A Bottom-Up Assessment of Land Use Related to Corn Ethanol Production

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Executive Summary

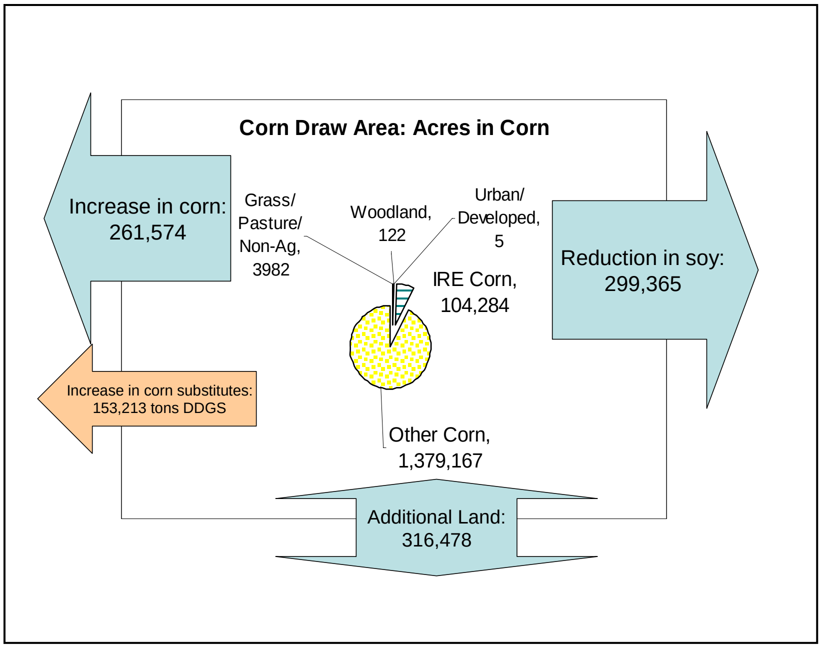
This study conducted by the University of Illinois at Chicago Energy Resources Center determined if corn extensification (conversion of non agricultural land to corn) and corn intensification (conversion of non-corn crop acres to corn or increased yield in current corn acres) occurred within the vicinity of an ethanol plant and if the ethanol plant was the likely cause of these effects. In addition to land use change, the present study also examined the land carbon balance for corn produced to supply the plant. The selected ethanol plant is the Illinois River Energy Center (IRE) currently operating at 58 mgpy. The plant is located in Rochelle, Illinois and it started operating in December, 2006.

The study combined remote sensing (USDA NASS cropland data layer derived from AWiFS) with a survey of 29 growers supplying corn to the ethanol plant. The present study determined corn-ethanol related land use changes from the "bottom-up": by carefully examining changes to each acre of land in the vicinity of the selected ethanol plant.

The USDA Cropland Data layer imagery was evaluated by creating a mask of 2007 corn and using it to mask out the same locations in the 2005 and 2006 cropland data layer. Simultaneously, a routine was applied to subtract a ¾ acre buffer along roadways and field edges. This avoided incorrectly categorizing 85,329 acres of corn as land use changes from non agricultural land when in fact field edges and roadway buffers triggered a misclassification.

Besides field edges additional incorrect classifications were avoided for 26,616 acres by confirming that these acres were in continuous crop rotations rather than going from agricultural use to non-agricultural use and back to agricultural use as the NASS data originally suggested. Test samples confirmed that a) roadway buffers and field edges are often classified by NASS as land use changes and b) that ag to non-ag and back to ag land use changes are improbable. With that the study documented that there is a substantial possibility for errors with a tendency toward indicating a greater percentage of land use change (as most mis-classifications are wrongfully identified as change) when applying remote sensing to ethanol related land use studies. Pre-existing datasets should only be used in the context that they were developed with an understanding that errors from year to year will amplify when comparing land use change.

The figure illustrates the corn balance within the growing area as well as exports from the area. From the 2006/2007 growing season only 4,109 acres (3,982+122+5) were converted from non-ag use such as grass, pasture, or woodland to corn growing (0.28% of the 1.487 million acres in corn). Conversion did not occur despite the fact that an additional 316,478 acres of land would have been available for

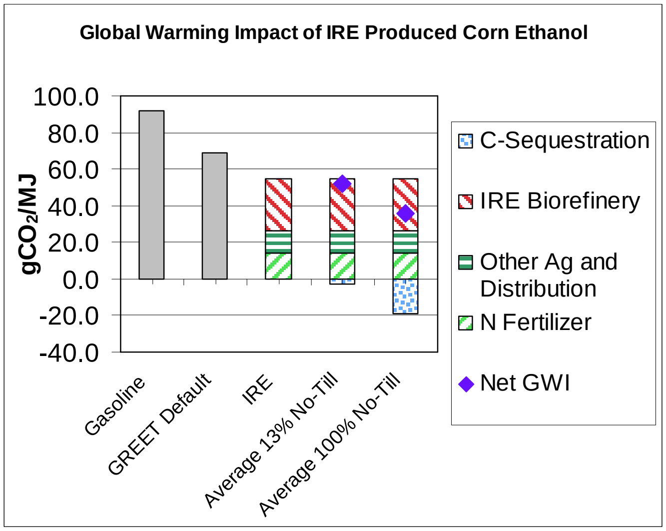


conversion to agriculture within the corn draw area. Therefore, it can be concluded that the start-up of the IRE plant did not promote corn extensification (the conversion of non-ag acres to corn).

IRE requires 20,450,000 bushels of corn to produce 55 mgpy of corn ethanol on an annual basis. At the surveyed yield of 196.1 bu/acre the 2007 land requirements totaled 104,284 acres. However, corn production in the corn draw area went up by 261,574 acres (2.5 times the IRE corn requirements) while soy production went down by 299,365 acres (almost 3 times the acres required for IRE corn production). Clearly, while IRE may have had a small influence towards corn intensification, other variables (maybe economics, high export demand) seemed to drive corn intensification. Furthermore, counting DDGS production as a corn co-product, yield increases within the draw area were sufficient to meet IRE's corn requirements. We realize that yields change over time and that the current study presents a snapshot of events.

Finally, based on the assessed crop rotations and surveyed tillage practices, the study calculated N_2O emissions and carbon sequestration rates according to several methodologies documented in the literature. In summary, N_2O emissions and carbon sequestration effects could be of the same magnitude. The increased carbon sequestration from no-till and winter cover crops can provide significant reductions to the GWI of corn ethanol. Therefore, ethanol plant operators could encourage these practices in their region.

The IRE GWI Study found that the life cycle global warming impact of corn ethanol produced at the plant totals 54.8 gCO_2e/MJ, which is 21% lower than the current GREET default natural gas dry mill corn ethanol plant and 40% lower than gasoline. Subtracting the average sequestration numbers for the 13% of IRE supply acres under no-till/strip till (CCX, UIUC, UIES average values for 13% no-till) from the life cycle of IRE corn ethanol of 54.8 gCO_2e/MJ reduces it to 52.2 gCO_2e/MJ. Subtracting the average sequestration numbers for encouraging 100% no-till on IRE supply acres from the life cycle of IRE corn ethanol reduces it to 35.9 gCO_2e/MJ. Since, as a first order estimate, encouraging 100% no-till in this case is likely equivalent to encouraging 50% no-till and 50% winter cover crops these practices would alternatively result in a GWI of 35.9 gCO_2e/MJ at IRE. These values exclude GWI contributions from indirect/international land use changes since, as demonstrated, IRE did not measurably effect land use.



GWI of IRE Produced Corn Ethanol

1) Introduction

Land use change can be determined according to several methods including a) conducting a census, b) using economic indicators, and c) using remote sensing. The Farm Services Agency does indeed conduct a census and assesses the land use for each field. However, this data is not publicly available. Several economic models (global equilibrium models such as GTAP) use land rent value as a proxy for land use change. We believe that remote sensing provides the second most accurate method for land use change studies next to conducting a census.

The USDA uses satellite data combined with survey data to determine their Crop-Production Report (posted on www.nass.usda.gov). Furthermore, it is our understanding that future land use studies related to corn ethanol may utilize satellite based data sets instead of the land rent assumptions and combine these data sets with national and global economic models.[i]

The present study also utilizes remote sensing combined with survey data. However, in contrast to economic modeling the present study determines corn-ethanol related land use changes from the "bottom-up": by carefully examining changes to each acre of land in the vicinity of a selected ethanol plant.

The ethanol plant is the Illinois River Energy Center (IRE), located in Rochelle Illinois, about 80 miles west of Chicago. IRE produces about 58 million gallons per year with an expansion underway to double capacity. The plant started operation in December 2006. Therefore, the time horizon for the land use analysis spans the years 2005 through 2007.

