COMMENTS ON VERSION 3 OF SOYBEAN BIODIESEL CALIFORNIA GREET MODEL FOR THE LOW CARBON FUEL STANDARD DEVELOPMENT

Prepared For:

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EXECUTIVE SUMMARY

California has taken a lead in North America in promoting, developing, and implementing a Low Carbon Fuel Standard (LCFS) for transportation fuels. The concept is that the effective carbon content of transportation fuels will be reduced by 10% by the year 2020. The means of achieving this reduction will be left to the marketplace but the benefits of all of the fuel options will be determined through a lifecycle assessment of each fuel. Other states and some Canadian provinces have announced plans to follow California's lead or are considering doing so.

The California Air Resources Board (CARB) has begun to release a series of papers, each one covering a fuel production pathway, and inviting comments on the results and findings of the California GREET model. A report covering the soybean biodiesel (esterified soyoil) was released on October 3, 2008. The National Biodiesel Board submitted a number of comments on the initial version of the soybean biodiesel pathway in a November 2008 report.

CARB released a Version 2.0 of the soybean biodiesel lifecycle analysis on Jan 20, 2009. This version incorporated two of the NBB comments from the November 5, 2008 report on the version 1.0 document, the lower energy requirements for soybean crushing and the allocation of the fossil carbon to the glycerine rather than a portion to the biodiesel. These two changes, along with other changes that CARB made to the GREET model resulted in a reduction of GHG emissions from 35.26 g CO_2eq/MJ to 26.93 g CO_2eq/MJ. The ULSD had a carbon footprint of 95.3 g CO_2eq/MJ, which was later reduced to 94.71 g CO_2 so the soybean biodiesel now yields a 71.6% reduction in GHG emissions without indirect land use change.

CARB released Version 3.0 of the soybean biodiesel lifecycle analysis on December 14, 2009. This report used an approximate mass allocation for the meal, an energy allocation for the glycerine, and a hybrid of mass and partial system expansion for the indirect land use change.

There are two issues with the revised direct emission calculations in Version 3.0 of the soybean biodiesel carbon intensity calculations.

1. CARB rounded up the mass allocation between oil and meal to 20% oil rather than the 18.9% used in the detailed calculations. This increases the carbon intensity by 0.45 g/MJ.
2. CARB has reverted to including the fossil carbon emissions in the biodiesel combustion emissions. This ignores the carbon emissions that are offset by the substitution of biological glycerine for fossil derived glycerine. The NBB has previously submitted comments on Version 1.0, which were accepted in Version 2.0. This inappropriate treatment of the co-product increases the biodiesel emissions by 3.7 g/MJ.

The sum of the two recommended changes to the soybean biodiesel direct GHG emissions is 1.15 g/MJ.

The indirect emissions for soybean biodiesel have been calculated with a new version of the GTAP model. While GTAP 7 is an improvement over GTAP 6, it is still not able to accurately model the impacts of an increase in the demand for soybean oil. Shocking the supply system for an increase in soybeans is not the same as shocking the system for an increase in soybean oil or vegetable oil demand, as it does not allow for full substitution for other equivalent oils for soybean oil anywhere in the system. GTAP 7 was also not able to model an increase in corn demand, as many of the sub-modules were turned off to get the soybean results.

Running the GTAP 7 soy file supplied by CARB also resulted in warnings for each of the scenarios that were run. These warnings are usually indicative of problems within the model. It was also noted that compared to the GTAP results presented earlier by CARB for the corn ethanol expansion scenario, the soybean expansion results in a much higher percentage of forest land in the converted land even though less land is being converted. This results in significantly higher estimated indirect land use emissions for soybean biodiesel than if the forest to pasture ratio from the corn ethanol modeling was used.

The combination of the warning messages, inactive modules, and the unexpectedly high amount of forest land converted is a significant concern and one that we were unable to resolve in the short time available to respond with comments. If more time were granted by CARB, we would investigate this issue further.

Nevertheless, the NBB analysis has found a number of very significant issues with the proposed GTAP modeling results that have a large impact on the final results.

1. The use of exactly the same elasticity factors for soybeans as was used for corn is inappropriate as the different crops have different production characteristics. Soybeans can be double cropped, whereas corn cannot be. Soybean yield is less influenced by fertilizer requirements and thus expansion into new areas does not suffer a significant yield impact.
2. The yield use for soybean is too low compared to the expected yield when the LCFS is expected to require the greatest amount of biodiesel.
3. The emission factors used by CARB to calculate the indirect emissions are too high. This is a result of using carbon inventories for the US and Canada that are inconsistent with official government data and not following IPCC methodologies to calculating changes in emissions resulting from land use change.
4. The GTAP model used by CARB assumes the same elasticity of land transformation for all types of land. This is not consistent with the real world and is even inconsistent with some of the GTAP working papers. The simplified assumption grossly overestimates the quantity of forest land converted.

The impact of these issues is shown in the following table.

Table ES- 1 Impact of Land Transformation Elasticity

Scenario	Mean	SB Specific	Higher Yield	Adj Emission factors	Revised CET
Economic Inputs					
Soy Biodiesel production increase (bill. gal.)	0.75	0.75	0.75	0.75	0.75
Elasticity of yield wrt area expansion	0.59	0.90	0.90	0.90	0.90
Crop yield elasticity	0.32	0.40	0.40	0.40	0.40
Elasticity of land transformation	0.20	0.20	0.20	0.20	
Elasticity of land transformation, crops					-0.18
Elasticity of land transformation, forest					-0.0056
Elasticity of land transformation, livestock					-0.2430
Elasticity of land transformation, other					-0.0056
Elasticity of harvested acreage response	0.50	0.50	0.50	0.50	0.50
Trade elasticity of crops	central				
Model Results					
Total land converted (million ha)	0.51	0.30	0.30	0.30	0.35
Forest land (million ha)	0.22	0.10	0.10	0.10	-0.07
Pasture land (million ha)	0.29	0.20	0.20	0.20	0.42
U.S. land converted (million ha)	0.21	0.13	0.13	0.13	0.15
U.S. forest land (million ha)	0.10	0.04	0.04	0.04	-0.04
U.S. pasture land (million ha)	0.12	0.09	0.09	0.09	0.19
LUC carbon intensity(gCO_{2e}/MJ)	62	31.65	28.42	11.4	8.9
% change from parameter change		-48.9	-10.2	-59.9	-21.9

Finally, the CARB analysis does not consider the GHG emission impacts of the change in crop types within the existing agricultural land. These emission reductions amount to at least an additional 5.2 g CO_2eq/MJ. When the calculated emissions of 8.9 CO_2eq/MJ are further adjusted for the overall reduction in land use emissions due to crop shifting, the emissions are reduced to 3.7 g CO_2eq/MJ.

In the short time available to analyze the GTAP model for soybeans, not all of the issues could be fully investigated. The model has significant capacity for further refinement that has not been fully investigated. For example, no resolution of the issue of idle land and how it is modeled could be achieved. The emissions could be even lower than 3.7 CO_2eq/MJ if any significant amount of idle land was used to offset the current estimate of pasture and forest land converted.

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1. INTRODUCTION

Climate change advocates point to increased levels of anthropogenic carbon emissions as the primary cause of global warming. As such, most greenhouse gas mitigation strategies are focused on reduction of carbon dioxide (CO_2) in the atmosphere. Since typically 30-40 percent of all carbon emissions are derived from mobile sources, automobiles and off-road equipment serve as focal points for many of these policies.

California has taken a lead in North America in promoting, developing, and implementing a Low Carbon Fuel Standard (LCFS) for transportation fuels. The concept is that the effective carbon content of transportation fuels will be reduced by 10% by the year 2020. The means of achieving this reduction will be left to the marketplace but the benefits of all of the fuel options will be determined through a lifecycle assessment of each fuel. Other states and some Canadian provinces have announced plans to follow California's lead or are considering doing so.

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CARB released Version 3.0 of the soybean biodiesel lifecycle analysis on December 14, 2009. This report used an approximate mass allocation for the meal, an energy allocation for the glycerine, and a hybrid of mass and partial system expansion for the indirect land use change. The direct GHG emissions have been reduced to 21.25 g CO_2eq/MJ. The indirect land use estimate is 62 g CO_2eq/MJ for a total GHG emission rate for soybean biodiesel of 83.25 g CO_2eq/MJ.

This report discusses the changes made between version 2.0 and 3.0 and makes recommendations to address some of the issues raised in version 3.0.

2. DIRECT EMISSION ISSUES

The direct emissions are those that result directly from the supply chain. California is calculating these using a modified version of GREET 1.8b.

2.1 CHANGES FROM VERSION 2.1

Version 3.0 of the analysis does make a change to the supply chain that had been recommended by the NBB. Soyoil is no longer shipped from the Midwest to Washington State for the production of biodiesel and then the biodiesel shipped to California. Soyoil is now moved directly from the Midwest to California. This is a much more appropriate assumption.

Version 3.0 also changes to using an approximate mass allocation method for determining the emissions associated with soyoil and with soybean meal. The approach assumes that 20% of the emissions are associated with the oil and 80% are allocated to the meal. The actual oil content used in the detailed calculations is 18.9%, so the 20% allocation is only approximate. This simplification increases the biodiesel GHG emissions by 0.45 g/MJ and should be corrected.

These two changes, the revised supply chain and the approximate mass allocation, reduce the GHG emissions associated with soyoil biodiesel production.

Version 3.0 also corrects the quantity of glycerine produced by the process as recommended by the NBB in past submissions. This slightly increases the GHG emissions.

Version 3.0 reverts to the methodology of version 1.0 for calculating the GHG emissions associated with the combustion of biodiesel. This approach tracks the fossil carbon in the methanol through the biodiesel reaction and calculates the GHG emissions associated with the ultimate oxidation of that carbon to carbon dioxide. The NBB pointed out the issues with this approach in their version 1.0 comments and it was corrected for Version 2.0 and 2.1. Since CARB has now reverted to the approach used in version 1.0, the NBB comments are repeated and expanded upon below. The NBB does not agree with this last change.

2.2 FOSSIL CARBON

CARB has undertaken a calculation to determine what proportion of the biodiesel carbon content is biologically derived carbon and what portion is fossil derived carbon from the methanol. While this is a reasonable approach, this approach must also consider the biological carbon that is found in the glycerine and the ultimate fate of the glycerine compared to fossil derived glycerine.

The basic properties (density, elemental composition, etc) of soyoil and soybean biodiesel are quite similar as shown in the following table.

Table 2-1 Properties of Soy Oil and Soy Biodiesel

	Soy Oil	Soy Biodiesel
Density	0.89-0.92	0.89
Carbon, wt %	79-80	77-78
Hydrogen, wt %	10-10.5	11-12
Oxygen, wt %	10-10.5	11-12

Since the assumed conversion in this version of the GREET model is 1.01 pounds of soybean oil produces one pound of biodiesel there is more carbon in the soyoil feedstock than there is in the soy biodiesel product. If one decides that some of the carbon in the product is fossil in origin, then some of the carbon in the glycerine co-product must be biological in origin.

The CARB approach in version 3.0 and version 1.0 effectively truncates the system boundary to include the production and use of the primary product but only the production (not the use) of the glycerine co-product. Depending on the ultimate use of the co-product this approach will provide an accurate assessment of the emissions in some cases, but a very inaccurate assessment in other cases. The version 3.0 CARB approach is only correct if the glycerine produced by the biodiesel process is wasted by landfilling or sending the product to a wastewater treatment plant, which has no energy recovery. According to NBB surveys, very little of the glycerine produced by its members is treated this way.

Ideally, the ultimate fate of the glycerine should be known to definitively answer the question of what are the avoided emissions from the utilization of the biodiesel glycerine. Glycerine has many different uses in foods, cosmetics, and other consumer products. Almost all of the products would eventually be oxidized to carbon dioxide and water vapor. If the glycerine, or a portion of it, were biological in origin then the CO_2 emissions would not be included in an emission inventory. If the glycerine were fossil derived, then all of the CO_2 would have to be included in an emission inventory. The use of biological glycerine therefore avoids the emissions of the oxidation of fossil derived glycerine. Because this can get quite complicated to keep track of, most of the LCA work that has been done with biodiesel has taken the simple approach and assumed that all of the carbon in the biodiesel is biological and all of the carbon in the glycerine is fossil in origin. The CARB approach of ignoring the indirect emissions benefit from biologically produced glycerine is inconsistent with the calculation of the indirect emissions being calculated for forecast land use change from the expansion of agricultural production.

According to NBB surveys of its producing members, almost all of them utilize the glycerine in some manner. More than 99 percent of glycerine from biodiesel plants is sold for one purpose or another:

48% of glycerine is refined for high value uses
33% of glycerine is used as livestock feed
14% of glycerine is sold without specifying the final use of the glycerine
4% of the glycerine is sold for fuel
1% of biodiesel production uses technology that reprocesses the glycerine into additional biodiesel product.

It is recommended that California take the same, simplified approach as used by other models (and the standard GREET model) and assume that all of the carbon in the biodiesel is biological and all of the carbon in the glycerine is fossil. This would reduce the GHG emissions associated with biodiesel by 3.7 g/MJ. Alternatively, CARB could develop two values for biodiesel, one where the glycerine is wasted and another where the glycerine is utilized. Soy biodiesel users in California would have to verify with their suppliers, which is the appropriate carbon intensity to use. This is similar to the multiple carbon intensity values being developed for corn ethanol by CARB.

3. INDIRECT LAND USE EMISSIONS

The most significant change in version 3.0 is the inclusion of a value for indirect land use change emissions for soybean biodiesel with which CARB is comfortable. Version 2.1 included a preliminary estimate that was based on an expansion of oilseed production and a manual adjustment for the allocation between oil and meal.

CARB uses the Global Trade Analysis Project (GTAP) model for estimating LUC impacts of increased biofuel production. For the preliminary modeling presented in Version 2.1, GTAP was severely limited in its ability to represent the soy biodiesel sector. Some key GTAP model limitations were as follows:

- The modeling employed the GTAP 6 global economic database, which used 2001 as the reference year. Very little biodiesel was being produced in 2001 and therefore the economic sector was not well developed.
- The model included an aggregated oilseeds sector and was not capable of specifically modeling changes in soybean demand. Because of this limitation, an external model adjustment for the difference in average fuel yield between biodiesel derived from soy and aggregated oilseeds was required.
- The modeling did not account for market effects of soy meal production and therefore an external adjustment for soy meal co-product credit was required. As an initial estimate, CARB assumed a 75 percent co-product credit for soy meal.

Recently several changes to the modeling of soy biodiesel were made to address these limitations. Revisions to the model are as follows:

- The present soy biodiesel land use change results are produced using the GTAP 7 database, which uses 2004 as the reference year. The global biodiesel sector was more fully developed in 2004.
- The current modeling separates out soybeans from the aggregated oilseeds sector and therefore is capable of specifically modeling changes in soybean demand.
- The modeling now allocates a feed co-product within the biodiesel sector. Soybean was assumed to consist of 20 percent oil and 80 percent soy meal by mass.

In spite of the improvements made to GTAP, the NBB believes that the values being proposed by CARB are not representative of any land use change that might occur with an expansion of the use of soybean biodiesel in California or elsewhere.

While GTAP 7 is an improvement over GTAP 6, it is still not able to accurately model the impacts of an increase in the demand for soybean oil. Shocking the supply system for an increase in soybeans is not the same as shocking the system for an increase in soybean oil or vegetable oil demand, as it does not allow for full substitution for other equivalent oils for soybean oil anywhere in the system. GTAP 7 was also not able to model an increase in corn demand, as many of the sub-modules were turned off to get the soybean results.

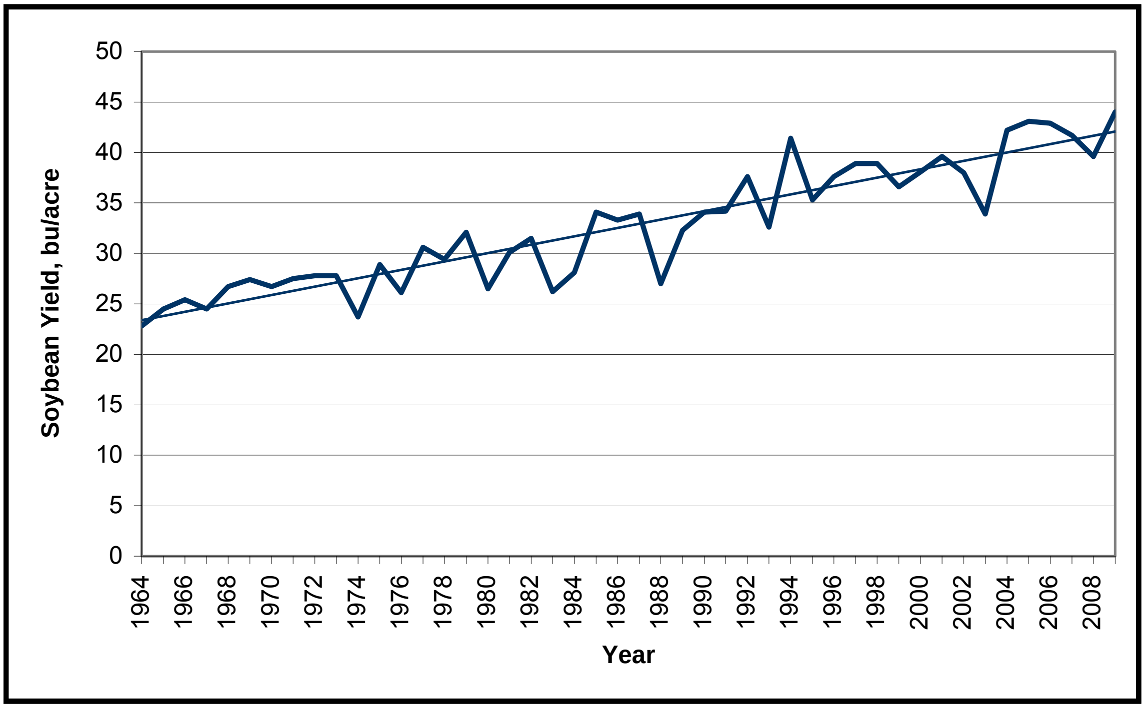
Running the GTAP 7 soy file supplied by CARB also resulted in warnings for each of the scenarios that were run. These warnings are usually indicative of problems within the model. It was also noted that compared to the GTAP results presented earlier by CARB for the corn ethanol expansion scenario, the soybean expansion results in a much higher percentage of forest land in the converted land even though less land is being converted. This results in significantly higher estimated indirect land use emissions for soybean biodiesel than if the forest to pasture ratio from the corn ethanol modeling was used.

