuracy of 84% (Shao *et al*, 2009). The US Cropland Datalayer is the best publically available dataset in the US that includes many (but not all) of the requirements for basic monitoring.

Analysis of the CDL, which combines RS and ancillary data, demonstrates that:

- Annual national monitoring of croplands and non-croplands is possible even in a country as large as the USA.

- It can identify spatial distribution of different crop types including important biofuel crops. This is an improvement over other standard RS products that report general ‘cropland’ class.

- Accuracy at county scale (and coarser) is good for cropland identification. If analysis of smaller crop areas was necessary, or land use changes at a sub-county level were required, the CDL would likely be substantially less robust.

The analysis and subsequent discussion in this paper highlighted a number of drivers for observed land use changes in North Dakota. This represents challenge in attribution of indirect land use changes solely to biofuels. If this challenge is to be met, detailed data will be needed on the specific land use changes taking place. The analysis suggests some potential improvements to the CDL:

- A CDL that expands on the current version and includes improvements in the classification of non-cropland land cover classes could provide valuable insight into the location and extent of dLUC and potential iLUC caused by biofuel crop expansion.

- Improvements in classifications as well as techniques for identifying types of grassland would enable better assessments of whether croplands are expanding into idled cropland or degraded pasture or into native vegetation. This would enable a better assessment of risks to a) the magnitude of iLUC - idled croplands are a ‘buffer’ to accommodate cropland increases and, b) the magnitude of changes in carbon stocks – idled croplands will have lower carbon stocks than long term fallow and native vegetation.

Using RS to monitor land use change associated with biofuels in countries for which no CDL were available would likely require:

a. RS imagery, such as IRS AWiS (50m resolution) or Landsat (30m resolution) for the entire assessment area for multiple times during a given year;

b. Spatially explicit agricultural statistics that could be used to help train the RS spectral signature, and verify crop type for specific locations;

c. Statistics that report crop cycles for a given year so that green-up and harvest dates could be correlated with RS imagery;

d. Other ancillary data such as digial elevation models, ecological zone maps, rainfall data, etc.

Using remote sensing data to monitor land use changes associated with biofuels could be resource intensive. A multi-scale approach to assess the relationship between biofuels and LUC would combine coarse-scale imagery to map hotspots where further in-depth RS analysis could be conducted to more accurately assess direct and potential indirect land use changes. Appropriate classification for land cover/land use classes should be developed that includes the important croplands and non-cropland land cover types in the region. It is possible that very detailed cropland classes would not be necessary, providing the classification includes all biofuel crop types and other major crop types. Based on the findings of this paper, the following activities would support the development of appropriate monitoring for biofuels but are also relevant for wider monitoring applications that concern land use change:

- Further investigation into MODIS 16-day NDVI data for monitoring land use should be conducted to enable its use at national and sub-national scales. Currently, the most useful RS imagery for classifying and monitoring biofuel-related LUC is moderate resolution (30-60m) imagery at national to sub-national scales because it provides relatively good detail with relatively limited resources. However, recent research suggests this coarser resolution (>60m) data has the potential to deliver useful information.

- Further research is needed to better define grasslands in different regions and climates. This would encompass grassland biophysical properties (field measurements including biomass, grass water content, canopy height, soil properties) and management information. For pasture this would include stocking rate, grazing rotation and timing of grazing compared with RS data to evaluate grassland/pasture condition and grazing impacts.

- Techniques to identify land cover categories should be developed to correlate with total carbon stock so that emissions can be better estimated, e.g. grassland which is idled cropland vs. long term native grassland). Ultimately, an assessment of biofuel LUC would not only identify areas that are detrimental for biofuel development (higher biomass and increased emissions), but also areas where the expansion of biofuels would be beneficial (reduce emissions and provide economic/social development opportunities).