The study attempts to determine if conversion of non-agricultural land to corn (corn extensification) occurred around IRE and if IRE is its likely cause. Secondly, the study attempts to determine if conversion of non-corn crop to corn (corn intensification) occurred and if IRE is its likely cause. In addition to land use change, the present study also examines the land carbon balance from IRE corn ethanol production. By using remote sensing for this type of "bottom-up" analyses the present study is able to determine the possibilities and limitations of remote sensing for other corn ethanol related land use studies.

The present study builds on an earlier study titled "The Global Warming and Land Use Impact of Corn Ethanol produced at the Illinois River Energy Center." The earlier study will be referred to as the "IRE GWI Study" throughout this report.

2) Data

The present study is based on two data sets: a survey of growers delivering corn to IRE and USDA NASS cropland data layer derived from satellite imagery. Both data sets are discussed below.

2.1) Grower Survey

This data was collected as part of the IRE GWI Study. Since some of the data is used in the present study we will summarize some of the key findings. A survey was conducted with 29 corn growers supplying 2,528,850 bushels of corn to IRE or 12% of all delivered bushels (representative of about 6.9 million gallon of ethanol production). The survey assessed key agricultural variables including yield, fertilizer inputs, and tillage practices.

a) Yield

As summarized in Table 1 the survey respondents report steady average yield increases between the 2005, 2006, and 2007 growing seasons. Yields in 2007 at 196.1 bushels per acre are on average 17% higher than those in 2005. The consistent standard deviations indicate that no single farmer introduced a significant bias in any one year.

Table 1: Surveyed Yields

	2005 Bu/acre	2006 Bu/acre	2007 Bu/acre
Yield	167.4	183.1	196.1
STD	23.3	23.3	19.5
N=28			

b) Tillage

The respondents were asked whether they employ a) conventional tillage, b) minimum tillage, c) no till, or d) strip till. The tillage methods differ by the amount of biomass left above ground: Conventional tillage leaves less than 10% of biomass above ground, minimum till leaves 30% to 60% above ground, strip till about 70-80%, and with no till about 90% of the biomass remains on top. Applying the surveyed percentages of practiced tilling to the amount of corn delivered to IRE results in a conservation tillage rate (generally defined as no-till plus strip till) of 13%. The results are shown in Table 2. The analysis assumes that farmers apply the same tillage practices to all of their farm land including land used for IRE production.

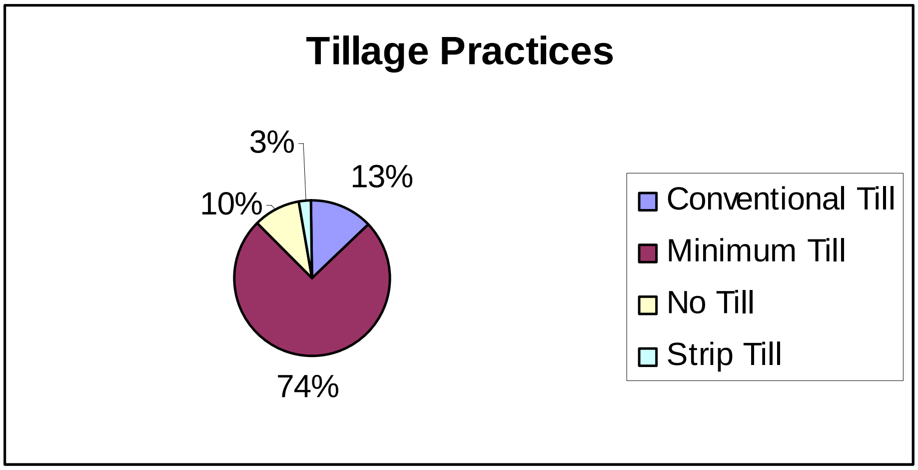


Figure 1: Surveyed Tillage Practices
Note: Graph is based on 2,478,850 delivered bushels. One farm did not report tillage practices

c) Nitrogen

The survey asked respondents what type of fertilizer products they use. Table 2 shows the results.

Table 2: Type of Fertilizer Product Used

	Nitrogen as NH_3	Nitrogen as 28%	Nitrogen as 32%	N-P-K as 18-46-0	N-P-K as 0-46-0	N-P-K as 0-0-60	Ammonium Sulfite	Ag-Lime
Number of Growers	17	5	13	14	6	21	1	8
N=27								

All surveyed growers apply nitrogen fertilizer to the crop. The most common form of nitrogen fertilizer used is in anhydrous form as NH_3 (ammonia). Some growers use 32% liquid N fertilizer and 28% liquid N fertilizer, often in combination with NH_3.
On average 368 g/bu of nitrogen are applied. Where growers apply nitrogen via a combination of NH_3, 28%, 32%, or 18-46-0 the total amount of N is calculated based on the mass fraction of N.[ii] The resulting fertilizer input values are listed in Table 3.

Table 3: Nitrogen Application

	lb/acre	g/bu
Mean	159	368
STD	40	90
N=27		

2.2) Satellite Imagery

Land use change can be determined according to several methods including a) conducting a census, b) using economic indicators, and c) using remote sensing. The Farm Services Agency does indeed conduct a census and assesses the land use for each field. However, this data is not publicly available. Several economic models (global equilibrium models such as GTAP) use land rent value as a proxy for land use change. We believe that remote sensing provides the second most accurate method for land use change studies next to conducting a census. Therefore, the IRE GWI study used remote sensing in its analysis.

The original IRE GWI Study identified land use change and crop rotation practices over the last three years by correlating the USDA NASS Cropland Data Layer (for crop types) and the national land cover dataset (for non-cropland conversions). While the USDA Cropland Data Layer has been shown to have accurate methods of around 95% for the delineation of corn and soybeans (Johnson 2007a,b) and that dataset is updated every year, the national land cover data set dates back to 2001 and introduces much higher uncertainties for non-agricultural areas.

The IRE GWI Study found that the NASS data suggests land use changes from non-crop land such as pasture land, woodland, etc. to crop land, which must be viewed with great caution. In fact the analysis conducted for the original IRE GWI Study identified several thousand acres of land converting from non ag use to ag use within the corn draw circle. Furthermore, the study found that significant additional acres would have rotated from ag use to non-ag use and back to ag use over the last 3 years, an unlikely scenario. Therefore, the present study analyzes NASS cropland data layers by a) applying an algorithm to the data that subtracts roadway buffers and field edges from the land use data, and b) sampling and closely examining illogical land use changes such as ag to non-ag to ag conversions.

3) Analysis

3.1) Corn Draw Area

The first step in the process was to create a draw area boundary for the Rochelle ethanol plant. Two different methods were used: a circle method and the ProExporter Network Polygon approach. Both methods are detailed below.

The circle method uses the address of the ethanol plant as the center point and survey information on growers delivering from farthest away as the radius. The surveys showed that growers deliver from as far as 40 miles away to the plant. Therefore, a 40 mile radius was developed as a geographic information system (GIS) polygon file (see Figure 2). This circle represents the approximate draw area for corn required for the production of ethanol by the plant.