The combination of the warning messages, inactive modules, and the unexpectedly high amount of forest land converted is a significant concern and one that we were unable to resolve in the short time available to respond with comments. If more time were granted by CARB, we would investigate this issue further.

3.1 Soybean Yield

GTAP 7 reportedly uses data from the year 2004 for crop yield and other parameters. 2004 was a very good year for soybean production in the United States with the harvested yield being significantly above the trend line as shown in the following figure.

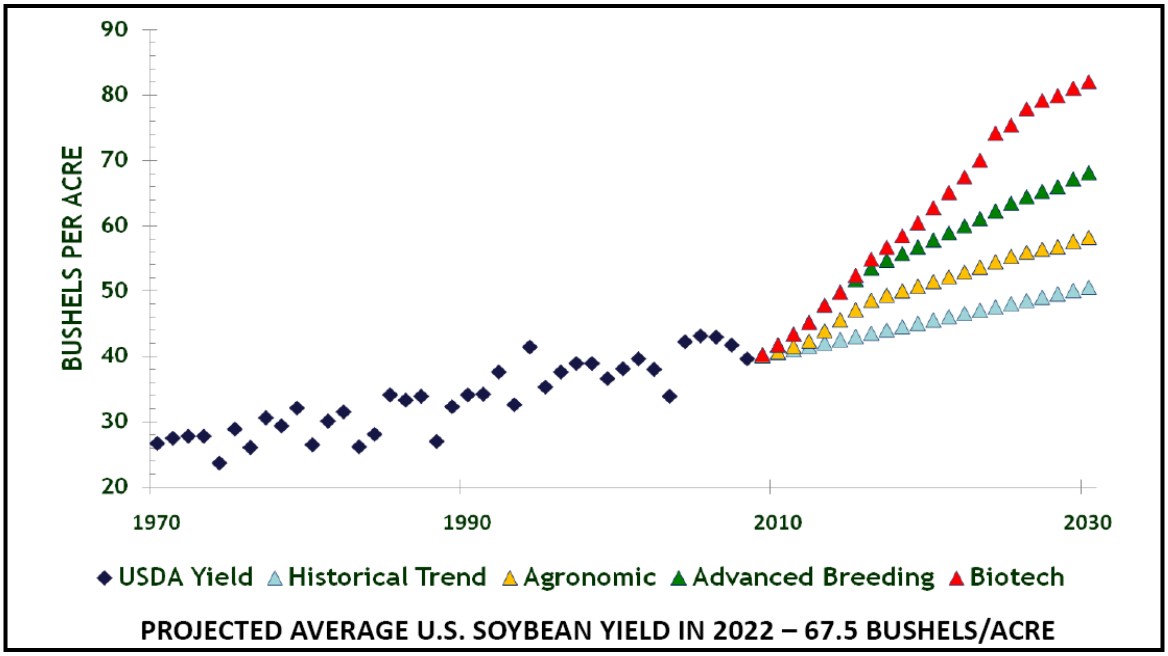
Figure 3-1 Soybean Yield



From the graph above it can be seen that the soybean yield in recent years, until 2009, had not been significantly higher than the 2004 yield, and for this reason CARB has not made any adjustments to the 2004 soybean yield in its calculations. However, since the premise of indirect land use change is to forecast what might happen in the future with an increase in demand for soybean oil for the production of biodiesel, it is more important to consider the future yield of soybeans. Since the LCFS is being phased in between 2010 and 2020, it is more appropriate to use the projected yield in 2020 as the yield for GTAP modeling. This is a simple calculation that CARB can do outside of the model as it did when it adjusted corn yields for the ethanol case.

A simple straight-line extrapolation of the yield trend line to 2020 produces a yield of 47 bu/acre rather than the 42.2 bu/acre achieved in 2004. This adjustment would reduce the ILUC factor by 10.2%. The soybean seed producers are adamant that a straight-line extrapolation of past yields is not appropriate for future yields, as it does not take into account the impact of new technologies that they are now using. The following figure shows the projected range of soybean yield from Monsanto based on the different breeding tools available to the company. Monsanto forecasts that the yield in 2020 will be greater than 60 bu/acre. This would reduce the ILUC emissions calculated by GTAP by more than 42%.

Figure 3-2 Forecast Soybean Yields



The NBB believes that soybean yield will increase faster than the demand for soybeans and that without new markets there is a risk that more productive agricultural land will be idled. Idled agricultural land is generally not reforested and may even have significant GHG emissions depending on how the land is managed. There is a significant probability that the California demand for soybean biodiesel and the traditional demand for US soybeans can be met through the rapid increase in soybean yield expected.

From GTAP it is not possible to extract the soybean yield in other countries for the base case. The yield that can be extracted appears to be the incremental soybean yields so it has been multiplied by the elasticity with respect to area expansion. However there are some discrepancies in this reported information with the FAO reported yield data. These are summarized in the following table for the primary countries that drive the results.

Table 3-1 GTAP Yield vs. FAO Yield

	GTAP Yield (Scenario A) 0.5 ETA	FAO 2002-2004 Yield	GTAP as a Percentage of FAO
Canada	1.70	2.35	72.2%
EU	2.29	2.66	86.2%
Brazil	1.46	2.57	56.7%
Japan	1.16	1.51	77.1%
China	2.18	1.79	121.7%
India	0.63	0.95	66.0%

If the GTAP data were up to date, one would have expected a constant percentage difference between the GTAP results and the FAO results.

3.2 Elasticity Assumptions

CARB has modeled a number of different scenarios using different elasticities for important parameters in GTAP. The average of the seven scenarios is then used to determine the indirect land use emissions.

There is a lack of solid supporting data for the choice of some of the elasticity factors and as noted above, some of the factors can be adjusted to compensate for other deficiencies in GTAP land categories.

The seven scenarios used for soybean biodiesel use exactly the same elasticity values as used for corn ethanol. It is valuable to investigate whether it is appropriate to use the same values for different crops. This done in the following sections.

3.2.1 Crop Yield Elasticity

This parameter determines how much the crop yield will increase in response to an increase in price for the crop. In theory, the elasticity value is multiplied by the percentage price change to arrive at the percentage increase in yield. The scenarios used by CARB vary this elasticity from 0.2 to 0.4. The oilseeds market price in the US increases by 1.44% for the 750 million gallon biodiesel shock. Based on the oilseed area in GTAP of 80 million acres and the 42 bushels/acre base yield, this results in a 9.7 to 19.5 million bushel increase in the US soybean crop. This is equivalent to a 16 to 32 million gallons of biodiesel. This factor supplies only 2-4% of volume of the shock.

A 1.44% increase in the price of soybeans is very low; there are many days when the market price of soybeans changes this much or more. One must question the accuracy of the model for system shocks this small. By contrast, the price increase for the corn ethanol scenario modelled by corn was 14.47%, so the yield response in the corn scenario would have supplied 20 to 40% of the increased demand.

The crop yield elasticity can be used to account for the use of idle land and double cropping. Double cropping is not an option for corn ethanol, so it is reasonable to utilize a higher crop yield elasticity value for soybeans than corn. Soybeans are often double cropped after winter wheat in many regions of the United States. The short growing season for soybeans makes this feasible. While yields on double cropped soybeans can be lower, if prices are higher due to increased demand then the practice becomes profitable. GTAP is not capable of accounting for the potential to double crop soybeans, other than through the use of a high crop yield elasticity.

Babcock and Carriquiry (2010) analyzed the potential impact of double cropping soybeans and determined that the crop yield elasticity should be increased by 0.08 for the United States and 0.24 for Brazil. This would suggest that at a minimum the yield elasticity should be 0.4 for soybeans rather than the average value of 0.32 used by CARB for both soybeans and corn ethanol. This higher value considers the double cropping potential of soybeans that is not available for corn.

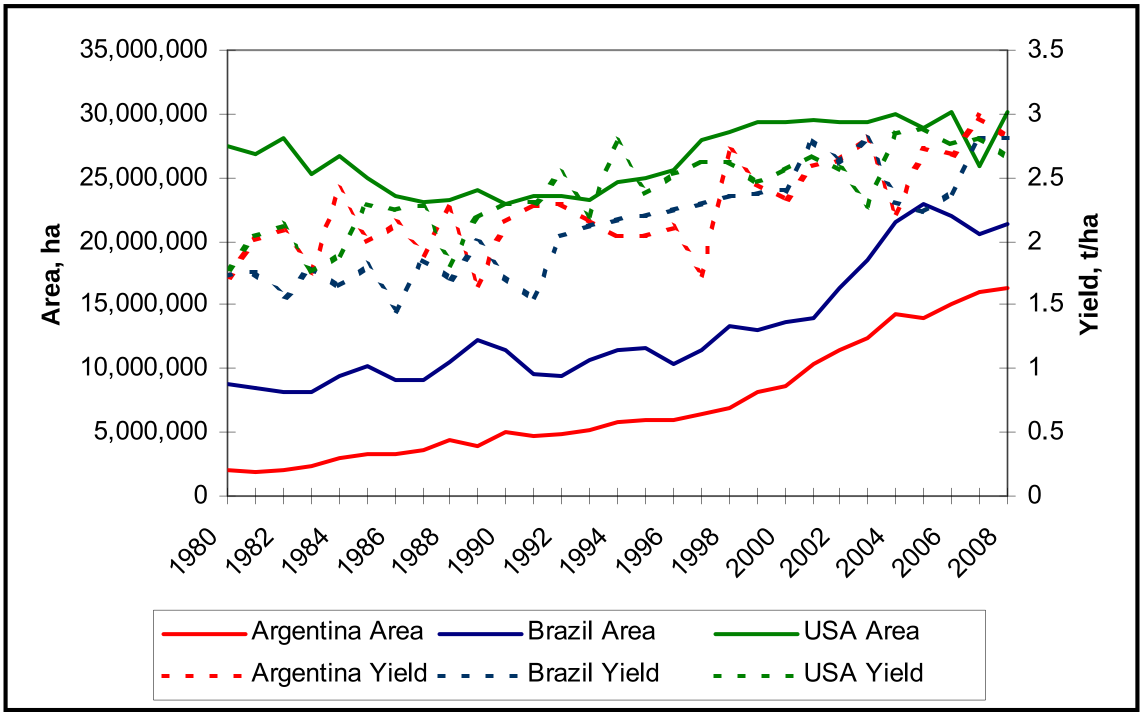
The crop yield elasticity is also one way to model idle land in GTAP. If very high values were used, then the total amount of soybeans could be increased without causing a change in pasture or forest land. The magnitude of this elasticity factor would be dependent on the size of the shock and the quantity of idle land available.

3.2.2 Elasticity of Yield with Respect to Area Expansion

This parameter expresses the yields that will be realized from newly converted land relative to yields on land previously used for that crop. CARB states that this is required because almost all of the land that is well suited to crop production has already been converted and that yields on newly converted land are almost always lower than yields on existing croplands.

The NBB does not agree with this hypothesis because the data available from North and South American governments does not support it. If one considers the soybean yield situation in Brazil and Argentina, where soybean acres have been expanding, one finds that yields have been increasing faster in those areas than in the US. This is shown in the following figure. There is no evidence that yields have suffered as area has expanded in these two major soybean producing countries.

Figure 3-3 Soybean Yield and Area



Babcock and Carriquiry (2010b) suggest a value of 1.0 for soybeans for Brazil. They calculated this value from the actual results in Brazil. They were unable to calculate a value for the US, because the domestic trend has been one of a decrease in overall crop acres and no increase of soy planting on acres that were not previously cropped.

The question is should this elasticity be different for soybeans than it is for corn? To address this question, the ratio of US yield to world yield for corn and soybeans is considered. This information is summarized in the following table.

Table 3-2 US Production vs. World Production

	Corn	Soybeans
US Production, tonnes	267,598,000	87,669,860
US Yield, t/ha	9.36	3.02
World production, tonnes	694.192,572	221,488,632
World Yield, t/ha	4.826	2.38
US Yield/World Yield	1.94	1.27

It can be seen that soybean yields in the US are not as different as yields in the rest of the world, whereas for corn there is a significant difference. The different yield result is not unexpected when one considers that soybeans produce their own nitrogen and the crop is therefore not as dependent on purchased fertilizer as corn is. Thus, it is likely that as soybeans expand, the yield is less likely to be constrained by crop inputs compared to corn and there is less potential for reduced yield.

The NBB recommends that an elasticity with respect to area expansion for soybeans be at least 0.9 and perhaps as high as 1.0.

3.2.3 Elasticity of Land Transformation

This elasticity determines the extent to which expansion into forestland and pastureland occurs due to increased demand for agricultural land. CARB has used an average value of 0.2. The issue here is not the average elasticity of land transformation but the way that GTAP determines how much of the land comes from forests and how much from pasture. This is discussed in detail by Babcock and Carriquiry (2010c) in their comments but the soybean GTAP model results have been developed assuming that there is the same percentage change in pasture land as there is in forest land, whereas Babcock suggests that the GTAP supporting documentation (Ahmed et al, 2008) supports the position that different elasticities should be used for each type of land.

This issue does have a very large impact on the results and is discussed further in Section 4 of the report. Using the same elasticity of land transformation overestimates the quantity of forest land converted and underestimates the amount of pasture converted to cropland.

3.3 TYPES OF LAND CONVERTED

GTAP has been used for many years to investigate changes in agricultural policy and the resulting implications on production (and therefore land requirements) and trade. By all accounts it does a reasonable job of this. Using GTAP to estimate changes in the ***type*** of land that would be brought into production due to changes in agricultural policy is a new application for the model.

It was noted above that the soybean results are predicting a higher proportion of forest land being converted than was the case for GTAP 6 and corn ethanol (43% vs. 22%). This occurs even though the total amount of new land required is less for soybeans than it was for corn. This is quite unexpected and at this stage can not be explained.

Some researchers (Kløverpris, 2008) have noted limitations in the way that GTAP manages the supply of land.

> *There are, however, also some aspects of the standard GTAP Model, which must be improved in order to use it for establishment of land use LCI data for crops.*

In the standard GTAP Model, the supply of land is normally fixed. This means that only intensification and displacement can be used to increase the production of a given crop, not expansion. Alternatively, land can be modelled as a production factor in endless supply but with a fixed price. The profitability of expansion compared to intensification can thereby be included in the modelling but still with a very poor representation of land markets, which does not consider regional land constraints (and their effects on land prices). To make the simulation of land markets more realistic, van Meijl et al. (2006) suggest the introduction of so-called land supply curves, which determine the regional relationships between land price and land supply (see Fig. 3). At low land utilisation, the supply of land is highly elastic, i.e. increased use only has a minor influence on the price (left side of the curve in Fig. 3). On the other hand, the supply of land is highly inelastic at high land utilisation, i.e. the price changes drastically even at small changes in the area being utilised (right side of the curve in Fig. 3).

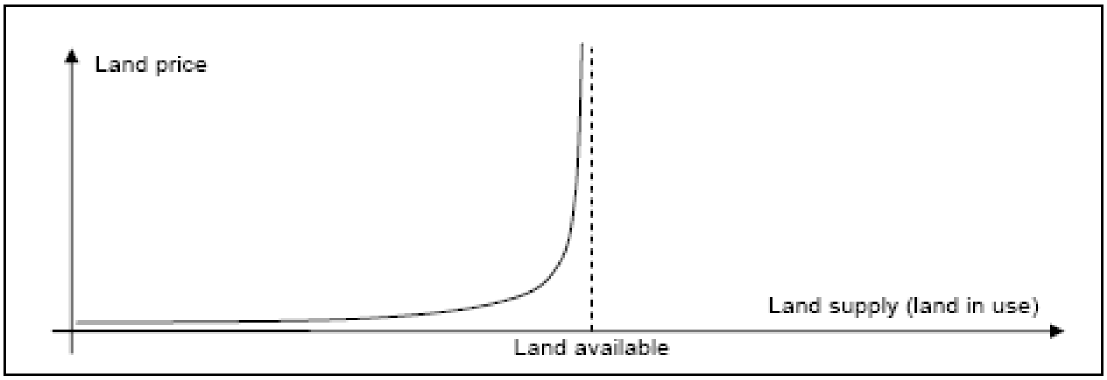


Fig. 3: General shape of a land supply curve. Adjusted from van Meijl et al. (2006).

The GTAP paper by Ahmed, et al, also proposes that different elasticities should be used for the different types of land, so this is an area in which a number of noted experts agree that improvements in the model should be made.