Any RS analysis will require detailed accuracy statistics for every year it is produced. Remote sensing is an incredibly powerful tool, but while primary literature may report "good results" in classification accuracies, policy decisions should be based on standards for RS that justify the potentially incurred benefits (e.g., increased international investment) or penalties (e.g., fines or no investment). At this time the author is not aware of any such standards, besides suggested standards for forest area monitoring from GOFC-GOLD that indicates a minimum 80% accuracy of a map that distinguishes the relatively straightforward classes of forest vs. non-forest[27].

[27] http://www.fao.org/gtos/gofc-gold/.

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APPENDIX 1

A. Cropland Data Layer Classification North Dakota 2009 and Reclassification

Table 8, below, is the Cropland Data Layer (CDL) classifications for 2009. The table includes the reclassification of the CDL used for this analysis. The table is organized first by the specific crop types used in this study, other crops, then non-cropland land cover. Each of these categories is ordered from most to least by area.

Table 8: Cropland Data Layer (CDL) classifications for 2009.

CDL Class 2009	Reclassification	Area ha	Area ac
Spring Wheat	Wheat	2,890,064	7,141,515
Soybeans	Soybean	1,583,327	3,912,493
Corn	Corn	823,442	2,034,774
Durum Wheat	Wheat	581,819	1,437,709
Winter Wheat	Wheat	187,087	462,303
Other Hays	Other crops	899,243	2,222,082
Canola	Other crops	326,371	806,481
Sunflowers	Other crops	312,696	772,689
Dry Beans	Other crops	206,838	511,109
Barley	Other crops	201,133	497,011
Peas	Other crops	164,814	407,264
Alfalfa	Other crops	105,730	261,266
Flaxseed	Other crops	83,024	205,157
Sugarbeets	Other crops	73,352	181,257
Lentils	Other crops	59,777	147,713
Oats	Other crops	42,150	104,154
Potatoes	Other crops	31,558	77,981
Millet	Other crops	4,802	11,867
Safflower	Other crops	4,752	11,742
Sorghum	Other crops	2,995	7,401
Other Crops	Other crops	2,539	6,275
Rye	Other crops	2,221	5,487
Mustard	Other crops	2,153	5,320
Seed/Sod Grass	Other crops	1,036	2,559
Clover/Wildflowers	Other crops	583	1,441
Other Small Grains	Other crops	407	1,006
Camelina	Other crops	65	161
Misc. Vegs. & Fruits	Other crops	35	87
Herbs	Other crops	33	82
NLCD - Grassland Herbaceous	Grass/Pasture/Non-Ag	5,563,937	13,748,809
NLCD - Pasture/Hay	Grass/Pasture/Non-Ag	1,168,830	2,888,246

CDL Class 2009	Reclassification	Area ha	Area ac
NLCD - Developed/Open Space	Developed/Barren	917,158	2,266,351
NLCD - Open Water	Water	669,882	1,655,318
NLCD - Herbaceous Wetlands	Wetlands	639,850	1,581,107
NLCD - Deciduous Forest	Forest	325,686	804,788
NLCD - Woody Wetlands	Forest	133,167	329,063
Fallow/Idle Cropland	Fallow/Idle Cropland	101,192	250,051
NLCD - Shrubland	Shrubland	64,121	158,446
NLCD - Developed/Low Intensity	Developed/Barren	62,767	155,101
NLCD - Barren	Developed/Barren	22,873	56,521
NLCD - Evergreen Forest	Forest	20,507	50,674
NLCD - Developed/Medium Intensity	Developed/Barren	12,252	30,276
Wetlands	Wetlands	6,333	15,650
NLCD - Mixed Forest	Forest	5,626	13,902
NLCD - Developed/High Intensity	Developed/Barren	2,931	7,242
Woodland	Forest	1,493	3,689

Note: CDL classes were not consistent for every year.
Note 2: Accuracy statistics are only available for cropland classes.

B. North Dakota County Maps

Figure 18: North Dakota County Maps