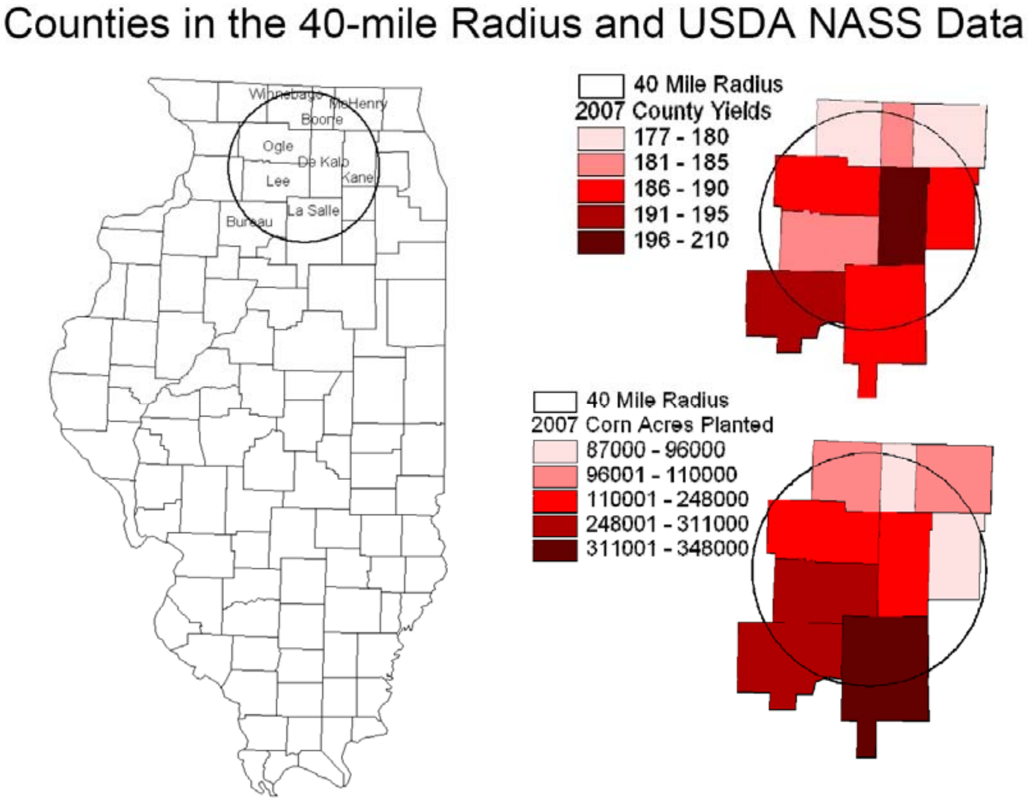


Figure 2: GIS Corn Draw Area

While the circle approach above uses survey information from the growers delivering from furthest away, the PRX Polygon combines survey information with geographic and economic variables.[iii] Geographic variables, for example, include the influence of urban areas on corn draw areas; sample economic variables include competition for grain between grain elevators and ports or railroads supporting export markets. It should be noted that, since this analysis is done at the plant level, the approach fits well within the bottom-up land use assessment context. The PRX Polygon development is offered as a for fee service to grain producers and ethanol plants. Courtesy of PRX, we have obtained the Polygon for the IRE plant in order to compare the Polygon approach to the circle approach.

As can be seen in Figure 3 the PRX Polygon for IRE differs from the circle: The Rockford urban area in the north and the Chicago urban area to the east push the corn draw area asymmetrically to the south. Furthermore, access to highways shape the draw area primarily on the southwestern fringe. However, as can be seen, the 40 mile radius circle chosen in our analysis substantially encompasses the PRX polygon. Therefore, a good match between the PRX Polygon and the 40 mile circle confirms that the analysis substantially covers the IRE corn draw area. For further analysis, the circle method was chosen because we felt that this method could be replicated more easily for future, additional corn draw area studies.

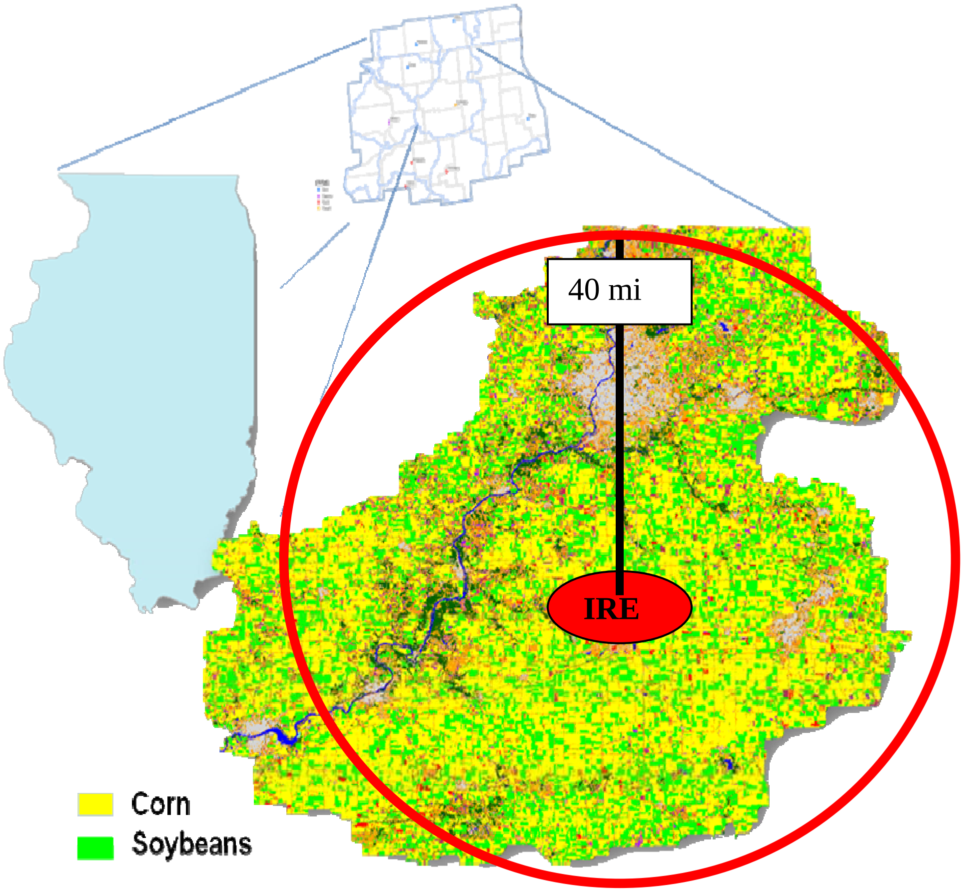
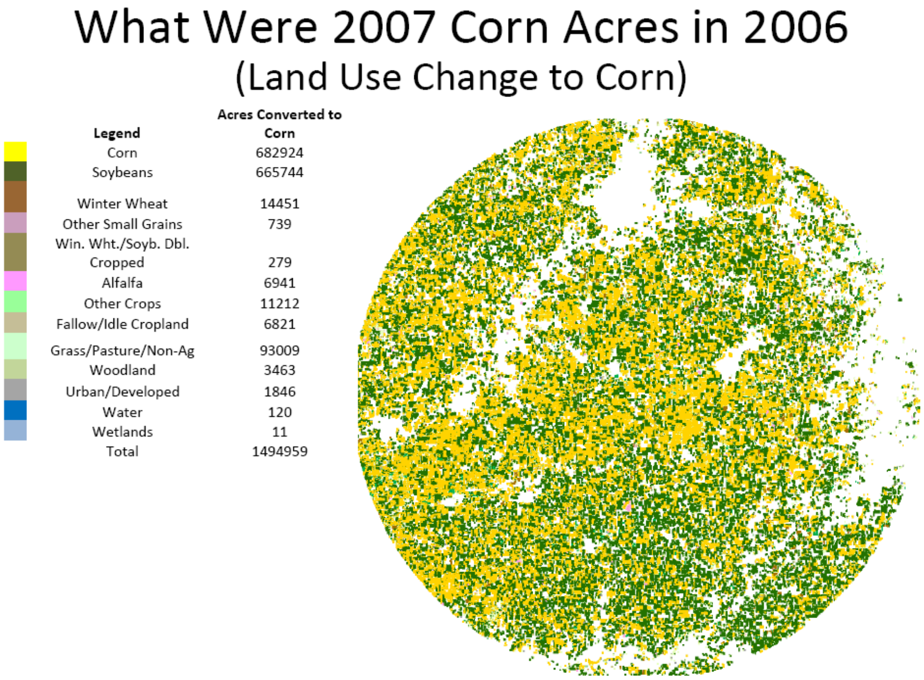


Figure 3: ProExporter polygon for Illinois River Energy plant

3.2) Corn Extensification

Based on the established corn draw area, the analysis in this section determines conversion of non-ag land to corn. The first step of this analysis combined USDA NASS Cropland Data Layer with the circle file (see Figure 4). The USDA NASS Cropland Data

Layer is a spatial crop type map developed from satellite imagery. The Cropland Data Layer has been shown to have accurate methods of around 95% for the delineation of corn and soybeans (Johnson 2007). NASS is only interested in crop land acreage and that data is updated every year. Classification of all land other than crop was performed using the national land cover dataset which was developed in 2001 also using remote sensing via satellite. (Homer 2007). Since the national land cover data set is dated higher uncertainties exist for land covers other than crops assessed in this study.



	Legend	Acres Converted to Corn
🟨	Corn	682924
🟩	Soybeans	665744
🟫	Winter Wheat	14451
🟪	Other Small Grains	739
🟫	Win. Wht./Soyb. Dbl. Cropped	279
🟪	Alfalfa	6941
🟩	Other Crops	11212
🟫	Fallow/Idle Cropland	6821
🟩	Grass/Pasture/Non-Ag	93009
🟩	Woodland	3463
⬜	Urban/Developed	1846
🟦	Water	120
🟦	Wetlands	11
	Total	1494959

Figure 4: Land Use of 2007 Corn Acres in 2006

Once the crop types were extracted for the ethanol plant draw area using the 2005, 2006, and 2007 Cropland Data Layers, analysis was performed to calculate the acres in corn in 2005, 2006, and the acres in corn in 2007. This is a straightforward process using the spatial data from the satellite classification. Each pixel (minimum discernable ground unit) of the satellite was 30 square meters in 2005 (Landsat satellite) and 56 square meters in 2007 (AWiFS sensor). AWIFS data has a revisit time for every location of every 5 days whereas Landsat has a revisit time of 16 days. Therefore AWIFS exhibits a higher accuracy for crop type detection. Going forward USDA will use AWiFS imagery.