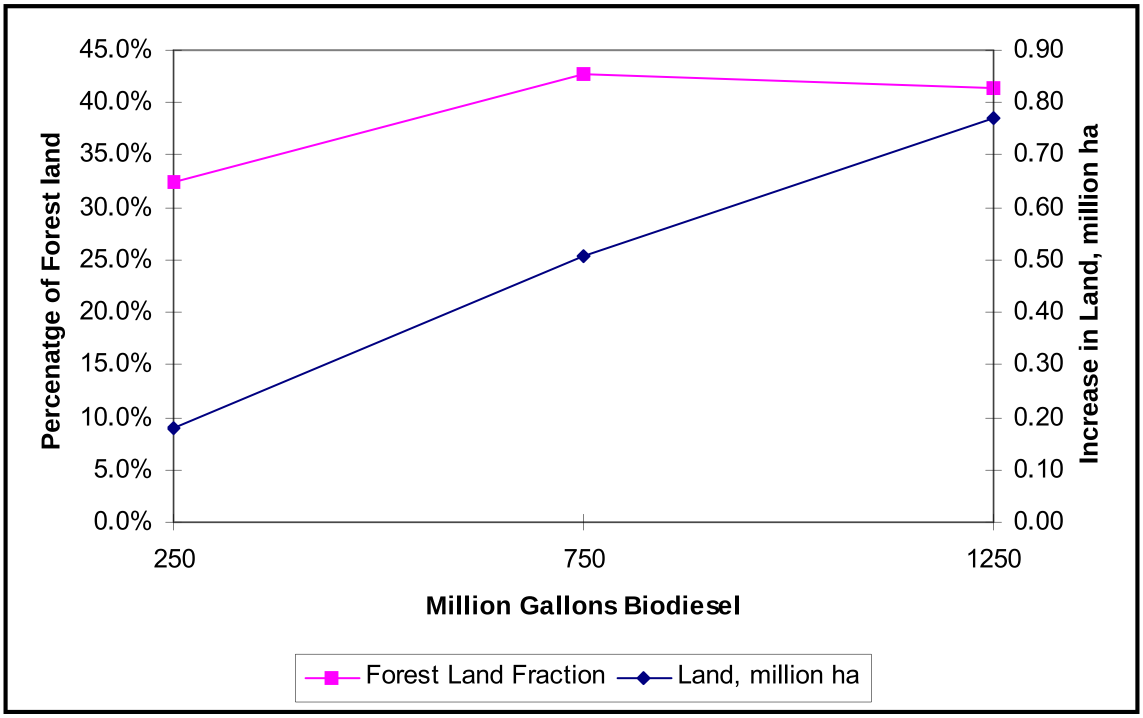
3.3.1 Forest and Pasture

The increased production of soybeans is met partially with a yield response and with some crop shifting on existing agricultural land. Demand which cannot be met with these two sources is met through the conversion of pasture and forest land. It is the change in the carbon stocks in and on these lands that determine the “indirect land use emissions”. The magnitude of the carbon loss on forest land is up to an order of magnitude higher than the loss of pasture land, depending on the region, and this has a large impact on the final results.

The results that are determined from using the GTAP 7 soy model would indicate that land supply is definitely not behaving as one would expect if there was a logical land supply curve. The soybean shock was modeled at three different levels, an increase of 250 million gallons of soybean biodiesel, a 750 million gallon increase and a 1.25 billion gallon increase. Since the land conversion costs for converting pasture land to cropland are lower than converting forest land to crop land, one would expect that the ratio of pasture land to forest land would change as the size of the shock changes.

To test this, the GTAP model was run for the three shocks described above for each of the seven scenarios of elasticity. The results are shown in the following figure, the percentage of forestland converted was the highest for the 750 million gallon case. There was only a slight trend to increasing forestland conversion rate as the total amount of land converted was increased. One would have expected that the lowest cost land would have been converted first and as that was converted then higher conversion cost land would have been increasingly brought into production. The fact that this didn't happen is a serious shortcoming in the model and the result is that the model overestimates the carbon impact compared to what would be expected to happen.

Figure 3-4 Results from Different Shocks



3.3.2 Idle Land

GTAP does not include idle cropland as a separate land category. Since bringing idle cropland back into production is the lowest cost source of new land, this is a significant shortcoming.

An examination of the quantity of cropland included in the model and comparing that to USDA data would suggest that the quantity of idle cropland is included in the model. However, the model sees it as land that is already occupied by existing cropland. The fact that it is not identified as available land means that the model has no capability to draw on this source of land except indirectly through the elasticity of crop yields. The GTAP cropland inventory is compared to the US Agricultural census data (USDA, 2009) in the following table. Note that the amount of cropland included in GTAP is 50% larger than the actual harvested cropland in the US.

Table 3-3 US Agricultural Land

	GTAP	2002 Census of Agriculture	2007 Census of Agriculture
	acres		
Agricultural land	454,158,564	434,164,946	406,424,909
Harvested cropland		302,697,252	309,607,601
Cropland used for pasture or grazing		60,557,805	35,771,154
Cropland idle or in cover crop		37,281,096	37,968,749
Cropland abandoned due to crop failure		17,069,564	7,405,898
Cropland in summerfallow		16,559,229	15,671,507

The sum of the sub-components of the Agricultural Census equals the total agricultural land. While there is still some land in GTAP that is unaccounted for, the quantity of idle land or cropland that can be put back into production is far larger than the 1.26 million acres (0.51 million ha) that GTAP has determined are required to be added to cropland from pasture and forests. GTAP needs to be modified so that it is capable of identifying this idle land and use it first before it calculates the need for additional land.

It is interesting to note that between 2002 and 2007, when there was a 50% increase in crop cash receipts (USDA, 2009b), the percentage of agricultural land used to produce a harvested crop increased.

The only way of currently including this idle land in GTAP is to use a high crop yield elasticity to increase production on the same land base. At low levels of increased demand, this elasticity could be very large, and as demand increases then the elasticity would be reduced as the available supply of idle land drops. One of the problems with this approach is that the availability of idle land will be different in each country, although GTAP can handle this. Another challenge is that the elasticity would vary as the quantity of land varied. It would be better if idle land were a separate category in GTAP so it could be identified in each country.

The availability of idle land is discussed further by Babcock and Carriquiry (2010d).

3.3.3 Land Summary

It would appear from USDA land use statistics that the productivity of agricultural land in the United States is not maximized. Only two-thirds of the cropland that is included in GTAP is actually used to produce a harvested crop. About 2% of the land has a crop failure but that leaves more than 30% of the cropland in the GTAP model available for crop production. This available land is two orders of magnitude larger than the land demand from increased soybean production. GTAP only uses a small portion of this land by using a high crop yield elasticity and because the model doesn't use the supply curve concept for determining where new land comes from, it still calls on pasture land and forest land to be converted to cropland even though there is sufficient idle cropland available to meet the demand.

It is apparent that the GTAP model used by CARB has some significant shortcomings when it is used to forecast where new land might be brought into production to satisfy new demand. These shortcomings result in a significant overestimation of land that needs to be converted from pasture and forest and leads to very high estimates for indirect land use emissions. In Section 4 of this report, the impact of improved elasticity parameters is investigated.

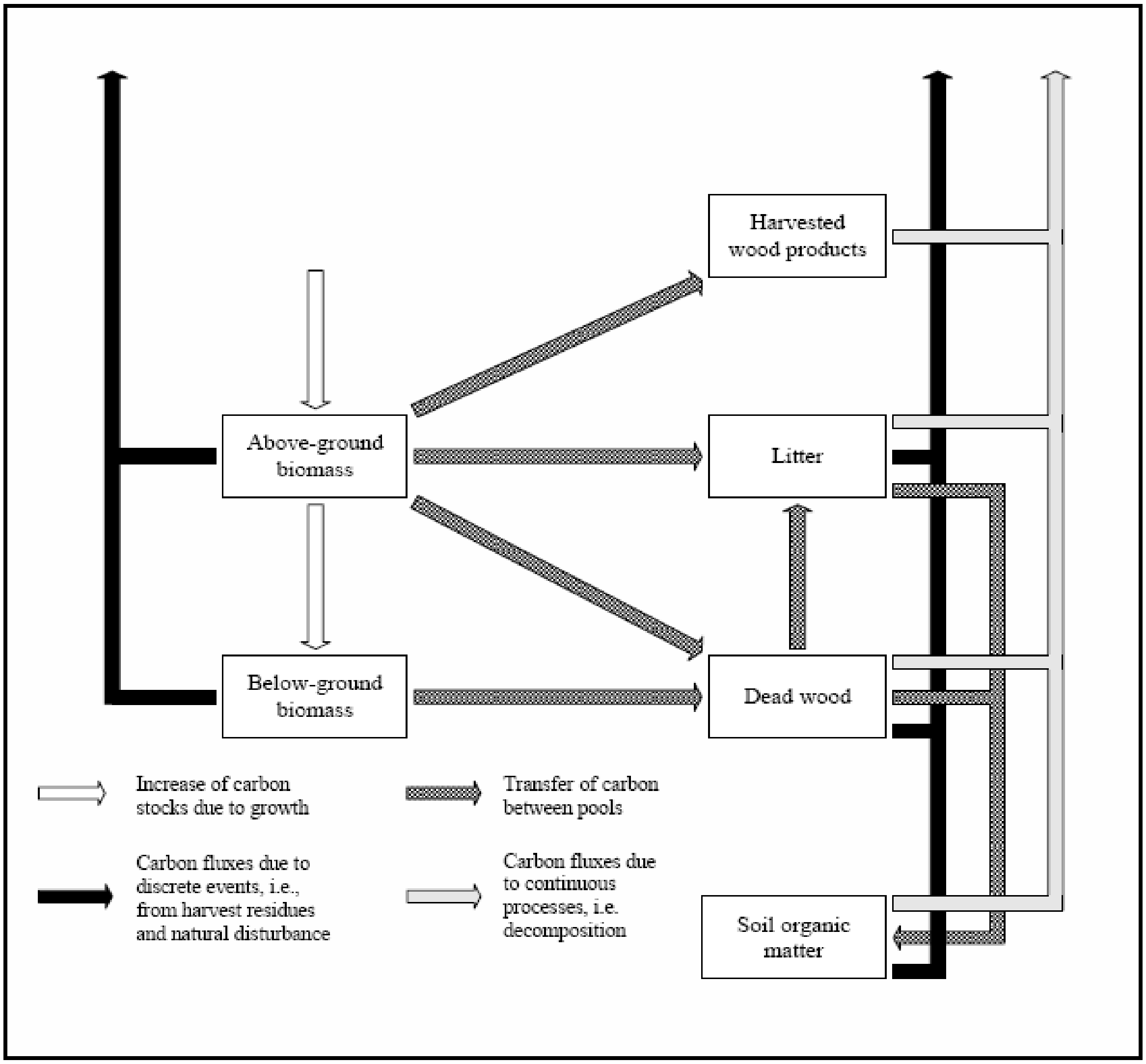
3.4 Emission Factors for Forest Land

Once the land use change has been forecast by GTAP, the GHG emission implications are calculated by considering the change in carbon inventories. The assumptions that have been used in GTAP are that 100% of the biomass carbon of forest and pasture is oxidized to carbon dioxide and that 25% of the soil carbon is lost due to changes in manage practices. There is also a calculation of the lost carbon sequestration potential, but this has a relatively small impact on the overall results.

The overall indirect land use emission results are driven in large part by the forest carbon emissions and over 70% of the new cropland from forests is in the United States and Canada so we have focused on those emission inventories.

The generalized forest carbon cycle developed by the IPCC is shown in the following figure.

Figure 3-5 IPCC Carbon Cycle



The GTAP emission factors do not make any allowance for the possibility that some of the wood is converted to wood products (harvested wood products in the previous figure). Particularly in developed countries, this should be factored into the analysis.

The basic assumption taken by CARB for the emission factor for forest land is that carbon stored in the forests is there permanently and unfortunately this is not true. Some of these issues are raised in a recent paper by Reijnders (2009). He argues that forestation is not an ideal means of offsetting carbon emissions. While this is a slightly different perspective than removing a forest, the core issue is essentially the same. Reijnders identifies the issues of permanence in that trees don't live forever and that unforeseen events such as fire, disease, and extreme weather events can further shorten the projected life of carbon storage in forests.

Trees are living organisms and like all living things, they have a life cycle and at the end they die. The end of the lifecycle could be caused by natural fires, by disease or pests, or simply by old age. At the end of the lifecycle, the carbon in the above ground biomass starts to decompose and is returned to the atmosphere. Thus if the forest land use was changed to produce crops and the carbon stored in the trees is released to the environment, then it may not change the total amount of carbon that is released but ***when*** that carbon is released. In a system that discounts future carbon changes, this will have an impact on the net present value of the carbon emissions but in a system that does not discount future changes, the premature release of carbon would not impact the overall emissions.

The IPCC recognize this. Equation 2.11 in the 2006 AFOLU guidelines is;

$$\Delta CL = L_{wood\ -\ removals} + L_{fuelwood} + L_{disturbance}$$

ΔCL = annual decrease in carbon stocks due to biomass loss in land remaining in the same land-use category, tonnes C yr-1

$L_{wood-\ removals}$ = annual carbon loss due to wood removals, tonnes C yr-1

$L_{fuelwood}$ = annual biomass carbon loss due to fuelwood removals, tonnes C yr-1

$L_{disturbance}$ = annual biomass carbon losses due to disturbances, tonnes C yr-1

The disturbances can include wildfires, disease and pests, and natural events (wind damage). The IPCC also makes estimates for mortality separate from disturbances and suggests that in actively managed stands mortality may represent 30 to 50% of the lifetime productivity of the stand.

The IPCC reports that the average mortality rate ranges from 1.16% for evergreen and deciduous forests to 1.77% for tropical forests.

Information on disturbances is more difficult to accurately assemble but the FAO 2005 Global Forest Resource Assessment reported that the annual disturbance rates for all regions due to fire was 0.70%, due to insects was 0.93%, due to disease was 0.78% and due to other factors was 0.21%. The total annual forest disturbance rate was thus 2.6%. This would be in addition to the average mortality rate. The total annual disturbance rate could be as high as 4 to 4.5% per year. The report contains information on individual countries so an in-depth analysis for each country could be performed.

By properly accounting for the future losses, as well as the future gains, a proper assessment of carbon changes over time can be performed. The approach used by CARB grossly overestimates the carbon losses over time by assuming that forest carbon is permanent, when it is not. In the 30-year time frame, it is likely that only one-third to one-half of the carbon that is removed from land in the first year due to deforestation would have been standing at the end of the period. This needs to be accounted for in the emission factors.

3.4.1 US Forest Land

The carbon inventory of US forest land used by CARB is based on the Woods Hole data that was presented by Searchinger et al (2008). That information is summarized in the following table. The weighted average of the biomass carbon inventory is 171 tonnes C/ha or 627 t CO_2eq/ha. In addition, there is another 160 tonnes C/ha (585 t CO_2eq/ha) of soil carbon.

Table 3-4 US Forest Land Carbon Inventory - CARB

	Forest Land Converted	Carbon Inventory Biomass		SOC
		Tonnes C/ha	T CO_2eq/ha	T CO_2eq/ha
Broadleaf Forest	4.2%	150	550	550
Mixed Forest	89.7%	170	623	587
Woodland	0.0%	90	330	330
Coniferous Mountain	0.0%	150	550	367
Coniferous Pacific	6.0%	200	733	587
Wt Average		171	627	585

This data can be compared to the official US Forest Service carbon inventory (USDA, 2008), which is shown in the following table.

Table 3-5 US Forest Service Carbon Inventory

	Biomass	Dead Plant Matter	Total Biomass	SOC
	t CO_2eq/ha			
East	**265**	**75**	**341**	**268**
Aspen/Birch	187	61	248	482
Elam/Ash/Cottonwood	256	94	350	363
Lobolly/Shortleaf Pine	200	55	255	203
Longleaf/Slash Pine	154	50	204	355
Maple/Beech/Birch	322	138	461	308
Oak/Gum/Cypress	318	58	376	367
Oak/Hickory	301	57	357	175
Oak/Pine	231	67	298	195
Spruce/Fir	205	152	358	662
White/Red/Jack Pine	333	84	417	342
Other East Type Groups	121	47	168	297
West	**268**	**150**	**418**	**157**
Alder/Maple	367	109	476	412
Aspen/Birch	234	145	379	211
California Mixed Conifer	517	243	760	183
Douglas Fir	451	208	659	239
Fir/spruce/Mt Hemlock	399	234	633	164
Hemlock/Sitka Spruce	689	280	968	382
Lodgepole Pine	240	131	371	133
Other Western Hardwoods	142	116	258	126
Other Western Softwoods	232	168	400	128
Pinyon/Juniper	97	81	178	79
Ponderosa Pin	216	120	336	133
Redwood	885	375	1,261	195
Tanoak/Laurel	531	153	684	199
Western larch	280	190	470	140
Western Oak	211	121	332	126
Western White Pine	278	172	450	166
Other West Type Groups	43	94	137	144
Total	**266**	**104**	**370**	**225**

The deadwood values do not include litter in the Forest Service inventory so that may account for some of the difference but it is apparent that the carbon inventory values used by CARB are much higher than the best estimates of actual values. The SOC values use the same basis (one metre depth) in both inventories and thus it is difficult to explain why they are so far apart.

The carbon in dead plant matter and litter will be converted to CO_2 and perhaps some to methane irrespective of the conversion of forest land to cropland and it is therefore inappropriate to include this biomass in any land use change calculation. The CARB emission factors for US forest land are compared to the emission factors calculated from the actual forest inventory in the following table. The CARB emission factors need to be corrected for the actual inventory data for the United States.

Table 3-6 Emission Factor Comparison – US Forests

	CARB	US Forest Service
	t CO_2eq/ha	
Above (biomass)	627	266
Below (SOC)	146	56
Lost Seq. over 30 years	49	49
Total	822	371

The emission factor for US forest land is more than twice what it when the same assumptions are made with respect to biomass losses but there are also issues with these assumptions.

In the United States, it is highly likely that the trees would be harvested for the timber rather than burned to clear the land. Storing a portion of the biomass as harvested wood products would reduce the emission factor. If 80% of the biomass is above ground and 40% of that is converted to wood products (the rest would be mill and forest residue) then the emission factor would be reduced to 233 t CO_2eq/ha, 28% of that used in GTAP.