A simple equation converted each pixel to acres to derive the spatial “mask” of corn acres in 2007. The mask of corn acres from the 2007 Cropland Data Layer was used to mask out the same locations in the 2005 and 2006 Cropland Data Layer. Again, the pixels were multiplied by acres to derive acreage for the land use of the masked area in previous years. The acres for each crop type derived with the above approach are listed in column 1 of Table 4 (NASS Unvetted). This data is identical to the data used in the IRE GWI study.

As part of the present study additional vetting of the data was performed by applying a routine to the masked area that subtracted a ¾ acre buffer along the roadways. As a result a total of 85,329 acres that were originally primarily categorized as grass/pasture/non-ag conversion to corn were now correctly identified as a mix of nonag use and corn and treated as neutral. It is generally the case that a mixed parcel consists of small strips of roadway, for example, and a larger area of corn with the roadway prompting the misclassification. The test samples in Figure 6 confirm that these parcels were indeed roadway buffers around agricultural land. Furthermore, an additional 26,616 acres which, in the imagery evaluation routine were classified as ag to non-ag to ag conversion (an unlikely scenario) were categorized separately. Test samples again confirmed that ag to non-ag to ag conversions are misclassifications and that the land was in fact in continuous agriculture (see Figure 6). With 111,945 acres in these two categories a corresponding decrease in the following categories was observed: urban areas to corn; woodland conversions to corn; grass pasture to corn conversions; grass/clover wildflowers to corn; fallow/idle cropland to corn. Additional test samples in each of these categories were taken and analyzed to confirm that, in fact, the decreases in these categories from the applied data vetting routines are justified. All samples showed that no actual land use change had taken place. These test samples are shown in Appendix A.

Table 4: Rotations into Corn from 2006 to 2007

Land Use	2007 Crop Acres in 2006		
	NASS Unvetted Acres	NASS Vetted Acres	
Corn	682,924	680,340	
Soybeans	665,744	661,660	
Winter Wheat	14,451	15,026	
Other Small Grains	739	274	
Win. Wht./Soyb. Dbl. Cropped	279	110	
Alfalfa	6,941	3,060	
Other Crops	11,212	9,428	
Fallow/Idle Cropland	6,821	1,608	
Grass/Pasture/Non-Ag	93,009	3,982	Non-ag to corn
Woodland	3,463	122	
Urban/Developed	1,846	5	
Water	120	0	
Wetlands	11	0	
Ag 2005 to Non-Ag to Ag Land		26,616	
Field and Roadway Fringes		85,329	
Total Analyzed	1,487,560	1,487,560	

The vetted data in column 2 of Table 4 indicates that only 4,109 acres were potentially converted from non-ag use to corn growing (0.28% of the 1.487 million acres in corn). Therefore, it can be concluded that the start-up of the IRE plant did not promote corn extensification (the conversion of non-ag acres to corn). Furthermore, conversion did not occur despite the fact that additional land would have been available for conversion to agriculture within the corn draw area. Table 5 below lists all acres additional categories that did not convert into cropland from 2006 to 2007.[iv] As can be seen more than 315,000 acres of additional land in categories where one could have expected a substantial conversion to corn. These conversions did not occur.

Finally, the study documented that there is a substantial possibility for errors when applying remote sensing to ethanol related land use studies. Without applying sophisticated masking routines, 111,945 acres (85,329+26,616) would haven been incorrectly identified as land use changes to corn.

Table 5: Non-ag Land within the IRE Corn Draw Area

Land Use	Acres
Fallow/Idle Cropland	5,227
Grassland herbaceous:	35,359
Grass/Pasture/Non-Ag	16,782
Pasture/hay	259,110
Total:	316,478

Test Samples: Errors from Roadways, Field Edges, and Building Structures were Eliminated with Buffer Routine

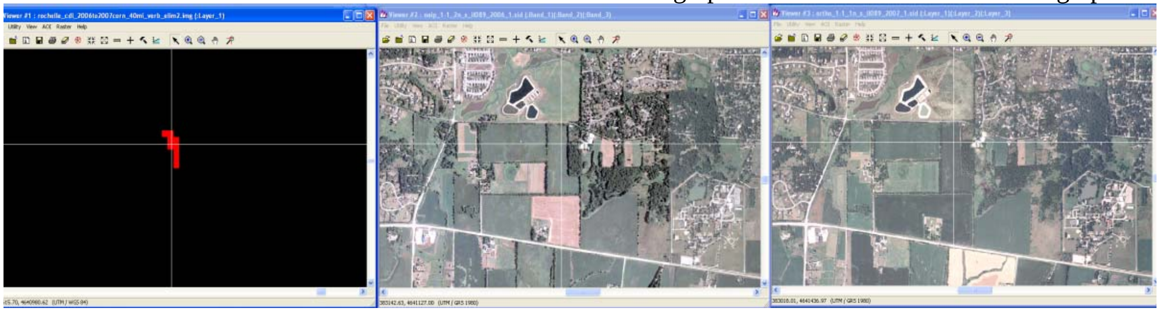
Pixels along field edges, roadways, and building structures are often a mixture of signals. These areas may fluctuate between agriculture and non-agriculture from year to year.

Area along roadway 2006 Aerial Photograph 2007 Aerial Photograph

This 11 acre area of roadway between two agricultural fields was identified as agriculture in 2006 and urban in 2007. Areas like this are often mis-classified when assessing land use change and were therefore removed from the project analysis.

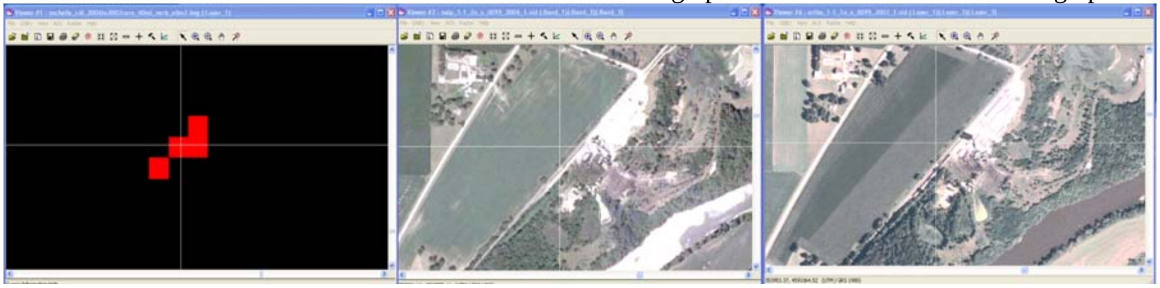
Areas identified as woodlands in 2006 and corn in 2007 (122 acres were estimated)

Area identified as woodlands to corn 2006 Aerial Photograph 2007 Aerial Photograph



This seven acre area was classified as woodlands in 2006 and corn in 2007 but appears to have been in agricultural production both years. Trees surrounding the field may have led to the mis-classification in 2006.

Area identified as urban to corn 2006 Aerial Photograph 2007 Aerial Photograph



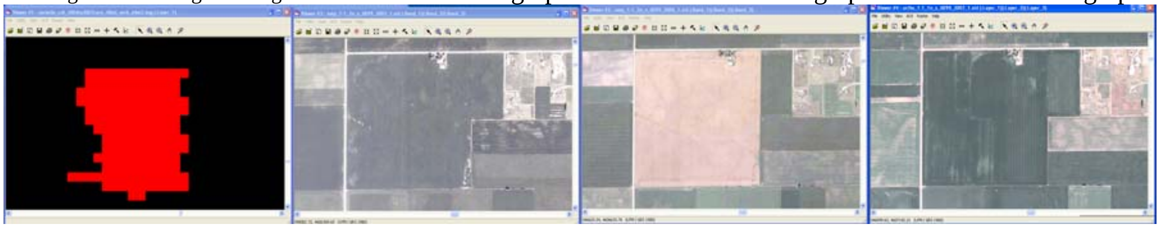
This five acre area (in red to the left) was identified as a land use change from urban in 2006 to corn in 2007. Aerial photography from each year indicates that the area was an agricultural field in both years. Its proximity to the buildings to the right probably caused the confusion in the classification.