If a further adjustment for the permanence of the above ground biomass is made then the total emission factor would be about 150 t CO_2eq/ha. This value is both much reflective of US carbon stocks and in much better alignment with IPCC methodologies for calculating changes in carbon stocks.

3.4.2 Canadian Forest Land

The available information on managed forests in Canada is not as detailed as it is for the United States. It has been estimated (Kurz, 2010) that the carbon stocks in biomass (above and below ground is 65 t C/ha (238 t CO_2eq/ha). The soil carbon content is estimated to be 86 t C/ha (315 t CO_2eq/ha). This information is compared to the GTAP values in the following table.

Table 3-7 Emission Factor Comparison – Canadian Forests

	GTAP	Canadian Forest Service
	t CO_2eq/ha	
Above (biomass)	587	238
Below (SOC)	123	78
Lost Seq. over 30 years	49	49
Total	764	365

The same adjustments need to be made for harvested wood products and the permanence of the carbon. These factors would bring the values down to the same level as the US emission factors.

Another consideration is that in Canada, almost all of the forest land is owned by the Government and is essentially leased to the private sector for the purpose of harvesting trees under strict conditions. Therefore, the likelihood that clear cutting of productive forests would be allowed for the purpose of expanding crop production is remote. The small amount of forested land that is privately owned would likely have much lower biomass inventories that used here.

3.4.3 Other Countries

It appears that the CARB emission factors for forest land in the rest of the world systematically overestimates the carbon content of forests. For example, the IPCC reports that the carbon content of above ground biomass in boreal coniferous forests as 10-90 t C/ha, boreal tundra woodland as 15-20 t C/ha, and for boreal mountain forests as 40-50 t C/ha. The total biomass would be about 20 to 25% higher when the root systems are included. The CARB emission factor is a flat 90 t C/ha for all boreal forests, which is at the very top end of the range for boreal forests and should not be used for a world average carbon inventory.

As with Canada and the US, there should also be factors applied to all forest land converted that account for harvested wood products and the permanence of the removed carbon.

3.4.4 Forest Land Summary

The CARB emission factors for forest land converted to crop land are far higher than they should be. There are several reasons for this:

1. The biomass and soil carbon inventories are far higher than official national inventories for the US and Canada, and for other countries the high end of ranges provided by the IPCC appear to have been used.
2. It is possible that some of the overestimation results from the inclusion of deadwood and litter in the inventories and this material will be converted to CO_2 (and perhaps some methane) whether there is a change in land use or not.
3. No allowance is made for harvested wood products in the inventory, even in developed countries where slash burning is illegal.
4. No consideration is given for natural losses of living trees due to mortality, diseases, pests, or natural forest fires.

It is likely that the total forest emission factor applied by CARB is two to four times higher than it should be.

3.5 EMISSION FACTORS FOR PASTURE LAND

The GTAP emission factors for pasture land converted to cropland range from 10 to 30% of the emissions from the same amount of forest land in any given region. Even though more pasture land is converted to cropland in the standard GTAP model, pasture land has less of an impact on the indirect land use emissions because of the lower carbon inventory.

The US and Canada pasture land conversion account for over 50% of the pasture land converted and are the focus of the comments here.

3.5.1 US Pasture Land

In GTAP, US pastureland is assumed to have 10 t of C/ha in biomass and 80 t C/ha in soil carbon. It is assumed that all of the biomass carbon is lost as the pasture land would have to be burned to prepare it for cultivation and 25% of the soil carbon is lost. These assumptions also come from the Searchinger paper.

While good quality data on grassland carbon and soil carbon is not as readily available as the forest land data, this approach also overestimates the emissions from land use change.

The 10 t of C/ha is used for a world average for grassland. The IPCC default estimates for standing biomass on grassland are shown in the following table.

Table 3-8 IPCC Default values for Grassland Biomass

	Peak Aboveground Biomass, t dry mater/ha		
	Average	No. of Studies	Error
Boreal, wet & dry	1.7	3	+/- 75%
Cold temperate, dry	1.7	10	+/- 75%
Cold temperate, wet	2.4	6	+/- 75%
Warm temperate, dry	1.6	8	+/- 75%
Warm temperate, wet	2.7	5	+/- 75%
Tropical, dry	2.3	3	+/- 75%
Tropical, moist & wet	6.2	4	+/- 75%

Typically the below ground biomass would be 25 to 40% of the above ground biomass. The amount of carbon in dry biomass is roughly 50% and thus the quantity of vegetation that would be lost in a fire is only one to three t of C/ha. The below ground biomass would not be lost in a fire. This biomass is also not permanent but the majority of it tends to die off each year to be replaced by new growth the following year. The dead growth eventually decomposes to CO_2 and is recycled through the atmosphere. Thus, the conversion of grassland to cropland does not result in any significant change in vegetation carbon inventories and should not be included in the GTAP emission factors.

Table 3-9 Emission Factor Comparison – US Pasture

	GTAP	Recommendations
	t CO_2eq/ha	
Above (biomass)	36.7	0
Below (SOC)	73	73
Total	100	73

The loss of 25% of soil carbon from grassland is typical of what has been seen historically, but it is not necessarily a good indication of future practice in a world in which the knowledge of the importance of soil carbon is so much better understood. Follett et al (2009) reported on the changes in soil carbon when CRP land was converted to no till corn. A study over a six year period found that soil carbon did not change significantly at any depth after the change in management practice. In these trials, the native grassland was not burned prior to being planted in corn, but rather it was treated with a herbicides to prepare the soil for no-till planting. The authors strongly recommend no-till management practice for any CRP land that is put back into crop production. This issue for projecting the future carbon loss is to determine how much of the converted land may be farmed with no-till management practice versus conventional tillage. The impact of varying amounts is investigated in Section 4.

3.5.2 Canadian Pasture Land

In the 2006 Canadian National GHG Emission Inventory report (Environment Canada, 2008) for the category of grassland converted to cropland the following comments are made. This approach supports the recommended changes to the GTAP emission factors noted above.

It is assumed that there is no loss of above-ground or belowground organic matter or dead organic matter upon conversion. Total emissions in 2006 from soils amounted to 0.45 Mt. This includes the carbon losses and N_2O emissions from the conversion itself, as well as a small sink from adoption of new practices on the croplands since conversion.

In terms of changes in soil carbon for grassland converted to cropland Environment Canada report that:

The average loss of SOC based on field observations was 22% (McConkey et al. 2007a). Many of the studies involved comparisons within 30 years of breaking, whereas others were 70 or more years from breaking. Since many of these studies did not specify the period since breaking, it is assumed that the 22% SOC loss would refer to about 50–60 years after breaking.

This supports the CARB approach of assuming that 25% of the soil carbon is lost over a 30 year period. However, the soil carbon estimate for grassland in Canada is far too high in the GTAP model. The model uses a soil carbon content of 189 t C/ha whereas Environment Canada report values of about 75 t C/ha for agricultural soils, which would infer a starting value for grassland of about 100 t C/ha and a loss of 20 t C/ha.

Table 3-10 Emission Factor Comparison – Canada Pasture

	GTAP	Recommendations
	t CO_2eq/ha	
Above (biomass)	26	0
Below (SOC)	173	73
Total	199	73

No till adoption rates are very high in many parts of Canada and this would have an impact on the emissions from pasture land as described above for the US.

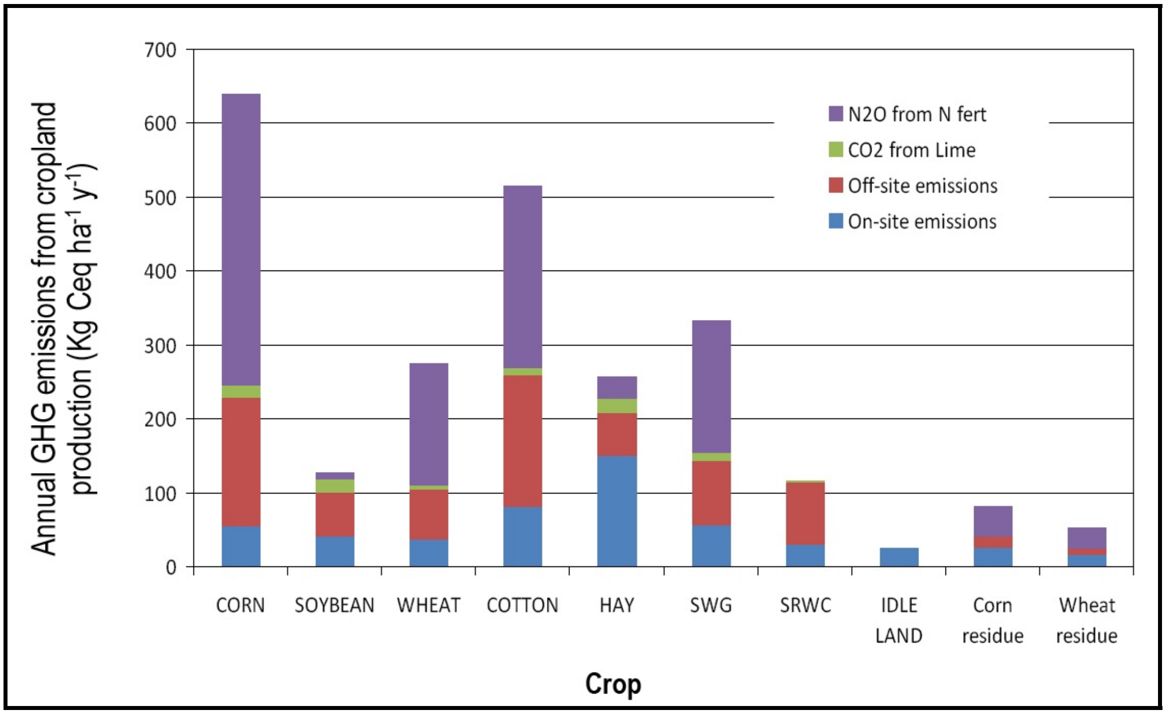
3.5.3 Summary Pasture Lands

The CARB emission factors for pasture land overestimate the GHG emissions. This is caused by at least three factors, including the loss of vegetative carbon, which is overestimated and is not permanent in any case, overestimating the soil carbon contents of grassland soils, and not considering the different management practices that will employed for future land use compared to historical practices.

3.6 EMISSIONS FROM LAND USE CHANGE

The GHG emissions associated with different crops are quite variable (Kline, 2009) when they are considered on a per hectare basis. Soybeans have the lowest emissions of any traditional crop as shown in the following figure. As the market responds to changes in demand there will be changes in GHG emissions associated not only with land use changes (e.g., pasture to cropland) but also with cropping patterns. This emission shift has not been factored into the ILUC emission calculation by CARB.

Figure 3-6 GHG Emissions per Hectare



The scenario A has some shifting of crops within the scenario as summarized in the following table. The land value in "Total Crops" is equal to the change in forest land and pasture land combined. The emission savings for Sugar Cane and Other Ag crops are assumed to the same as Other Grains.

Table 3-11 Scenario A Crop Shifting

Crop	Land	Difference in GHG emissions between crop and soybeans	Change in GHG Emissions
	hectares	Kg C/ha	Kg C/ha
Coarse Grains	-194,697	510	99,295,470
Oilseeds	1,113,943	0	0
Other Grains	-274,516	150	41,177,400
Sugar Cane	-10,817	150	1,622,550
Other Ag Products	-92,354	150	13,853,100
Total Crops	541,559		155,948,520

The total reduction in GHG emissions of 155,948 tonnes of carbon when converted to CO_2 eq and divided by the 750 million gallons of biodiesel produced, provides and offsetting land use credit of 5.2 g CO_2eq/MJ. These land use shifts are after the allocation between oil and meal and the total land shifts would be five times this value and the total GHG emission savings would be 26 g CO_2eq/MJ. This is a large and significant offset to the calculated GHG emissions from indirect land use change and should be included in the calculations.

In its proposed rulemaking, the EPA did go through a similar calculation for domestic agriculture production and did find that domestic agriculture emissions decreased when soybean biodiesel was expanded. This was the case even though there was an error in the calculations of N_2O emissions from soybean production. When the N_2O error is removed from the calculations, the EPA found that an increase in soybean production reduced GHG emissions for biodiesel by 24.5 kg CO_2eq/MM BTU. This more detailed calculation also included some other factors such as changes in livestock emissions and changes due to rice production.

4. DISCUSSION AND RECOMMENDATIONS

The impact of the various issues identified in Section 2 and 3 of the report are presented here.

4.1 DIRECT EMISSIONS

There are two issues with the revised direct emission calculations in Version 3.0 of the soybean biodiesel carbon intensity calculations.

1. CARB rounded up the mass allocation between oil and meal to 20% oil rather than the 18.9% used in the detailed calculations. This increases the carbon intensity by 0.45 g/MJ.
2. CARB has reverted to including the fossil carbon emissions in the biodiesel combustion emissions. This ignores the carbon emissions that are offset by the substitution of biological glycerine for fossil derived glycerine. The NBB has previously submitted comments on Version 1.0, which were accepted in Version 2.0. This inappropriate treatment of the co-product increases the biodiesel emissions by 3.7 g/MJ.

The sum of the two recommended changes to the soybean biodiesel direct GHG emissions is 1.15 g/MJ.

4.2 INDIRECT LAND USE EMISSIONS DISCUSSION

The most significant change in Version 3.0 is the calculation of the indirect land use emissions. CARB have modeled a number of scenarios with a new version of GTAP and have arrived at the value of 62 g CO_2eq/MJ of biodiesel. The summary of these scenarios is shown in the following table.

Table 4-1 CARB Land Use Emissions

Scenario	A	B	C	D	E	F	G	Mean
Economic Inputs								
Soy Biodiesel production increase (bill. gal.)	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Elasticity of yield wrt area expansion	0.50	0.75	0.50	0.50	0.50	0.66	0.75	0.59
Crop yield elasticity	0.40	0.40	0.20	0.40	0.40	0.25	0.20	0.32
Elasticity of land transformation	0.20	0.20	0.20	0.30	0.10	0.20	0.20	0.20
Elasticity of harvested acreage response	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.5
Trade elasticity of crops	central							
Model Results								
Total land converted (million ha)	0.54	0.36	0.67	0.65	0.39	0.50	0.45	0.51
Forest land (million ha)	0.23	0.13	0.30	0.29	0.18	0.22	0.18	0.22
Pasture land (million ha)	0.31	0.23	0.37	0.36	0.21	0.28	0.26	0.29
U.S. land converted (million ha)	0.24	0.16	0.28	0.28	0.16	0.20	0.18	0.21
U.S. forest land (million ha)	0.11	0.06	0.13	0.12	0.08	0.09	0.08	0.10
U.S. pasture land (million ha)	0.13	0.10	0.14	0.16	0.08	0.11	0.11	0.12
LUC carbon intensity(gCO_{2e}/MJ)	66	41	84	83	49	61	53	62

It can be seen from the table that the results are quite strongly influenced by the assumptions made with respect to the elasticities. In Section 3, comments and information was presented with respect to some of the elasticity. The impact of changing some of the elasticity factors is discussed below.

4.2.1 Soybean Specific Elasticity Factors

It was noted that the elasticity factors used were exactly the same values used for the corn ethanol evaluation. Soybeans are not the same crop as corn and it may not be reasonable to assume that exactly the same parameters are used for modelling. Two aspects that warrant different elasticities are the potential for double cropping in response to a price increase and the yield response to area expansion. In the following table, the impact of these two variables is shown.

Table 4-2 Soybean Specific Elasticity Land Use Emissions

Scenario	CARB Mean	Soybean Specific
Economic Inputs		
Soy Biodiesel production increase (bill. gal.)	0.75	0.75
Elasticity of yield wrt area expansion	0.59	0.90
Crop yield elasticity	0.32	0.40
Elasticity of land transformation	0.20	0.20
Elasticity of harvested acreage response	0.5	0.50
Trade elasticity of crops	central	
Model Results		
Total land converted (million ha)	0.51	0.30
Forest land (million ha)	0.22	0.10
Pasture land (million ha)	0.29	0.20
U.S. land converted (million ha)	0.21	0.13
U.S. forest land (million ha)	0.10	0.04
U.S. pasture land (million ha)	0.12	0.09
LUC carbon intensity(gCO_{2e}/MJ)	62	31.65

Both of the revised elasticity parameters are conservative in NBB's view and higher values could be used in the model for specific regions. The soybean specific values reduce the land use by 40% and the indirect land use emissions by 50% compared to the CARB mean value. Forest land is reduced slightly more than pasture, which is why the emission reduction is greater than reduction in land area.

4.2.2 Future Soybean Yield

The soybean yield that CARB model has been assumed to be static over time. In the CARB modeling of corn ethanol an updated value for the corn yield was used, but the update was only for the current yield and did not consider the potential for future yields. Soybean yields have been increasing for more than 70 years and all forecasts have the yields continuing to increase. The issue should be therefore not if the yield will increase in the future but by how much, and what is the appropriate year to use.

The NBB believes that since the LCFS will be fully implemented by 2020, that 2020 is the year for which the soybean yield should be modeled with. Using the most conservative estimate of a linear trend for soybean yield in 2020, this would reduce the indirect land use emissions by 10.2%. This factor can be applied outside of the model and for the revised soybean value of 31.65 g CO_2eq/MJ; the emissions would be further reduced to 28.42 g CO_2eq/MJ. If a more realistic estimate for future yield was used then the emissions would be even lower.

4.2.3 Emission Factors

It has been determined that the emission factors used by CARB in GTAP use estimates of carbon inventories that can not be supported by official government estimates in the United

States and Canada. Furthermore, the methodologies that have been used to estimate the changes in carbon intensity are not in alignment with IPCC guidelines or the approach used in national inventories. The result is that the land use emissions are overstated for all CARB scenarios.