Figure 5: Errors in Land Use Changes from Roadways and Field Edges

Test Samples: Ag to Non-Ag to Ag Conversions Were Excluded as Improbable

Areas identified as agriculture in 2005 to a non-agricultural area in 2006 and then back to an agricultural area in 2007 were excluded from the analysis as improbable scenarios

2005 Ag/2006 Non-Ag/2007 Ag
2005 Aerial Photograph
2006 Aerial Photograph
2007 Aerial Photograph



This 114 acre field was identified as an agricultural area in 2005, a non-agricultural area in 2006 and an agricultural area in 2007. Based on the aerial photography, the area remained in agriculture in 2006. Likely, the field was planted late but even if it was left fallow it would still be considered agriculture.

2005 Ag/2006 Non-Ag/2007 Ag
2005 Aerial Photograph
2006 Aerial Photograph
2007 Aerial Photograph

These 45 and 11 acre fields also appear to be late plantings or fallow in 2006 which may have led to the mis-classification as non-ag areas in 2006, but it is clear that this is not a land use change location.

Figure 6: Errors in Land Use Changes Resulting in Ag to Non-ag to Ag Conversions

3.3) Corn Intensification

The analysis in the last section on corn extensification determined if, potentially driven by the new ethanol plant, non-agricultural land went into new corn production. Conversely, this section looks at corn intensification: whether the new ethanol plant may have influenced crop conversions from non-corn crops to corn.

As shown in Table 6, IRE requires 20,450,000 bushels of corn to produce 55 mgpy of corn ethanol on an annual basis. At the surveyed yield of 196.1 bu/acre the 2007 land requirements totaled 104,284 bushels. However, corn production in the corn draw area went up by 261,574 acres (2.5 times the IRE corn requirements) while soy production went down by 299,365 acres (almost 3 times the acres required for IRE corn production). Clearly, while IRE may have had a small influence on corn intensification, other variables (maybe economics, high export demand) seemed to drive corn intensification.

The current IRE land demand of 104,284 amounts to 7% of the total corn acres within the corn draw circle, a relatively small fraction of corn acres. While 7% of corn acres are diverted to IRE corn ethanol production, yield increases in the corn draw area between 2007/2006 and between 2006/2005 were 5.4% and 11%, respectively. In other words, the corn requirements for IRE were almost met by yield increases in the corn draw area. Counting DDGS produced at IRE as a corn-substitute co-product, IRE's corn supply/co-product balance was likely met by yield increases alone. We recognize that this is a snapshot of past conditions and yields may vary over time.

However, a recent report estimates national yields to reach 289 bu/acre by 2030 (Korves, 2007). If this is the case for the IRE corn draw are, the IRE land requirements would drop from currently 104,284 acres to 70,761. If corn acreage stays the same in the corn draw area, IRE will require only 4.8% of the land for its corn supply.

Table 6: Corn Intensification within the IRE Corn Draw Area

	2007	**2006**	**2005**
Corn Yield IRE Grower Survey (bu/acre)	196.1	186.1	167.4
Corn Yield Increase 2007-2006	5.4%		
Corn Yield Increase 2006-2005		11.2%	
IRE Delivered Corn (bu)	20,450,000		
IRE Required Acres	104,284		
IRE Acres as Percent of Corn Draw Area	7.0%		
Corn Acres	1,487,560	1,225,986	1,158,809
	261,574		
Soy Acres	540,975	840,340	851,540
	-299,365		

In summary, we conclude that much larger adjustments in corn vs. soy acres have taken place than could have been prompted by IRE’s operation: Corn intensification cannot be attributed to the operation of the ethanol plant.

4) CO_2 Sequestration and N_2O Emissions

Greenhouse gas emissions from most agricultural systems (rice excluded) are primarily driven by the balance between N_2O emissions and carbon sequestration. Emissions and sequestration assessments differ by a large variety of variables (soil type, climate, management practices). Likewise, the employed methods that quantify emissions and sequestration effects differ by the treatment of these variables. The IRE GWI study assessed emissions and sequestration effects for the IRE corn draw area according to several methodologies including those by Mummey et al (1998) and Eve et. al. (2002). Since these assessments depend on crop rotations and since the present study produced more accurate land use change data, we must first reassess crop rotation patterns as well.

4.1) Crop Rotations

Using the vetted land use data detailed in Table 4 a model routine was created to reassess the crop rotations (of each 30 square meter location). In contrast to the above analysis, the model allows a location specific correlation: what was the specific land use of one particular acre in 2005, 2006, and 2007 (as opposed to how did the land use change within a masked area analyzed above). Figure 7 and Figure 8 below show land use rotations are dominated by corn-soy-corn (34%) followed by corn-corn-corn (26%). The diversified category includes primarily rotations of wheat, small grains, and other crops to corn.

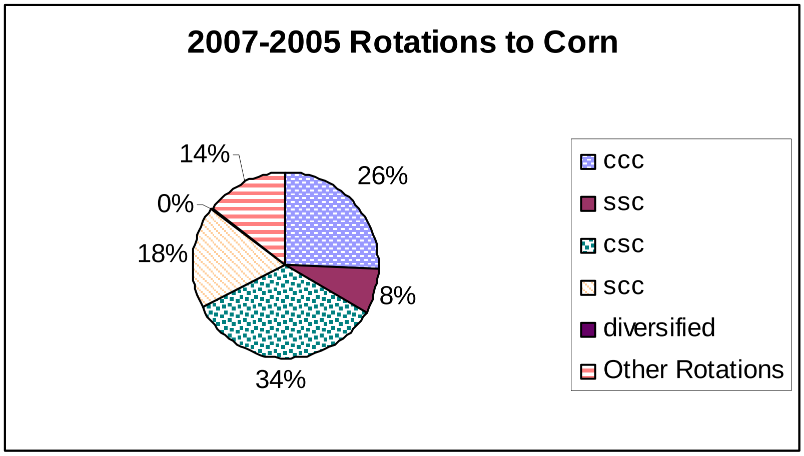


Figure 7: Land Rotations in Percent

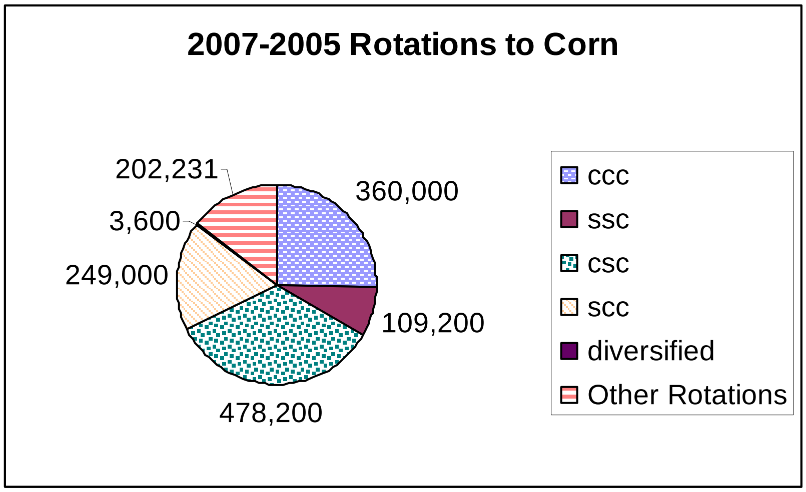


Figure 8: Land Rotations in Acres

4.2) N_2O Emissions and Carbon Sequestration

The N_2O Emissions below are calculated according to several different methodologies. Detailed background on the employed methodologies can be found in the IRE GWI Study.

Using the reassessed crop rotations and the surveyed tillage practices, the N_2O - Emissions based on Mummey et al (informed by Wander) total 15.09 g/bu or 91,403 tonnes CO_2e (from N_2O) for all bushels delivered to IRE (Mummey, 1998).[v,vi,vii] The supporting table is provided in Appendix B. The second methodology followed Argonne's GREET model, which is based on an emissions factor approach. The current GREET default value results in 11.7 g/bu or 70,822 tonnes of CO_2e emissions for IRE's corn demand. Applying the surveyed N-fertilizer inputs (368 g/bu or 0.811 lb of N per bushel) to the GREET emissions factor equation results in 10.6 g/bu or 64,164 tonnes of CO_2e emissions. Finally, several N_2O measurements using measurement chambers at the University of Illinois at Urbana Champaign yielded lower results in the range of 0.94 to 1.41 g/bu of CO_2e emissions (Wander, 1998). The midpoint of 1.2 g/bu resulted in 7,113 tonnes of CO_2e emissions.