In the following table the impact of these emission factor corrections and improvements are presented. Three adjustments for the factors are made:

1. The carbon inventory for US and Canadian forests is overstated. This is corrected in the first column.
2. The above carbon stocks of grasslands have been included in the emission loss for pasture. This emission loss would have occurred anyway and it is not in alignment with IPCC methodology or that used by governments to calculate the national inventories. This is applied to all regions.
3. It has been assumed that trees live forever and, unfortunately, this is not the case. Some of the forest carbon would have been lost even if no land conversion had occurred. In addition, no allowance has been made for harvested wood products even though it is illegal to burn trees to clear land in many jurisdictions.

Table 4-3 Impact of Emission Factor Corrections

Scenario	Mean	SB Specific	Higher Yield	Proper forest C inventory	Pasture adj	Permanence of forest C
Economic Inputs						
Soy Biodiesel production increase (bill. gal.)	0.75	0.75	0.75	0.75	0.75	0.75
Elasticity of yield wrt area expansion	0.59	0.90	0.90	0.90	0.90	0.90
Crop yield elasticity	0.32	0.40	0.40	0.40	0.40	0.40
Elasticity of land transformation	0.20	0.20	0.20	0.20	0.20	0.20
Elasticity of harvested acreage response	0.50	0.50	0.50	0.50	0.50	0.50
Trade elasticity of crops	central					
Model Results						
Total land converted (million ha)	0.51	0.30	0.30	0.30	0.30	0.30
Forest land (million ha)	0.22	0.10	0.10	0.10	0.10	0.10
Pasture land (million ha)	0.29	0.20	0.20	0.20	0.20	0.20
U.S. land converted (million ha)	0.21	0.13	0.13	0.13	0.13	0.13
U.S. forest land (million ha)	0.10	0.04	0.04	0.04	0.04	0.04
U.S. pasture land (million ha)	0.12	0.09	0.09	0.09	0.09	0.09
LUC carbon intensity(gCO_{2e}/MJ)	62	31.65	28.42	19.9	17.3	11.4

The impact of these corrections is very significant. With all of the proper corrections applied, the indirect land use emissions are now only 11.4 g CO_2eq/MJ. These emissions will be even lower with any reasonable assumption with respect to the use of no till management practices for the conversion of grassland to cropland.

4.2.4 Land Transformation Elasticity

One of the most important findings of the NBB work with the GTAP model has been the finding that all of the work done by CARB has assumed a constant elasticity of land transformation. This is in spite of the fact that GTAP Research Memorandum No.14 (Ahmed, et al, 2008) discusses the need for different elasticities in some detail.

Evaluation of the CET parameter by Babcock and Carriquiry (2010c) has shown that the elasticity of transformation for forest should be much lower than for pasture and crops. They suggest the following values:

- Crops: -0.18
- Pasture: -0.243
- Forest: -0.0056

GTAP was modified to utilize these different elasticities. The method used to do this is described in Appendix 1. To check the model after modifications, we ran the model, setting all three values to -0.2, the same as the single CET parameter. The results were exactly the same as before the modifications. The results are summarized in the following table.

Table 4-4 Impact of Land Transformation Elasticity

Scenario	Mean	SB Specific	Higher Yield	Adj Emission factors	Revised CET
Economic Inputs					
Soy Biodiesel production increase (bill. gal.)	0.75	0.75	0.75	0.75	0.75
Elasticity of yield wrt area expansion	0.59	0.90	0.90	0.90	0.90
Crop yield elasticity	0.32	0.40	0.40	0.40	0.40
Elasticity of land transformation	0.20	0.20	0.20	0.20	
Elasticity of land transformation, crops					-0.18
Elasticity of land transformation, forest					-0.0056
Elasticity of land transformation, livestock					-0.2430
Elasticity of land transformation, other					-0.0056
Elasticity of harvested acreage response	0.50	0.50	0.50	0.50	0.50
Trade elasticity of crops	central				
Model Results					
Total land converted (million ha)	0.51	0.30	0.30	0.30	0.35
Forest land (million ha)	0.22	0.10	0.10	0.10	-0.07
Pasture land (million ha)	0.29	0.20	0.20	0.20	0.42
U.S. land converted (million ha)	0.21	0.13	0.13	0.13	0.15
U.S. forest land (million ha)	0.10	0.04	0.04	0.04	-0.04
U.S. pasture land (million ha)	0.12	0.09	0.09	0.09	0.19
LUC carbon intensity(gCO_{2e}/MJ)	62	31.65	28.42	11.4	8.9
% change from parameter change		-48.9	-10.2	-59.9	-21.9

The total quantity of land converted increased with these changes, but there was an increase in forest land in total, so all of the new land was from pasture. The emission factor used for gaining forest was the same emission factor used by CARB in GTAP. In general, these emission factors are all lower, reflecting the relatively short period being studied.

4.3 INDIRECT LAND USE EMISSIONS RECOMMENDATIONS

The indirect land use emissions are strongly influenced by the assumptions that are made for modeling purposes. The parameters modeled by CARB could be significantly improved with values that are more realistic for soybeans by:

1) Using emission factors that reflect official forest inventories in the US and Canada;
2) Applying emission factor methodologies that are compliant with IPCC guidance and with national inventories in the US and Canada; and
3) Using elasticity factors for land transformation that are reflective of each type of land.

The cumulative impact of the various improvements recommended reduces the indirect land use emissions for soybean biodiesel down to 8.9 g CO_2eq/MJ. When this value is further adjusted for the overall reduction in land use emissions due to crop shifting, the emissions are reduced to 3.7 g CO_2eq/MJ.

In the short time available to analyze the GTAP model for soybeans, not all of the issues could be fully investigated. The model has significant capacity for further refinement that has not been fully investigated. For example, no resolution of the issue of idle land and how it is modelled could be achieved. The emissions could be even lower than 3.7 if any significant amount of idle land was used to offset the current estimate of pasture and forest land converted. The individual elasticities of land transformation could be better refined if the original data in the Ahmed paper was available. It is possible to use specific elasticities for individual regions.

5. REFERENCES

Ahmed, Hertel, Lubowski. 2008. Calibration of a Land Cover Supply Function Using Transition Probabilities. GTAP Research Memorandum No. 14. October 2008. https://www.gtap.agecon.purdue.edu/resources/download/4199.pdf

Babcock and Carriquiry. 2010. Using GTAP's Yield Elasticity with Respect to Price to Capture Production from Double Cropping. Prepared for the National Biodiesel Board.

Babcock and Carriquiry. 2010b. Is Converted Land Less Productive than Current Land? Prepared for the National Biodiesel Board.

Babcock and Carriquiry. 2010c. Implications of the CET Supply Function Approach of GTAP. Prepared for the National Biodiesel Board.

Babcock and Carriquiry. 2010d. Recent Land Use Changes in the United States. Prepared for the National Biodiesel Board.

Environment Canada. 2008. 2006 Canadian National GHG Emission Inventory Report. http://www.ec.gc.ca/pdb/ghg/inventory_report/2006_report/2006_report_e.pdf

FAO. Global Forest Resources Assessment 2005. Data Tables. http://www.fao.org/forestry/static/data/fra2005/global_tables/FRA_2005_Global_Tables_EN.xls

Follett, R., Varvel, G., Kimble, J., Vogel, K. 2009. No-till Corn after Bromegrass: Effect on Soil Carbon and Soil Aggregates. Agronomy Journal. 101:261-268 (2009). DOI: 10.2134/agronj2008.0107

Kløverpris, J. 2008. Consequential Life Cycle Inventory Modelling of Land Use induced by Crop Consumption.

Kurz, W. 2010. Personal communication with Dr. W Kurz, Senior Research Scientist, Global Change and Landscape Ecology, Canadian Forest Service, Natural Resources Canada. Jan 6, 2010.

Reijnders, L. 2009. Are forestation, bio-char and landfilled biomass adequate offsets for the climate effects of burning fossil fuels? Energy Policy. Volume 37, Issue 8, August 2009, Pages 2839-2841. http://dx.doi.org/10.1016/j.enpol.2009.03.047

Searchinger et al. 2008. Supporting Online Material for Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land Use Change. Published 7 February 2008 on Science Express. DOI: 10.1126/science.1151861

U.S. Department of Agriculture. 2008. U.S. Agriculture and Forestry Greenhouse Gas Inventory: 1990-2005. Global Change Program Office, Office of the Chief Economist, Technical Bulletin No. 1921. 161 pp. August, 2008. http://www.usda.gov/oce/global_change/AFGGInventory1990_2005.htm.

USDA. 2009. 2007 Census of Agriculture, Table 8: Land. http://www.agcensus.usda.gov/Publications/2007/Full_Report/Volume_1,_Chapter_1_US/st99_1_008_008.pdf

USDA. 2009b. 2007 Census of Agriculture, Table 2: Market Value of Agricultural Products Sold Including Landlord's Share and Direct Sales:2007 and 2002. http://www.agcensus.usda.gov/Publications/2007/Full_Report/Volume_1,_Chapter_1_US/st99_1_002_002.pdf

West, T. O., Eaton, L. M., Hellwinckel, C, Downing, M. E., Dale, V. H., Kline, K, L.. 2009. Energy Inputs for 1st and 2nd Generation Ethanol Feedstocks: Modeling Effects of Cultivation Practices and Crop Selection on GHG Emissions. Oak Ridge National Laboratory, Agriculture Policy Analysis Center.

6. APPENDIX 1. METHOD OF SPLITTING THE LAND TRANSFORMATION ELASTICITY

In the original GTAPSOY model code, two similar equations were used in crop and non-crop calculations. The same elasticity of land transformation variable (input as ETL1 in the code) was applied in both equations. To split the elasticities, three new variables and two additional equations were introduced to the model's parameter data base and code. The three new elasticity variables correspond to the land transformations for crops (ETLC), forest (ETLF), and graze (ETLG) for livestock/pasture. The original land transformation variable was kept and used for the remaining "other" areas.

In the GTAP code, the crop equation was left unchanged, except for replacing the original ETL1 variable with the new crop variable, ETLC. The non-crop equation was then duplicated twice. The first duplicate was changed to only loop over the forest calculations and use ETLF instead of ETL1. Similarly, the second equation was changed to only loop over the livestock (graze) calculations and use ETLG instead of ETL1. The original non-crop equation was not modified. However, its looping parameter was changed so that only the remaining "other" areas were covered.

To ensure that the model had been properly modified, AIR reran the 7 CARB scenarios and compared the results to those of the original version. All values agreed to within the GEMPACK convergence tolerances.

7. APPENDIX 2. BABCOCK DOUBLE CROPPING MEMO

Using GTAP's Yield Elasticity with Respect to Price to Capture Production from Double Cropping

Bruce A. Babcock
Miguel Carriquiry

Before expanding into new area, it is expected that producers explore increasing the productivity of their land in response to higher returns. The analysis conducted for CARB acknowledges and partially captures this observation by making yields responsive to changes in returns. However, the analysis seems to ignore other forms of intensification avaiable to producers in many areas of the world, namely multi-cropping. This is somewhat surpsiring because one of the first farmer responses to higher crop prices is an increase is the amount of double cropping that takes place. Double cropping in the United States generally consists of planting soybeans after winter wheat is harvested. Figure 1 shows that the number of acres of double cropped soybeans increased substantially in 2007 and 2008 in response to higher crop prices.

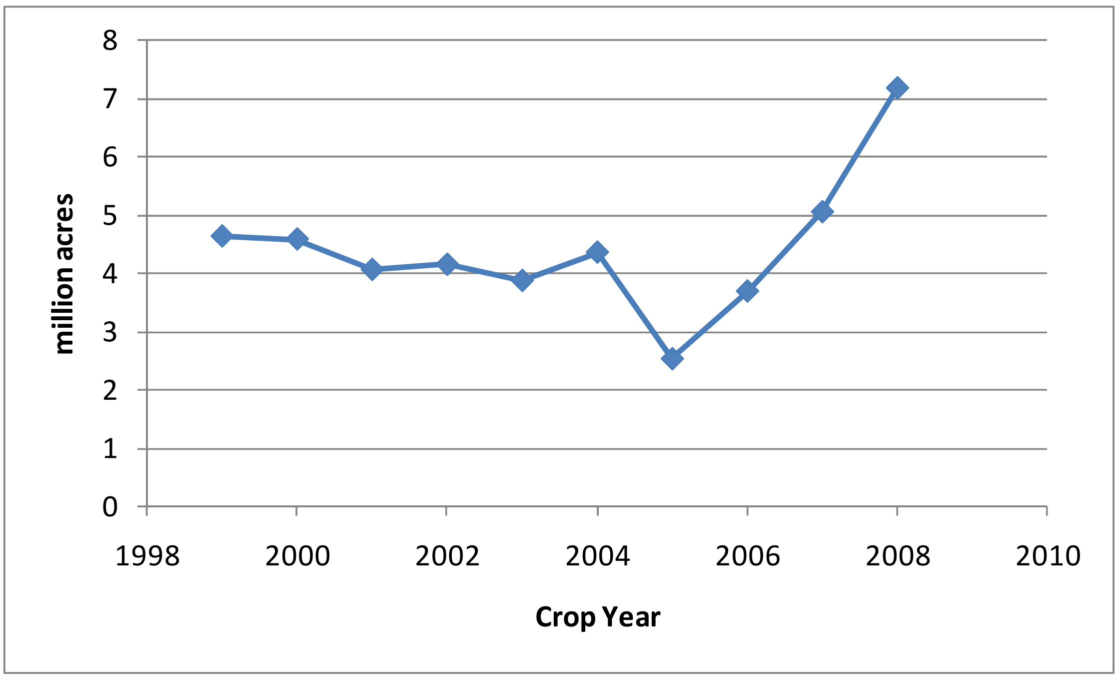


Figure 1. Number of Double Cropped Soybean Acres in the United States
Source: FAPRI Agricultural Outlook

In Brazil, double cropping consists of planting a crop of corn after a crop of soybeans. This second crop of corn is referred to as "safrinha." Figure 2 shows that total Brazilian safrinha has increased substantially over the last 15 years.

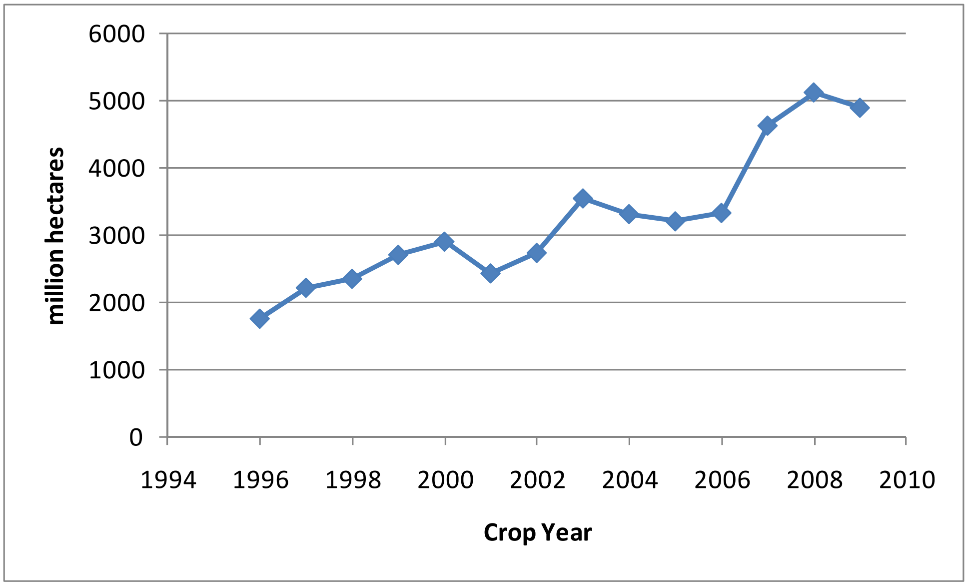


Figure 2. Safrinha (Double Cropped Corn) Land in Brazil
Source: FAPRI Agricultural Outlook

If all safrinha corn is on land used for the main summer crop (usually soybeans), output expands without the need of new land brought into production. It is "as if" yields per unit of land cropped are increasing faster than usually assumed by "technology" and price responsiveness. To illustrate the potential of double cropping to accelerate yield growth per unit of land, Figure 3 shows the evolution of corn yields for the first crop, and the implied combined corn yield. This implied combined yield is calculated as total corn production divided by the area of the first crop of corn. The implicit assumption is that all the area planted to the second crop of corn had been planted in the main season. For the last year in the figure, double cropping implies yield increases of over 50% when compared to those based on the first crop alone.

It is important to account for double cropped acres because double cropping creates production without using up land. Hence, an increase in double cropping can help accommodate expanded biofuels production without causing conversion of pasture or forest to cropland. The challenge to properly account for double cropping is that no land category called double cropped land exists in GTAP. However, because an increase in double cropping increases production without increasing land, it is as if yield increases. And GTAP captures increases in yield through the yield elasticity with respect to price. So this yield elasticity could be adjusted to account for increased production from double cropping.

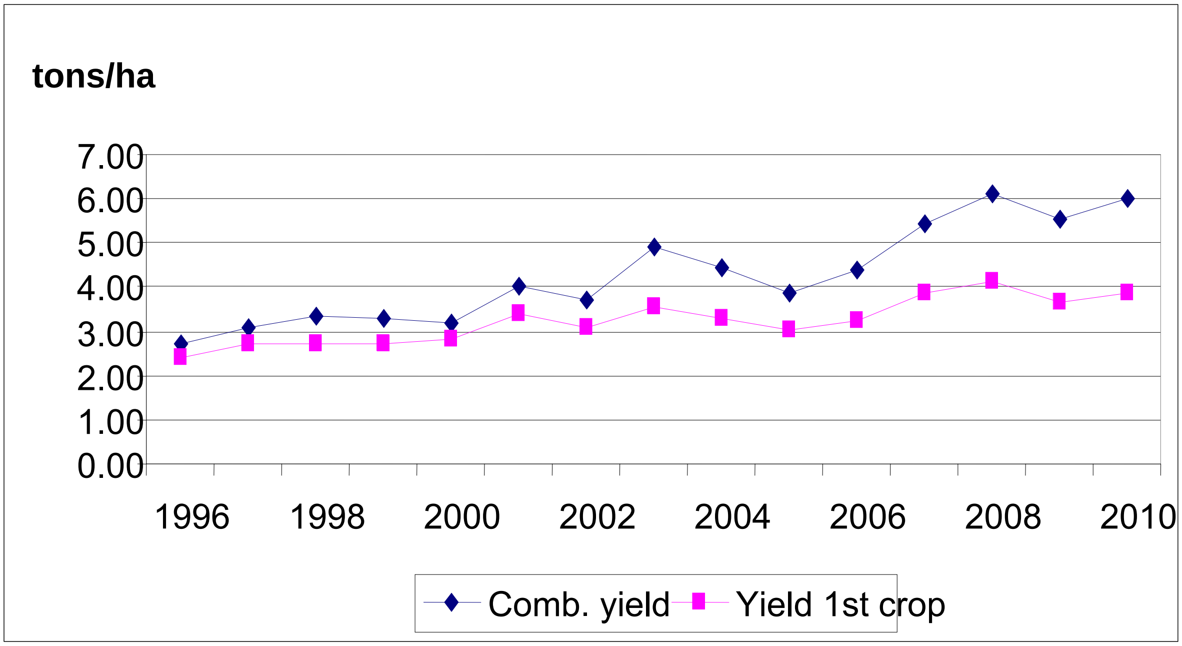


Figure 3. Corn yields for the first crop and the implied combined yield

Adjusting price-yield elasticities

When there are double crop acres, it is typical for reporting agencies to calculate yield by dividing total production of the crop by total acres planted to the crop. That is

$$Y = \frac{Q}{A_1 + A_2}; \quad Q = A_1 Y_1 + A_2 Y_2$$

This derivation was accomplished by noting that Y = Q/A, and then multiplying and dividing by the appropriate variable to turn the derivatives into the resulting elasticities.

where Y is the reported yield of a crop (soybeans), A is land devoted to soybeans, and the subscript denotes first crop or second crop. The yield elasticity with respect to price is meant to capture how yield changes in response to price. However, yield is not measured directly. Rather aggregate production and total acreage are measured and yield is calculated by division. This means that price affects reported yields through both its impact on acreage and on per-acre yields:

$$\frac{\partial Y}{\partial P} = \frac{A_1\left(\frac{\partial Y_1}{\partial P} A_1 + \frac{\partial A_1}{\partial P} Y_1 + \frac{\partial Y_2}{\partial P} A_2 + \frac{\partial A_2}{\partial P} Y_2\right) - \frac{\partial A_1}{\partial P}(Y_1 A_1 + Y_2 A_2)}{(A_1 + A_2)^2}$$

which implies

$$\frac{\partial Y}{\partial P}\frac{P}{Y} = \frac{A_1\left(\frac{\partial Y_1}{\partial P}\frac{P}{Y} A_1 + \frac{\partial A_1}{\partial P}\frac{P}{Y} Y_1 + \frac{\partial Y_2}{\partial P}\frac{P}{Y} A_2 + \frac{\partial A_2}{\partial P}\frac{P}{Y} Y_2\right) - \frac{\partial A_1}{\partial P}\frac{P}{Y}(Y_1 A_1 + Y_2 A_2)}{(A_1 + A_2)^2}$$

This expression can be greatly simplified by expressing it in terms of elasticities. Denoting the elasticity of *i* with respect to a change in *j*, as $\eta_{i,j}$, after simplifying, the price yield elasticity equals:

$$\eta_{y,P} = s_1\left[\eta_{y_1,P} + \eta_{A_1,P}\right] + s_2\left[\eta_{y_2,P} + \eta_{A_2,P}\right] - \frac{A_1}{A_1 + A_2}\eta_{A_1,P} - \frac{A_2}{A_1 + A_2}\eta_{A_2,P}$$

where the share of production is denoted by *s*.[1] This expression makes it clear that the yield elasticity with respect to price measures changes in both per-acre yields on both first and second crop acreage, as well as changes in both first and second crop acreage.

If we want to measure the elasticity holding acreage constant then

$$\eta_{y,P} = s_1\eta_{y_1,P} + s_2\eta_{y_2,P}$$

which is just the share-weighted elasticities of yield on first and second crop acreage.

From a land use perspective, increased production on second crop acreage implies that less land is needed to meet any given demand. This is exactly analogous to what happens when yield increases: demands can be met with fewer acres of land. From equation (1), we can capture the additional production from second crop acreage in response to a price increase by accounting for production changes in the numerator, but by holding second crop acreage constant in the denominator. When acreage is allowed to change this gives rise to a new yield elasticity with respect to price:

$$\eta^*_{y,P} = s_1\left[\eta_{y_1,P} + \eta_{A_1,P}\right] + s_2\left[\eta_{y_2,P} + \eta_{A_2,P}\right] - \frac{A_1}{A_1 + A_2}\eta_{A_1,P}$$

All that changes is that the elasticity of second crop acreage with respect to price no longer appears in the expression. That is, if we subtract the unadjusted elasticity from the adjusted elasticity the difference is $\frac{A_2}{A_1 + A_2}\eta_{A_2,P}$. This means that we can account for the impacts of increased production on second crop acreage by simply adding this term to the GTAP elasticity that is currently being used.

Alternatively, if the GTAP yield elasticity is supposed to hold acreage constant, then we want to account for increased production caused by an increase in double cropped acreage. Then

$$\eta^*_{y,P} = s_1\eta_{y_1,P} + s_2\eta_{y_2,P} + s_2\eta_{A_2,P}$$

and the only difference between the current GTAP elasticity and the adjusted elasticity that accounts for the additional production form double cropped acreage is $s_2\eta_{A_2,P}$. Notice that the only difference in the adjustment factor is that when acreage is allowed to change, then the adjustment factor includes the double crop share of acreage. When changes in acreage are not accounted for then the adjustment factor includes the share of production. Because yields on second crop acreage are typically lower than yields on first crop acreage, the adjustment will be lower when acreage changes are not accounted for.

Application to U.S. Soybeans

The share of acreage and production of double cropped soybeans in the United States can vary dramatically. USDA reports yields of soybeans following another crop and not following another crop for Arkansas and Missouri only. The average yield difference for these two states was 17.5%. Figure 4 uses this yield difference and FAPRI's estimate of total double cropped acres to calculate shares from 2000 to 2008.

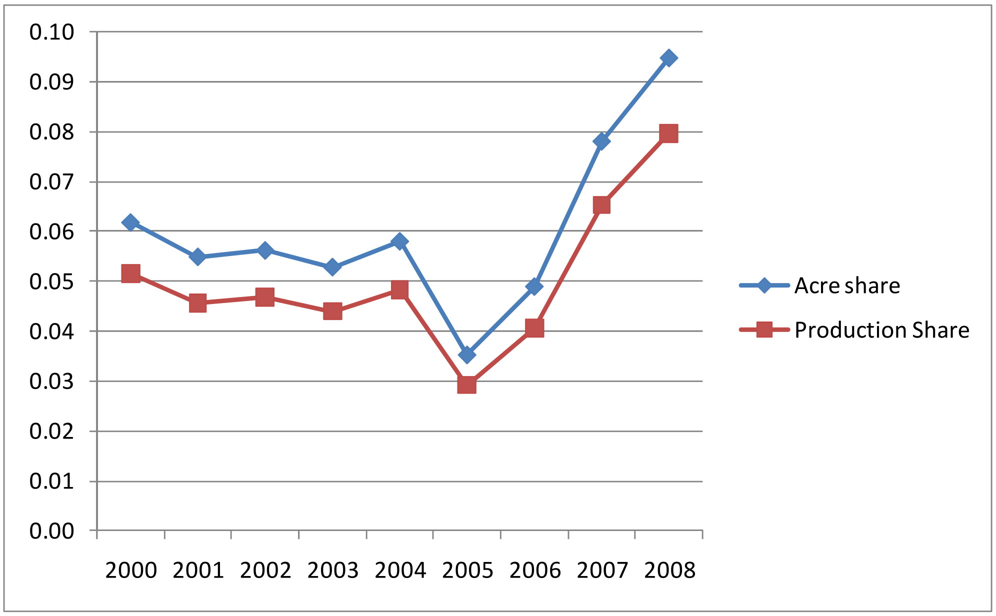


Figure 4. Share of Double Cropped Acres

The remaining step is to calculate the elasticity of double cropped acres with respect to price. Figure 5 shows both soybean returns per acre and the number of acres of double crop. Although the relationship is not consistent over time, the sharp increase in soybean returns beginning in 2007 is associated with a large increase in double cropped acres. Because there is a limit to the number of farmers and the regions where double cropping is feasible, it is likely that the elasticity of double cropped acres is high when acreage is low and low when acreage is high. Hence, it is not clear what value to use. An upper limit would be to calculate the percent change in returns averaged in 2005 and 2006 relative to 2007 and 2008 and to calculate the corresponding average double cropped acres. This results in a return elasticity of 1.3. This translates into a price elasticity (holding costs constant) of approximately 2.0. This elasticity is an upper bound and is appropriate when double cropped acreage is quite low as it was in 2005 and 2006. If we multiply the share of acreage in 2005 and 2006 by 2.0, we get an adjustment to the soybean yield elasticity of between 0.07 for 0.085. Thus if the central yield elasticity used by CARB is 0.3, we would increase this central point to 0.37 or 0.385 for soybeans. Note that an increase in share from Figure 4 in 2007 and 2008 is likely associated with a decrease in the elasticity the actual amount of adjustment is not likely to differ by much across years.

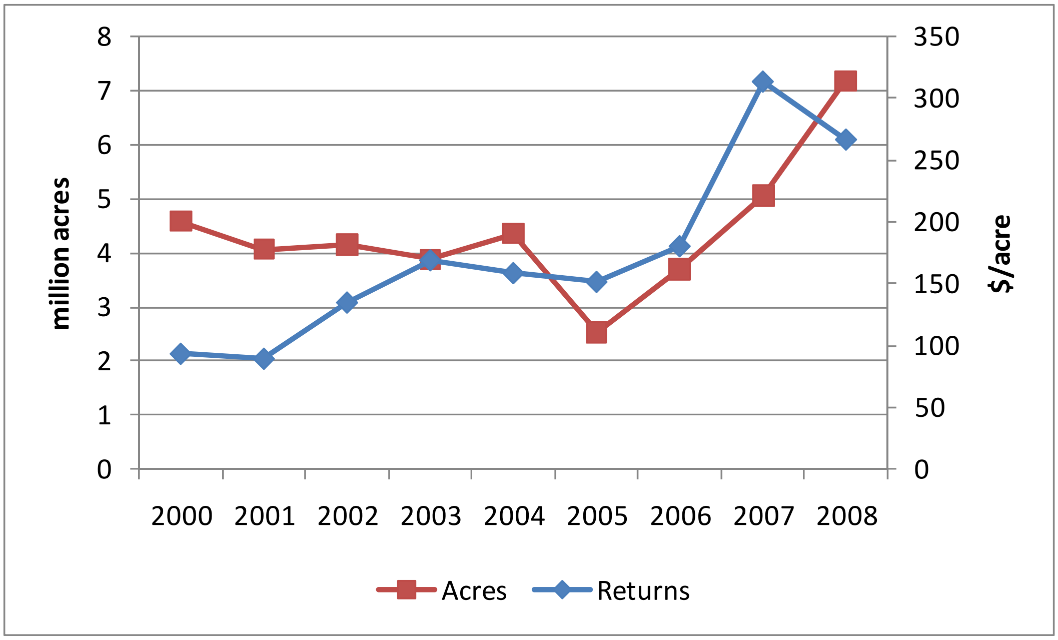


Figure 5. Comparing U.S. Double Cropped Acres and Soybean Returns

Adjustment for Brazil

In Brazil, corn is double cropped after soybeans. The yield elasticity of corn could be increased to accommodate the production increase from double cropping, using the same procedure as was used above for the United States. Or, focus could remain on soybeans, and the double cropped acreage could be accounted for by allowing total corn acreage to increase by the amount of the double cropped acreage and counting the production of soybeans on the double cropped acreage as accruing to soybeans but subtracting the acreage that is double cropped from reported soybean acreage. The total number of acres in production is the same for either treatment. Given that the focus of the CARB analysis is on soybeans, it makes sense to account for the extra production from double cropping as accruing to land planted soybean land that is not double cropped.
Second cropped corn yields about 7% less than first crop corn in Brazil. Thus there is a much smaller difference between the share of production and the share of acreage. The share of acreage that is double cropped in Brazil from 2000 to 2009 is shown in Figure 6. A share of 20% seems reasonable to use to calculate the adjustment factor. There was a 150% increase in double cropping from 2004-2006 relative to 2007-2009 periods. This was associated with an increase in the profitability of growing the second crop of corn. Taking the average percentage changes over this time period gives a return elasticity equal to 1.13. This translates into a price elasticity (holding costs constant) of approximately 1.6. Again, this is likely an upper limit on the elasticity. But if we multiply 1.6 by 0.15, which is the approximate share in 2004, we get an adjustment factor for Brazil equal to 0.24. Thus if the GTAP yield elasticity is 0.25, the adjustment factor would increase the elasticity to 0.49. Note that this adjustment is much larger than the U.S. adjustment. This reflects the larger share of double cropping in Brazil.

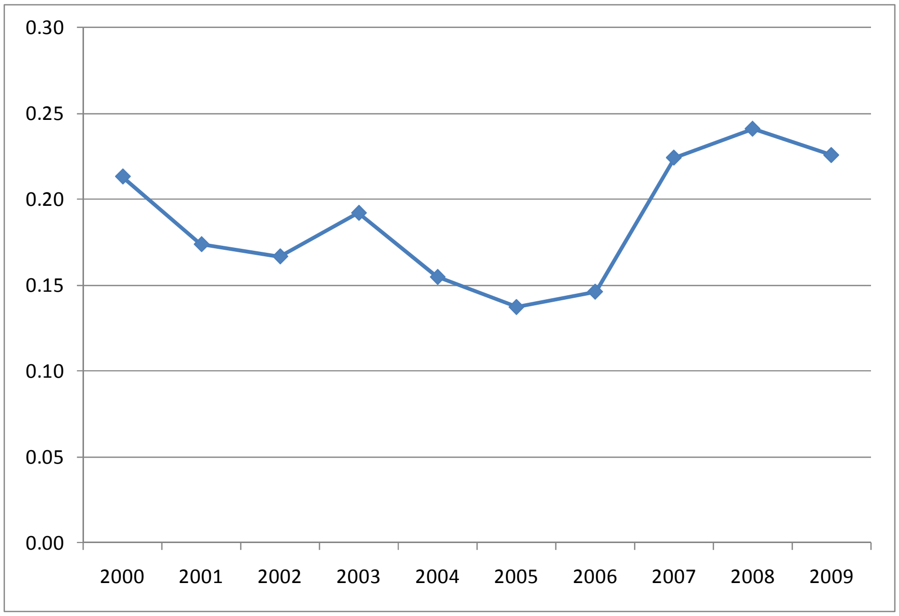


Figure 6. Share of Brazilian Soybeans Grown in Double Cropping System

One difficulty with implementing this adjustment would be if GTAP does not allow the elasticity of yield with respect to price to differ by crop. Both in the United States and Brazil, soybeans are involved with double cropping systems. If the increase in production from double cropping is attributed in both cases to soybeans, then the elasticities for the other crops should not be adjusted.

8. APPENDIX 3. BABCOCK YIELD OF CONVERTED LAND MEMO

Is Converted Land Less Productive than Current Land?

Bruce A. Babcock
Miguel Carriquiry

One of the crucial assumptions for the calculation of the LUC carbon intensity of biofuels is the elasticity of crop yields with respect to area expansion. This elasticity attempts to capture differences in yields from newly converted lands and established areas of the same crop. The basic premise of CARB is that “all of the land that is well-suited to crop production has already been converted to agricultural uses, yields on newly converted lands are almost always lower than corresponding yields on existing cropland.” For the CARB analysis, this input for the GTAP model was selected in the range of 0.5 to 0.75. Sensitivity analysis indicates that a change from 0.5 to 0.75 results in a 38% reduction in LUC intensity. Of the seven scenarios run for GTAP, four placed the crop yield elasticity on the lower end of the selected range, the upper end (0.75) was selected for two runs, and the remainder used a value close to the center of the range (0.66). Given the prevalence of scenarios on the lower end of the range, the average across scenarios is only 0.57, increasing the calculated carbon intensity of biodiesel. A more balanced approach, in which the average elasticity across scenarios is closer to the average of the assumed range (i.e., 0.625) would have resulted in carbon intensities 8.6% lower that mean value obtained by CARB.

More fundamentally, what is the evidence point that "all of the land that is well-suited to crop production has already been converted to agricultural uses"? This assumption is critical in order to justify the imposed lag of yields in new lands, relative to areas where the crops was previously established. While the well-suited area for expansion may be limited, there exist evidence that some land with good potential for crops is still available. Thus, "yield drags" from agricultural expansion, while plausible are not necessarily a fact to be imposed without strong evidence. Doubt should also be cast on the large magnitude of the average yield reduction assumed.