While nitrogen inputs of 0.811 lb/bu are already fairly low a potential further reduction in nitrogen inputs could be possible. High fertilizer prices, sophisticated precision agriculture technologies, or government incentives may be potential drivers to reduce N inputs in the future. If we assume an N-input rate of 0.65 lb/bu (294.8 g/bu) close to the theoretical minimum and the GREET emissions factor equation, N_2O emissions drop to 9.1 g N_2O per bushel or 55,085 tonnes for the IRE demand.

CO_2 Sequestration effects were also calculated according to different methodologies. Using the reassessed crop rotations and the surveyed tillage practices, the CO_2 sequestration effects based on Eve et al. (informed by Wander) total 259 g/bu or 5,300 tonnes for all IRE bushels (Eve, 2002).[viii,ix,x] The supporting table is provided in Appendix B. For the Illinois region, the Chicago Climate Exchange (CCX) offers soil carbon management offsets of 0.6 metric tonnes per acre per year for agricultural land treated with conservation tillage practices. At the surveyed rate of 13% no-till/strip till for IRE acres the CCX rate would result in soil carbon management offsets of 8,134 tonnes per year (assumes 13% of 104,450 acres required for IRE supply or 13,560 acres use conservation tillage). A long term study by the University of Illinois Extension Service (UIES) measured carbon sequestration on fields in no-till since 1967. The study summary data is listed in Appendix C. Over a period of 12 years, the study determined an annual sequestration rate of 1.67 metric tonnes per acre, which, at a 13% no-till/strip till rate would result in 22,645 tonnes per year.[xi][xii]

There is further room for improvement. Using Eve et al and encouraging 100% no-till (as opposed to the currently practiced 13%) would increase CO_2 sequestration to 30,820 tonnes on IRE supply acres (but it would in turn slightly increase N_2O emissions in the Mummey model). Eve et al and direct measures show that adding winter cover crops could additionally double the carbon sequestration rates to 61,640 tonnes on IRE supply acres. Using the CCX factors, if we assume 100% no till on all IRE supply acres we calculate 62,570 metric tons of carbon management offsets. Using UIES sequestration values and going to 100% no-till would result in 174,432 tonnes of carbon sequestered per year. Also, since the survey showed no-till practices for 13% of acreage around IRE, carbon sequestration values according to CCX for all acres in the corn draw area were calculated. Based on these assumptions 13% of the 1.48 million acres would sequester 116,030 tonnes of CO_2. Using UIES sequestration values would result in 321,308 tonnes.

The Table 7 and Figure 9 below summarize the carbon assessment findings. The left y-axis displays the total carbon emissions/sequestration values on all acres supplying IRE (104,450 acres). The right y-axis displays the carbon emissions/sequestration values per heating content of ethanol produced. In summary, N_2O emissions and carbon sequestration effects could be of the same magnitude. The increased carbon sequestration from no-till and winter cover crops can provide significant reductions to the GWI of corn ethanol. Therefore, ethanol plant operators could encourage these practices in their region. If ethanol plants in addition to their own suppliers could take credit from encouraging no-till in their region, large additional GWI reductions could be possible.

The solid bars on the right represent the carbon emissions/sequestration values assuming 13% no till across the whole draw area and applying the CCX and UIES sequestration values (rather than for the IRE supply acreage only). If IRE was able to take credit for the sequestration associated with these no till efforts in its whole corn draw area, the contributions using CCX and UIES values would amount to 25 gCO_2e/MJ and 69.1 gCO_2e/MJ, respectively. The potential implication from this assessment is the following question: Should or could an ethanol plant be able to take sequestration credits for its product by encouraging no-till among farmers in an ethanol plant's whole draw area?

The IRE GWI Study found that the life cycle global warming impact of corn ethanol produced at the plant totals 54.8 gCO_2e/MJ, which is 21% lower than the current GREET default natural gas dry mill corn ethanol plant and 40% lower than gasoline (see Table 8 and Figure 10). Subtracting the average sequestration numbers for the 13% of IRE supply acres under no-till/strip till (CCX, UIUC, UIES average values for 13% no-till from

Table 7) from the life cycle of IRE corn ethanol of 54.8 gCO_2e/MJ reduces it to 52.2 gCO_2e/MJ. Subtracting the average sequestration numbers for encouraging 100% no-till on IRE supply acres from the life cycle of IRE corn ethanol reduces it to 35.9 gCO_2e/MJ. Since, as a first order estimate, encouraging 100% no-till in this case is likely equivalent to encouraging 50% no-till and 50% winter cover crops these practices would alternatively result in a GWI of 35.9 gCO_2e/MJ at IRE. These values exclude GWI contributions from indirect/international land use changes since, as demonstrated, IRE did not measurably effect land use.

Table 7: N2O Emissions and Sequestration Values

Metric Tons Sequestered on IRE Acres	**CO2e for IRE Supply Acres (tonnes/y)**	**IRE Ethanol GWI Contribution (g/MJ LHV)***
N2O: Mummey Factors	91,403	19.6
N2O: GREET Default	70,822	15.2
N2O: GREET IRE Customized	64,164	13.8
N2O: GREET N-Application Optimized	55,085	11.8
N2O: IL Measured	7,113	1.5
Sequestr.: UIUC Factors, 13% no till	-5,300	-1.1
Sequestr.: CCX CMO, 13% no till	-8,134	-1.7
Sequestr.: UIES, 13% no till	-22,645	-4.9
Sequestr.: UIUC Factors, 100% no till	-30,830	-5.8
Sequestr.: UIUC Factors, 100% no till, Winter Cover	-61640	-11.7
Sequestr.: CCX CMO, 100% no till	-62,570	-13.4
Sequestr.: UIES, 100% no till	-174,432	-37.5
Whole Draw Area: CCX CMO 13% no till	-116,030	-25
Whole Draw Area: UIES 13% no till	-321,308	-69.1