Some evidence of the extent of well suited land still available can be obtained from the work of Fisher et al (2002).[2] Utilizing their agro-ecological zoning, combined with land cover information, these authors estimated that close to 19% of the global land with rain-fed cultivation potential (Very Suitable, Suitable, and Moderately Suitable in their classification) was under forest ecosystems at that time. This would amount to an area of 464 million hectares out of a total of 2,430 million hectares. Considering only Very Suitable land, about 237 million hectares are occupied by forest ecosystems. While expansion over forest ecosystems should be discouraged, it seems the analysis conducted for CARB penalizes biodiesel twice; first by the alleged forest displacements, and second by yield reductions when the evidence indicates that there is still quality land available.
In this line, Table 2 presents regional information extracted from Table 5.13 in Fisher et al. (2002). While the land used in crop cultivation refers to the 1994-1996 period, the table indicates that globally, only half of the land classified as moderately suitable for rain-fed cultivation potential or better was being used for that purpose.

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[2] Fisher, G., H. van Velthuizen, M. Shah, and F. Nachtergaele. 2002. "Global Agro-Ecological Assessment for Agriculture in the 21st Century: Methodology and Results." International Institute for Applied Systems Analysis, and Food and Agriculture Organization of the United Nations.

Region	Total land (10^6ha)	Land for Use in Crop Cultivation (FAOSTAT 1994-1996) (10^6ha)	VS+S+MS[a] Land with rain-fed cultivation potential (mixed inputs) (10^6ha)
North America	2,138.50	225.3	366.3
Eastern Europe	171	81.7	121.9
Northern Europe	172.5	21.6	43.8
Southern Europe	131.6	45.6	46.5
Western Europe	109.5	35.1	64.2
Russian Federation	1,674.10	130.1	225.9
Central America & Caribbean	271.8	43.5	58.8
South America	1,777.60	114.8	669.2
Oceania & Polynesia	849.7	53.2	101.8
Eastern Africa	639.5	46	240.9
Middle Africa	657.1	24.8	270.3
Northern Africa	794.1	44.1	94
Southern Africa	266.4	17.4	28.8
Western Africa	633	65.4	178.6
Western Asia	433	46.1	31.7
Southeast Asia	444.5	89.6	102
South Asia	671.8	231.6	196
East Asia & Japan	1,149.50	144.1	144.8
Central Asia	414.4	45.2	15.5
Developing	**8,171.50**	**909.6**	**2,024.70**
Developed	**5,228.00**	**595.5**	**976.1**
World total	**13,399.50**	**1,505.20**	**3,000.80**

[a] VS=very suitable, S=suitable, MS=Moderately suitable.

The extent to which agricultural expansion for biofuel production must all be accommodated by a combination of forestland and pastureland conversion could also be questioned. A recent peer reviewed study (Campbell et al 2008)[3] concluded that between 385 and 472 million hectares of abandoned agricultural land (cropland and pasture) could be brought back into production. It is important to notice that this figure excludes abandoned agricultural land that had transitioned to other ecosystems such as forest. The authors highlight that their estimates are between 66% and 110% of the figures reported in previous assessments. This indicates the numbers are consistent with the range provided in other studies.

After establishing that additional suitable land is available for crops, we assess the second part of the premise which states **"yields on newly converted lands are almost always lower than corresponding yields on existing cropland"**. This assumed fact is used to

[3] Campbell, J. E., D. B. Lobell, R. C. Genova., and C. B. Field. 2008. "The Global Potential of Bioenergy on Abandoned Agriculture Lands" Environmental Science & Technology, 42, 15: 5791-94

justify the steep yield discounts on new areas assumed by GTAP for the CARB analysis.[4] CARB assumes that new cropland that comes from pasture and forest land is intrinsically less productive than cropland that is planted in the baseline. CARB uses a parameter called the “Elasticity of crop yields with respect to area expansion” which is justified and defined as (page 2 and 3 of the CARB report titled "Land Use Change Effects for Soy Biodiesel") “This parameter expresses the yields that will be realized from newly converted lands relative to yields on acreage previously devoted to that crop. Because almost all of the land that is well-suited to crop production has already been converted to agricultural uses, yields on newly converted lands are almost always lower than corresponding yields on existing crop lands.”

If this parameter is an elasticity, it is not clear how crop yields on new land are calculated. If this parameter is simply the ratio of yields on newly converted land relative to yields on existing land, then it is certainly misnamed. Regardless of how it is measured, the assumption is that average yields on new land are lower than average yields on old land.

In the United States, this assumption may seem reasonable if we make the assumption that all “well-suited” cropland is currently being planted. But, in fact, U.S. cropland has been going down over time due to increases in productivity and to competing demands. If some of the cropland that has left agriculture is actually idled, then there exists a pool of available cropland that was once considered to be “well-suited” for growing crops and could be consider “well-suited” once again.

Presumably, crop ground that was idled was idled for a reason. It likely was less productive than cropland that continued in production. And the marginal cropland that came out of production was likely devoted to crops that had the lowest returns. Figure 1 shows the percentage change in acreage by crop from 2009 relative to 1998. This suggests that the returns to most crops declined substantially over this time relative to the returns to the crops that did not decline substantially, most notably corn and soybeans with wheat and rice close behind. What this suggests is that most marginal crop acres probably came out of marginal crops.

One might be tempted to test the CARB assumption by determining if the crops that have lost the most acreage since 1998 have had the highest rate of yield growth because the remaining crop acreage is the most suited for growing the crop. But this would result in the perverse finding that the crops that have gained the most acreage (corn and soybeans) have also had the highest rate of yield growth because it is well known that yield growth for corn and soybeans (especially corn) has outstripped yield growth of nearly every other U.S. crop. One reason why corn and soybean acreage has grown over time is precisely because of this differential yield growth. Higher yields make it more likely that farmers will choose to plant a crop.

[4] As an aside, this across the board yield penalty may not be adequate for several crops that are not very demanding in terms of land quality.

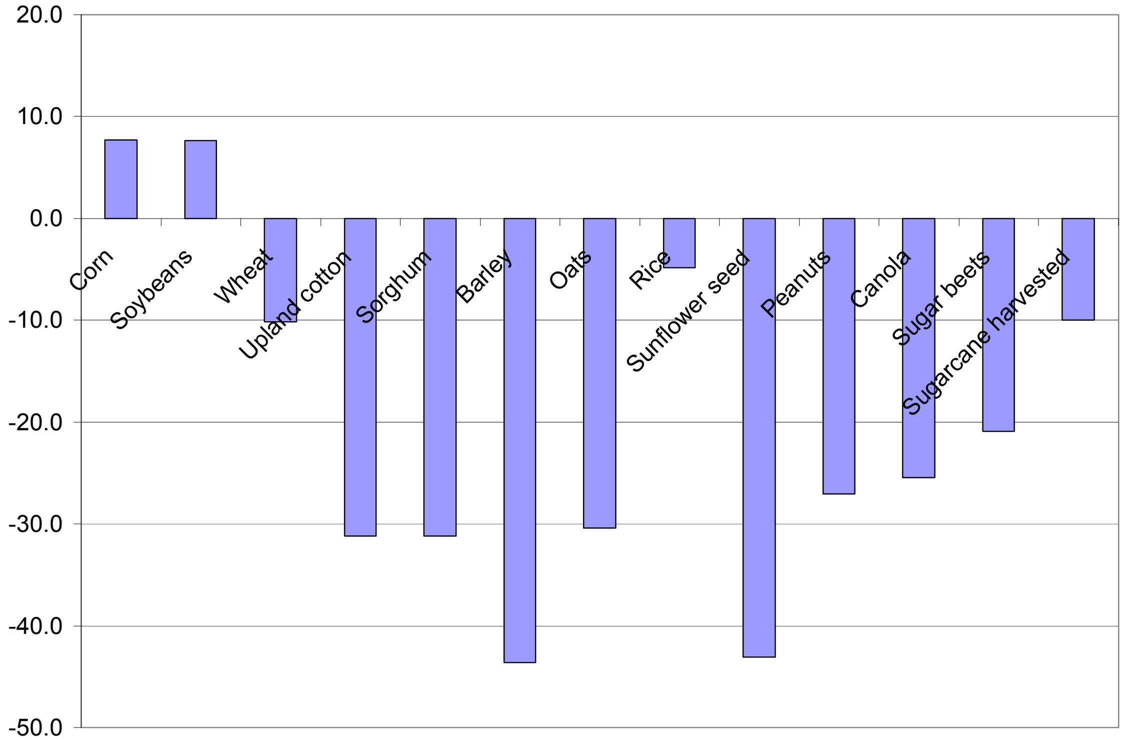

Figure 1. Percentage Change in Acres: 2009 vs 1998

This shift in crops makes it difficult to carefully test for or implement the CARB assumption in the United States. For example, with the biodiesel demand shock, CARB estimates that oilseed acreage increases and coarse grain acreage decreases, which makes sense if soybean acreage increases relative to corn acreage in response to an increase in the price of soybean oil. If new land is converted from hay or pasture, in response to the overall increase in crop returns, then which crop is likely to be planted on the new land? Because the reduction in cropland is associated with a reduction in marginal crops, it is reasonable to expect that marginal crops will be planted on the marginal lands. Any change in corn and soybean acreage will likely take place on land that is already being planted because that land is relatively more productive. For example, an expansion in soybean acreage will likely be met primarily by a reduction in corn acreage because most soybeans are grown in rotation with corn. If more soybeans are grown in the Corn Belt, it is difficult to see why soybean yields will drop. Rather, cotton yields, or small grain yields that are planted on the new acreage could be lower if they are planted on marginal ground.

How crop mix changes in the United States is the key to understanding how crop yields will change in response to new land being cultivated. A test of the CARB assumption would require a careful accounting for the dramatic changes in crop mix that the United States has experienced in the last 10 years. Such a test is beyond the scope of this analysis.

However, the situation in Brazil allows for such a test because much of the expansion in cropland in Brazil is due to the dramatic increase in soybean acreage. So there is no doubt that soybeans have been planted increasingly on land that has been newly brought into production. If the CARB assumption is correct, then we should be able to see it in the Brazilian soybean yield data. In particular we should be able to discern if those regions in Brazil with the most rapid expansion have either lower yields or lower yield growth because of that expansion.

Testing Whether Yields on New Land are Lower than on Old Land

Our test of whether yields on new land are lower than on old land needs to account for both the addition of new area and changes in yields over time. Let *t* denote the base year which defines what is existing or old land. The average reported yield at any point *n* years after the base year after the base year are given by

$$\bar{Y}_{t+n} = \frac{A^{old}Y^{old}_{t+n} + A^{new}_{t+n}Y^{new}_{t+n}}{A^{old} + A^{new}_{t+n}} \qquad (1)$$

where A is land and $A^{new}_t = 0$. Suppose that yield on new land equals $Y^{new}_{t+n} = \gamma Y^{old}_{t+n}$, where γ is the crop yield parameter that measures the ratio of yields on new relative to old land. Equation (1) can then be rewritten as

$$\bar{Y}_{t+n} = \left(\frac{A^{old} + \gamma A^{new}_{t+n}}{A^{old} + A^{new}_{t+n}}\right)Y^{old}_{t+n},$$

with the reported yield being a scaled version of the yield that would have been observed in the base area. Because $A^{new}_t = 0$, the change of yields between the base and time *t+n* can be expressed as

$$\bar{Y}_{t+n} - \bar{Y}_t = \left(\frac{A^{old} + \gamma A^{new}_{t+n}}{A^{old} + A^{new}_{t+n}}\right)Y^{old}_{t+n} - Y^{old}_t$$

which can be rearranged as

$$\bar{Y}_{t+n} - \bar{Y}_t = \frac{A^{old}}{A^{old} + A^{new}_{t+n}}\left(Y^{old}_{t+n} - Y^{old}_t\right) + \frac{A^{new}_{t+n}}{A^{old} + A^{new}_{t+n}}\left(\gamma Y^{old}_{t+n} - Y^{old}_t\right), \qquad (2)$$

which is a weighted average of the yield growth in the base area and an adjusted yield growth affected by γ. Thus, if the yield in new areas is lower than in base areas ($\gamma < 1$), equation (2) decreases with the share of new land on total land.

Defining $\alpha_n = \frac{A^{old}}{A^{old} + A^{new}_{t+n}}$, equation (2) can be rewritten as

$$\bar{Y}_{t+n} - \bar{Y}_t = \alpha_n\left(Y^{old}_{t+n} - Y^{old}_t\right) + \left(1 - \alpha_n\right)\left(\gamma Y^{old}_{t+n} - Y^{old}_t\right). \qquad (3)$$

If we assume yields on established areas grow at constant trend of $\delta = Y^{old}_{t+1} - Y^{old}_t$ for all *t*, equation (3) becomes

$$\bar{Y}_{t+n} - \bar{Y}_t = \alpha_n n\delta + \left(1 - \alpha_n\right)\left(\gamma\left(Y^{old}_t + n\delta\right) - Y^{old}_t\right)$$

or

$$\bar{Y}_{t+n} - \bar{Y}_t = \alpha_n n\delta + (1-\alpha_n)\gamma Y_t^{old} + (1-\alpha_n) n\gamma\delta - (1-\alpha_n) Y_t^{old} . \tag{4}$$

Notice that equation (4) is increasing in γ, with

$$\frac{\partial\left(\bar{Y}_{t+n} - \bar{Y}_t\right)}{\partial\gamma} = (1-\alpha_n)\left(Y_t^{old} + n\delta\right) > 0 . \tag{5}$$

A direct regression of equation (4) (for δ and γ) has its problems since α_n is perfectly correlated with $(1-\alpha_n)$. Notice however that, in the absence of yield drags ($\gamma = 1$), rearranging equation (4) we obtain

$$\frac{\bar{Y}_{t+n} - \bar{Y}_t}{n} = \delta ,$$

where the LHS is observable and the RHS is an unknown constant. This suggests a way to test whether land expansion effects yield growth. In terms of a model, one could run

$$\frac{\bar{Y}_{t+n} - \bar{Y}_t}{n} = \beta_o + \beta_1 X_n , \tag{6}$$

where X_n is a variable that affects average yield growth if yields on new and established lands are different. Examples of possible regressors are A_{t+n}^{new} or $\frac{A_{t+n}^{new}}{A^{old} + A_{t+n}^{new}}$. The share of new land may be preferred because of large differences in land across regions.

The null hypothesis that yields on new and old areas are the same (i.e., $\gamma = 1$) is to test whether $\beta_1 = 0$, versus the alternative $\beta_1 \neq 0$. However, if the null hypothesis is rejected, we would want to know if this is because a yield drag is present (i.e. if $\gamma < 1$). Given equation (5), if $\gamma < 1$ then

$$\frac{\bar{Y}_{t+n} - \bar{Y}_t}{n} < \delta .$$

In terms of the model (6), and for $X_n > 0$, the null hypothesis that yields on new lands are lower than yields on established areas is $\beta_1 < 0$. In this way, we have a one sided test. Before moving to a statistical test, a visual examination of yield and yield growth data reveals that the CARB assumption in Brazil does not immediately show up in the data.

Data

Table 1 shows how three year average regional soybean yields vary with expansion of soybean area in Brazil. Figure 2 plots the same yields in the last three year period against total cropland expansion in Brazil. If new land were less productive than old land, then we would expect to see a negative relationship. Clearly, the data shown in Figures 1 and 2 do not support this assumption. If anything, the data support a positive relationship. Thus, there is no obvious support for the hypothesis that the yield of newly converted land is less than the yield of new soybean land in Brazil.