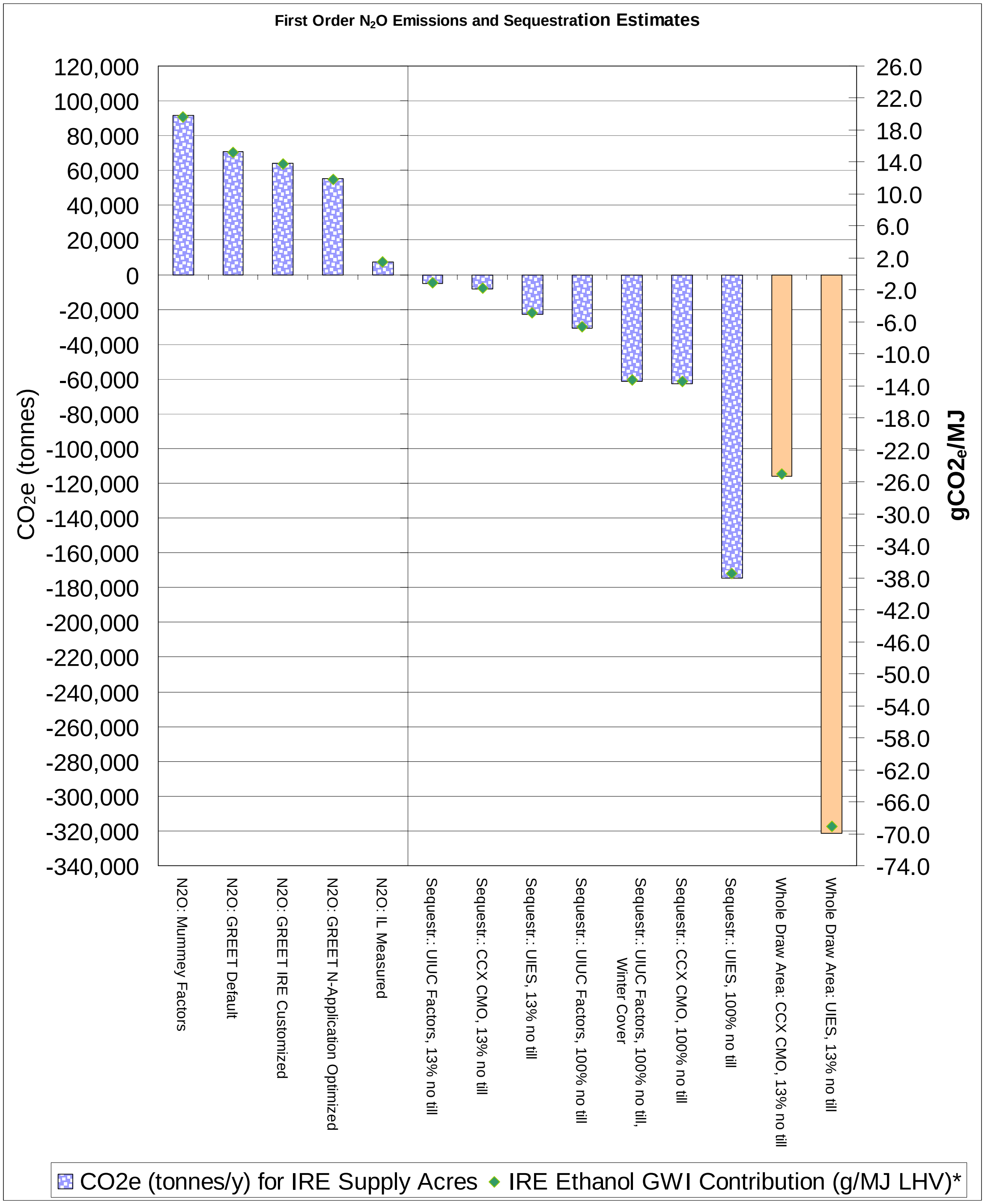


Figure 9: Carbon Assessment Summary

Table 8: GWI of IRE Produced Corn Ethanol

	Gasoline	GREET Default	IRE	IRE & Avg 13% No-Till	IRE & Avg 100% No-Till
N Fertilizer			14.2	14.2	14.2
Other Ag and Distribution			11.9	11.9	11.9
IRE Biorefinery			28.7	28.7	28.7
C-Sequestration			0.0	-2.6	-18.9
Net GWI	92.1	69.1	54.8	52.2	35.9

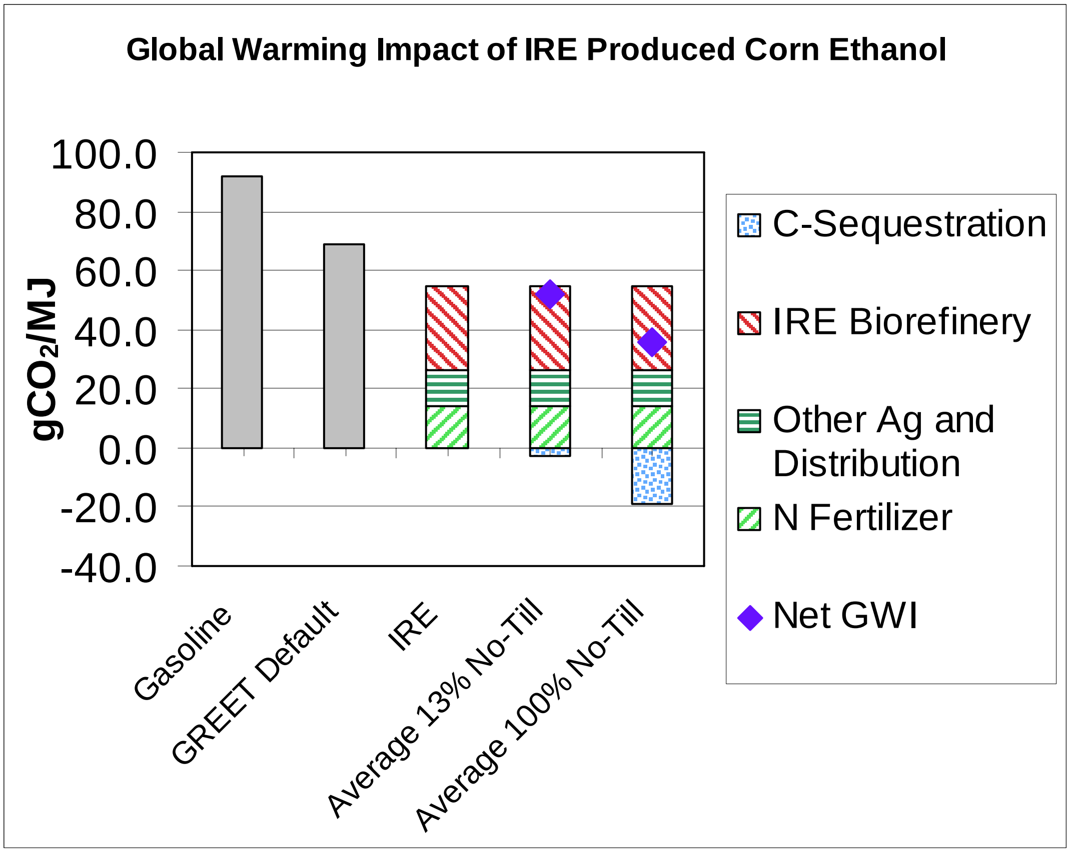


Figure 10: GWI of IRE Produced Corn Ethanol

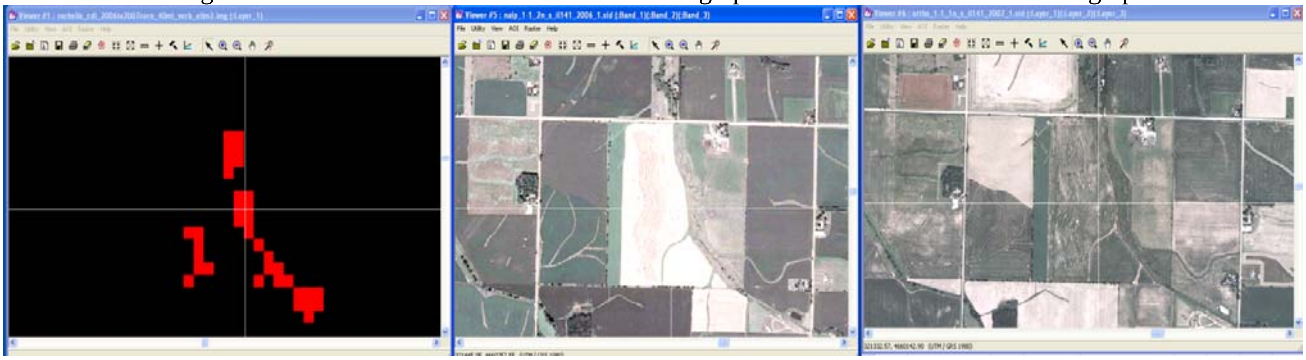
Appendix A: Examples of Errors in Non-Agriculture Land Use Change

Test Samples: The test samples below confirm that the data vetting routines correctly eliminate errors in land use change classifications. The decreases in several categories (woodlands to corn, grass/pasture to corn, grass/clover/wildflowers to corn) reflect the correct classifications.

Area identified as woodlands to corn 2006 Aerial Photograph 2007 Aerial Photograph

This six acre area that was classified as woodlands in 2006 and corn in 2007 appears to have been in woodlands both years according to the aerial photography from each year. Again, its narrow east to west dimensions may have led to pixels with a combination of agriculture and forestry being identified as each class in 2006 and 2007.

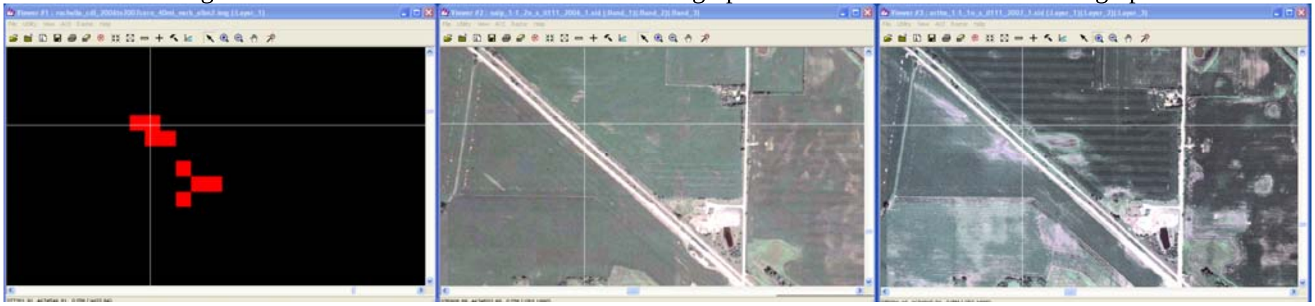
Grass/Pasture/Non-Ag in 2006 to Corn in 2007 (3,982 acres were estimated)



Area identified as grass to corn 2006 Aerial Photograph 2007 Aerial Photograph

This 21 acre field appears to be in bare soil but an agricultural field in the 2006 image which may have led to it’s classification as a non-agricultural area in 2006, but in corn production in 2007.

Area identified as grass to corn 2006 Aerial Photograph 2007 Aerial Photograph



This 6.5 acre area along a roadway was identified as grassland in 2006 and corn in 2007. The aerial photography, however, does not indicate any land use change between these two years.

Areas identified as grass/clover/wildflowers in 2006 and Corn in 2007 (216 acres)

Area identified as grass/clover to corn 2006 Aerial Photograph 2007 Aerial Photograph

This 4.5 acre location identified as grass/clover/wildflowers in 2006 and corn in 2007 appears to be a home site with grass surrounded by agricultural production which probably led to the errors in classification.

Area identified as grass/clover to corn 2006 Aerial Photograph 2007 Aerial Photograph

This seven acre area which appears to be a stream buffer does not indicate, from a review of the aerial photograhy, any land use change associated with a grass/clover/wildflower area being converted to agriculture. The area appears to be grass in both years.

Appendix B: N2O Emissions and Carbon Sequestration Calculations

		CSC,SSC, Other Rot.	SCC/CCC	Other Rotations, Diversified
N-Emissions Factors		kg N2O-N/ha per y	kg N2O-N/ha per y	kg N2O-N/ha per y
Conventional Till		3.7	2.9	4.8
No Till		4.2	3.6	4.6
Surveyed Tillage Practice				
Conventional Till (%)	0.87			
No Till, Strip Till, Minimum Till (%)	0.13			
Blended Emissions Factor (kg N2O/ha per y)		3.765	2.991	4.774
Blended Emissions Factor (kg N2O/acre per y)		1.524	1.210	1.932
Bushels Delivered to IRE	20,450,000			
Average Yield	196			
Corn Acres Needed for IRE Supply	104,337			
What were 2007 IRE Acres in 2005 (%)		42%	43%	14.7%
What were 2007 IRE Acres in 2005 (acres)		43,707	45,314	15,315
Emitted N2O-N (kg/y)		66,596	54,851	29,590
Total Emitted N2O-N on IRE Acres (kg/y)	151,037			
Total Emitted N2O-N of IRE Del. Corn (g/bu)	7.39			
Total Emitted N2O of IRE Del. Corn (g/bu)	11.61			
Indirect Emissions Factor	30%			
Total direct and indirect emissions (g/bu)	15.09			

		CSC,SSC, Other Rot.	SCC/CCC	Other Rotations, Diversified
CO2 Sequestration Factors		tC/acre per year	tC/acre per year	tC/acre per year
Conventional Till		0.01	0.05	-0.15
No Till		0.02	0.2	-0.1
Surveyed Tillage Practice				
Conventional Till (%)	0.87			
No Till, Strip Till, Minimum Till (%)	0.13			
Blended Squestration Factor		0.011	0.070	-0.144
Bushels Delivered to IRE	20,450,000			
Average Yield (bu/acre)	196			0
Corn Acres Needed for IRE Supply	104,337			
What were 2007 IRE Acres in 2005 (%)		42%	43%	15%
What were 2007 IRE Acres in 2005 (acres)		43,707	45,314	15,315
Sequestered Carbon (t/y)		494	3,149	-2,198
Total Sequestered Carbon on IRE Acres (Mt C/y)	1,445			
Total Sequestered Carbon on IRE Acres (MT CO2/y)	5,300			
Total Sequestered Carbon on IRE Acres (MT CO2/acre)	0.05			
Total Sequestered Carbon on IRE Del. Corn (g CO2e/bu)	259			

Appendix C: Carbon Sequestration Using No-till Production in Southern Illinois

Michael Plumer, University of Illinois Extension

The study was conducted at the University of Illinois Extension Ewing Field site near Mt. Vernon, Illinois. Established in 1969 this site has the oldest continuous no-till plot in the Midwest. The plot has been in continuous no-till production since that time and is in a corn soybean rotation. An adjoining plot was in conventional tillage, moldboard plow and disk system until 1992 when it was converted to continuous no-till. This plot is in a corn, corn, soybean, wheat rotation. The soil type is a *Cisne gray prairie claypan silt loam, fine, smectitic, mesic Mollic Albaqualfs*. Both sites started with the same organic matter level of 1%.

Each site has 15 sample points and the data represents the average value for those samples. Sampling has been done in 1" increments to a depth of 8"and in 2" increments to a depth of 14". The A horizon is at a depth of 8"with an acidic subsoil in the range of 4.5 to 5.0 pH. Both plots received a lime application initially and again in 1983. No lime has been added since and soil tests do not require any pH modification.

No-till planting has been done on a timely basis, and as early as soil moisture conditions would allow. All nitrogen was surface applied as 34-0-0 until 1995 when nitrogen was injected as liquid fertilizer 28%. Residue was not disturbed from harvest till spring planting. Fertility was applied based on crop removal. The following table represents the changes in carbon in the soil profile.

	Ewing Field Carbon			
	1992	2003	1992	2003
	long no-till	long no-till	conv.1992	conv. 1992
Surface Depth	carbon (#/a)	carbon (#/a)	carbon (#/a)	Carbon (#/a)
0-1	6045.0	6692.7	1727.1	5181.4
1-2	4533.7	6692.7	2374.8	5181.4
2-3	4102.0	6692.7	2158.9	5181.4
3-4	3454.3	6692.7	2158.9	5181.4
4-5	3022.5	6692.7	2158.9	5181.4
5-6	1727.1	6908.5	1727.1	5397.3
6-7	2374.8	6908.5	1079.5	5181.4
7-8	2590.7	6260.9	1079.5	4317.8
8-10	4317.8	12521.7	2158.9	8635.7
10-12	3022.5	10362.8	3886.1	7772.1
12-14	4317.8	7340.3	4749.6	7772.1
Sum	39508.2	83766.1	25259.4	64983.5
	Carbon Increase in Continuous No Till System:		Carbon Increase in Converting Conventional Till to No Till System:	
Difference (#)	44257.9		39724.1	
Difference per Year (#)	3688.2		3310.3	
Difference per Year (Mt)	1.67		1.50	

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Endnotes:

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[i] The US EPA is starting to use satellite based data from Winrock International in their ethanol lifecycle modeling efforts.

[ii] The correlation coefficient between N applied and yield was calculated. At -0.12 the correlation coefficient is weak. The negative sign may indicate that further N application may not increase yield. However, the study design and collected data is likely insufficient to perform a yield response analysis.

[iii] The Proexporter Network (PRX) is a consulting firm specialized in U.S. grain flows, transportation demand, and the impact of these items on cash grain markets. Besides mapping systems for detailed analysis of U.S. grain movements PRX has also developed a geographic tool that assesses the corn draw areas around ethanol plants (the PRX Polygon).

[iv] This data has not been vetted to the above described standards but provides a first estimate of land additional land.

[v] Michelle Wander is the Director of the Agroecology and Sustainable Agriculture Program at the University of Illinois at Urbana-Champaign and Associate Professor of Soil Fertility and Ecology.

[vi] Emissions factors by Mummey et al informed by Wander:

	CSC,SSC, Other Rot.	SCC/CCC	Other Rotations, Diversified
N-Emissions Factors by Mummey et al.	kg N2O-N/ha per y	kg N2O-N/ha per y	kg N2O-N/ha per y
Conventional Till	3.7	2.9	4.8
No Till	4.2	3.6	4.6

[vii] This value is slightly lower than the IRE GWI study due to the adjusted crop rotations. The CO2e emissions in the IRE GWI study were 92,917 tonnes.

[viii] It should be noted that carbon gains generally occur in surface depth (0-30 cm). At deeper depths gains disappear which means that conversions away from carbon storing management practices may have a reversible effect. Furthermore, these are so-called linear rates that are applicable for about 10 years of a particular land use practice.

[ix] CO2 sequestration factors by Eve et al. informed by Wander:

	CSC,SSC, Other Rot.	SCC/CCC	Other Rotations, Diversified
CO2 Sequestration Factors by Eve et al.	tC/acre per year	tC/acre per year	tC/acre per year
Conventional Till	0.01	0.05	-0.15
No Till	0.02	0.2	-0.1

[x] This value is higher than the IRE GWI Study due to the adjusted crop rotations. The value in the IRE GWI Study was 2,160 tonnes

[xi] The 13% no-till/strip till include 3% strip till. The carbon sequestration rates of strip till are probably slightly lower than for no-till (about 10% lower per Michael Plumer, UIES). However, IRE is located in a slightly colder region than the Ewing plots, which should increase carbon sequestration. Therefore, the sequestration value of 1.67 Mt should be close for the assessed tillage practices.

[xii] The soil type from this sequestration study may not be fully reflective of the soil type surrounding IRE. However, the Uof I Extension study was able to document (for the studied conditions) long-term continuous sequestration effects.