Table 1. Regional Soybean Yields and Area in Brazil

	South	Southeast	West Central	Amazon	Northeast
	Area (million has)				
1996-98	5.68	1.07	3.70	0.64	0.64
1999-01	6.03	1.13	4.57	0.88	0.92
2002-04	7.52	1.56	6.73	1.54	1.39
2005-07	8.48	1.70	8.03	2.22	1.82
2008-10	8.38	1.46	7.59	2.50	1.94
	Yield (tons/ha)				
1996-98	2.17	2.17	2.49	2.65	1.98
1999-01	2.29	2.42	2.80	2.96	2.24
2002-04	2.38	2.61	2.76	2.96	2.26
2005-07	2.16	2.61	2.62	3.16	2.57
2008-10	2.44	2.83	2.94	3.08	2.82

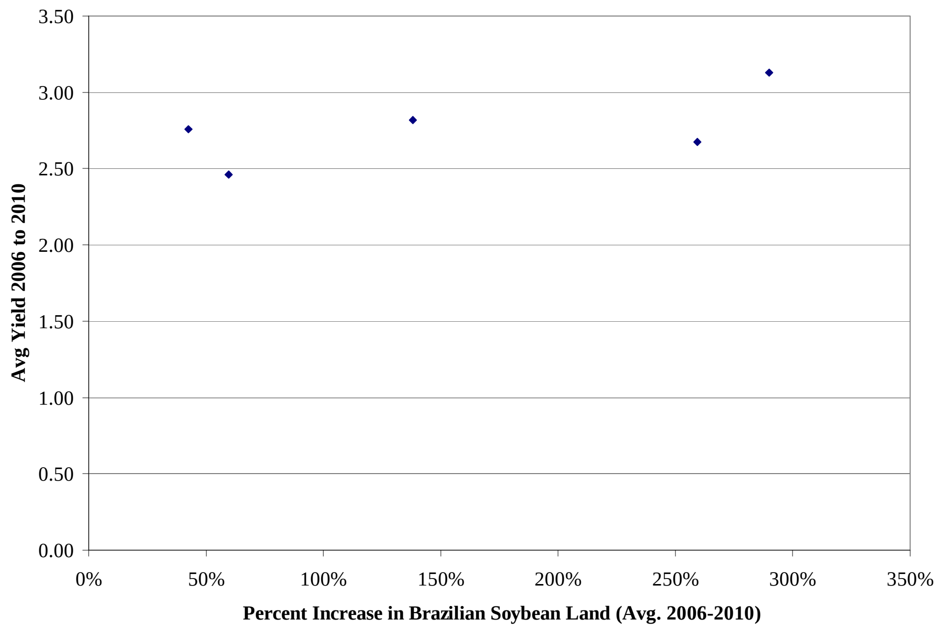

Figure 1. Relationship Between Recent Soybean Yields and Soybean Land Growth

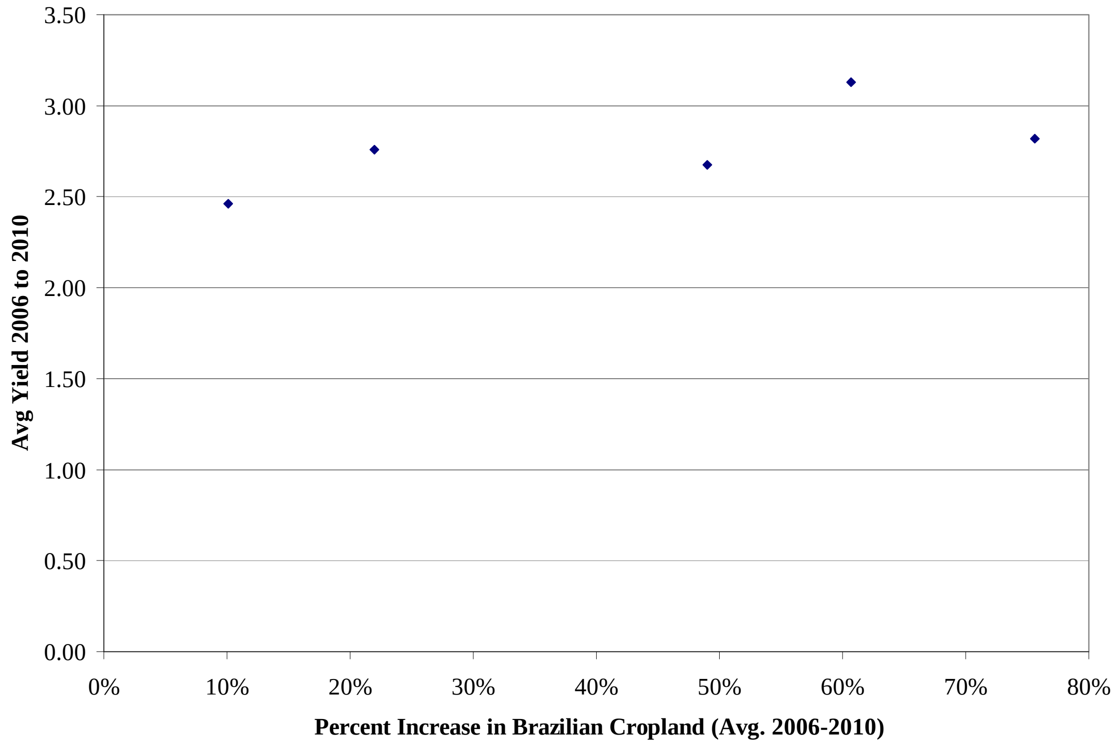

Figure 2. Relationship Between Recent Soybean Yields and Cropland Growth

However, this finding can also be explained by differences in intrinsic land quality, in that regions that have had the most land expansion could be the regions with the best growing conditions. If true, then the assumption of CARB is still contradicted, but it could still be true that yield growth could be negatively impacted by land expansion. Such a finding would imply that regional average yields in Brazil would be even higher had land expansion not occurred. Equation (6) is used to test this hypothesis.

A strict application of equation (6) would use actual yields in the base year and subsequent years to calculate the dependent variable $\frac{\bar{Y}_{t+n} - \bar{Y}_t}{n}$. If the base period yield $\bar{Y}_t$, is equal to trend yield in year t with no land expansion, then the expected value of the dependent variable equals trend yield. However, if weather conditions are such that the base period yield is higher or lower than trend yield, then the expected value of the dependent variable is either lower or higher than trend yield. Thus, the implementation of equation (6) requires some care in selection of a base period yield.

Two alternatives definitions are used. The first alternative uses the predicted value of 1996 yields from a regression of actual yields on time by region. This alternative greatly reduces the impact of weather conditions on the base period yield, but it also introduces the possibility that the predicted yield in the base period could be impacted by the impacts of land expansion in subsequent periods. The second alternative is to use a three year average of yields from 1996 to 1998 as the base period yield. This lessens any impact of land expansion in subsequent years, but is more susceptible to abnormal growing conditions in the first three years.

It is important to account for regional differences so regional intercept terms are allowed. Two alternatives measures of land expansion are used. The first is the share of new cropland by region. The second is the share of new soybean land by region.

Table 2 shows the regression results. All the intercept terms (the coefficients corresponding to the Region variables) are positive, as expected. All four models results in a negative coefficient on the share of new land, which is suggestive that if cropland expansion had been less, then yield increases would have been greater. However, none of estimated coefficients are statistically different from zero. (T statistics are given in parentheses) Therefore the null hypothesis that expansion of cropland has had no impact on yield growth cannot be rejected.

Table 2. Regression Results

	Soybean Land		Total Land	
Variable	1996 Trend Yield	3-Yr Average	1996 Trend Yield	3-Yr Average
Region1	0.018	0.016	0.017	0.014
Region2	0.047	0.050	0.046	0.050
Region3	0.029	0.041	0.030	0.044
Region4	0.044	0.056	0.038	0.051
Region6	0.074	0.063	0.069	0.059
Share of New Land	-0.006	-0.007	-0.021	-0.033
t-statistic	(-1.15)	(-1.44)	(-0.71)	(-1.16)

Not rejecting the null hypothesis simply means that the evidence is not strong enough to conclude that land expansion has affected yield growth. However, if it has, then one would expect that soybean yield growth would be lowest in the regions with the most expansion. Figures 3 and 4 show that this simply is not case. The figures show that trend yields do vary across regions, but if anything, those regions with a higher growth in land have a higher growth in yields.

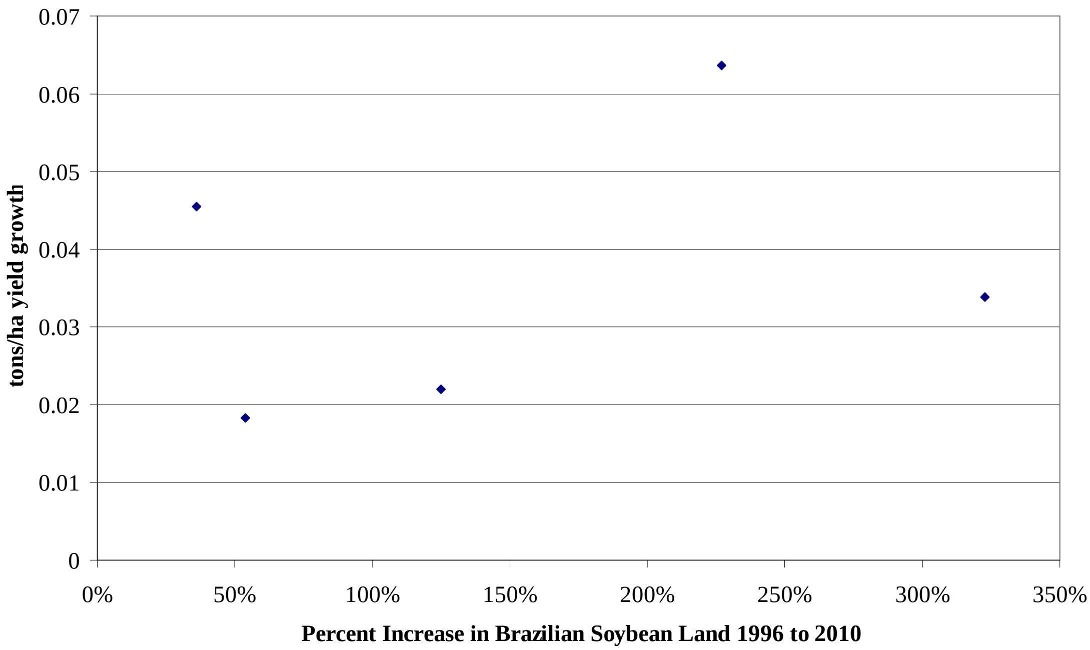

Figure 3. Relationship Between Soybean Yield Growth and Soybean Land Growth

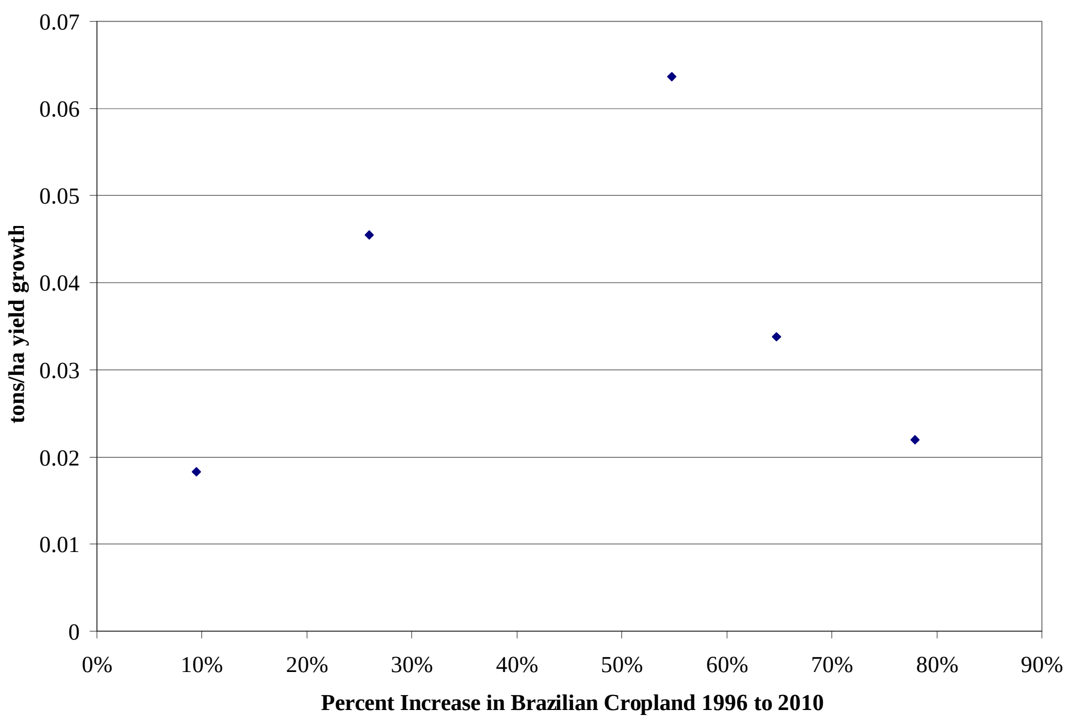

Figure 4. Relationship Between Soybean Yield Growth and Cropland Growth

Concluding Remarks

The CARB assumption that yields on new land are lower than yields on currently planted land seems straightforward. After all, if the new land were more productive than existing land, then farmers would be planting the new land rather than the old land. But a closer look at the situation in the United States and Brazil shows that the actual situation is more complicated than this common sense view of farmer decision making.

In the United States, the last 15 years have seen dramatic changes in the mix of crops grown and a significant drop in the aggregate amount of cropland being planted. This change in crop mix was facilitated by the 1996 farm policy changes that dramatically reduced the incentive to grow particular crops for farm subsidies. Large reductions in acres devoted to crops other than corn, soybeans, wheat and rice have resulted. This change in crop mix combined with a reduction in aggregate acreage means that, on average, marginal land that went out of production was devoted to producing the least profitable crops. One key factor that determines profitability is crop yield. Those crops with lower yields and lower yield growth are less profitable, holding all else constant. This suggests that a biofuels demand shock that leads to an expansion in the demand for either corn or soybeans, will result in most additional corn or soybeans being planted on on existing cropland, rather than on new cropland, if the new cropland is actually the cropland that went out of production. Because it was the acreage of marginal crops that was planted, on average, on land that went out of production, it would also be the marginal crops that are planted on any new land that comes into production. Existing land would be allocated, on average, to the more productive crops if the existing land is more productive than new land. Because the shifting of crops between production regions in the United States is far more important in determining the impacts of crop area expansion on yields than the intrinsic productivity of land, it seems prudent to infer yield changes from a change in demand for a crop by measuring where the crop is likely to be grown at the margin. Given the U.S. experience, this means that the marginal yield on land devoted to crops likely varies dramatically across crops.

In the GTAP model, the broad crop categories (oilseeds, coarse grains, other grains, and other crops) makes it difficult to differentiate between marginal crops and non-marginal crops because each category contains both. Thus it seems that it would be difficult for the GTAP framework to reasonably allocate new land to marginal crops that is consistent with the U.S. experience. So while it seems reasonable to conclude that marginal U.S. land that is brought into production in response to an increase in the demand for corn and soybeans is less productive than existing land, the share of marginal land that is actually devoted to the production of corn and soybeans rather than marginal crops is likely less than corn and soybean shares of production because they will be planted to a greater extent on existing land.

The situation in Brazil is far different however, because the recent large expansion in crop acreage allows for a direct test of the assumption that new land is less productive than old land. Because soybeans is the dominant crop in Brazil, it is appropriate to measure whether this assumption holds for soybean yields. Using soybean yields as a metric, there is no support for the hypothesis that the Brazilian land that has been brought into production since 1996 is less productive than land that was already planted in 1996. If anything, the aggregate data suggest that yields and yield growth are highest in the regions that have expanded the most. At a minimum, this suggests that for Brazil, the “elasticity of crop yields with respect to area expansion" should have a central value of 1.0. This rejection of the assumption that new land is less productive than existing land is consistent with a frontier country where transportation costs limit production rather than the intrinsic productivity of land.

9. APPENDIX 4. BABCOCK LAND TRANSFORMATION MEMO

Implications of the CET Supply Function Approach of GTAP

Bruce A. Babcock
Miguel Carriquiry

The way that GTAP allocates land between crops, pasture, and forest is to use a function called the constant elasticity of transformation (CET) supply function. This is a function that allocates land based on a function that depends on the share of revenue from each type of land cover and the transformation elasticity σ. This function is used because it is parsimonious and because it gives necessary convexity so that a solution to the maximization problem can be obtained. However, the convenience of this function imposes some restrictions that are quite important in predicting how much pasture land relative to forest land is converted in response crop price increases related to biofuels expansion.

Following the notation on page 4 of Ahmed, Hertel, and Lubowski, the cross price elasticity of the supply of forest land in response to a crop price increase equals $\varepsilon_{forest,\,crop} = \theta_{crop}\sigma$ where θ_{crop} is the share of revenue from crops. The cross price elasticity of pasture land in response to a crop price increase is $\varepsilon_{pasture,\,crop} = \theta_{crop}\sigma = \varepsilon_{forest,\,crop}$. This means that a 10% increase in crop prices will result in the same percent change in pasture and forest land.[5]

Homogeneity of supply means that the own price elasticity equals (in absolute value) the sum of the cross price elasticities so that the own price elasticity of pasture, forest and crop in GTAP differ only by the share of revenue:

$$\varepsilon_{pasture,\,pasture} = -\sigma(1-\theta_{pasture})$$
$$\varepsilon_{forest,\,forest} = -\sigma(1-\theta_{forest})$$
$$\varepsilon_{crop,crop} = -\sigma(1-\theta_{crop})\,.$$

The central value of *σ* in CARB's biodiesel analysis is -0.2, which is equal to the revenue-share-weighted average of the estimated individual land cover CET parameters (discussed below) after five years. Page 5 of Ahmed, Hertel, and Lubowski reports revenue share values of 0.7489 for crops, 0.0975 for pasture, and 0.1023 for forest. This means that the GTAP own return elasticities of supply are 0.05, 0.18 and 0.18 for crops, pasture, and forest respectively. One cost of using the CET function to allocate land is that the own return elasticities for pasture and forest are significantly different than what Ahmed, Hertel, and Lubowski estimate them to be. Their estimates are derived from analysis of plot-level National Resources Inventory data from 1982 to 1996 conducted by Lubowski and Lubowski, Plantinga, and Stavins. Their own estimates of the own price elasticities at five years are approximately 0.045, 0.22, and 0.005 for crops, pasture, and forest respectively[6]. Thus the

[5] The equilibrium solution will not typically be exactly the same percent change because the own supply elasticities of forest and pasture may differ and the demand elasticities for forest products may differ from pasture products.
[6] These estimates were obtained from Figure 2 of Ahmed, Hertel, and Lubowski. The approximation of the forest elasticity was difficult because the five year value was so close to zero.

GTAP own price elasticities for crops and pasture are roughly equal to the empirically based own price elasticities. But the forest elasticity in GTAP is 36 times higher than the estimated value.

The estimated values for this elasticity of land transformation for the each type of land cover can be found in Figure 3 of Ahmed, Hertel, and Lubowski. These values are approximately -0.006 for forest, -0.26 for pasture, and -.25 for crops. The difference between the CARB central value of -0.2 and the elasticity of land transformation for forest that is consistent with the empirical data is particularly important when considering the response of forest land to higher crop prices.

As stated above, GTAP imposes the homogeneity condition that the own price elasticity equals the absolute value of the sum of the cross price elasticities. Because both cross price elasticities are negative (a higher price of crops leads to less forest land) we know that their value must be between zero and the value of the own price elasticity. Using a forest own price elasticity of 0.18 allows the cross price elasticities to be between 0 and -0.18. For example, if the cross price elasticity of forest with respect to pasture equals -0.08, then the cross price elasticity of forest with respect to crops equals -0.1.[7] If GTAP had instead used 0.005 as the own price elasticity of forests, then this implies that the cross price elasticity of forest land with respect to crop prices would be limited to between 0 and -0.005.

The most important factor affecting the magnitude of the change in greenhouse gas emissions from land use changes is the response of forest land to an increase in crop prices. Thus use of the GTAP own price elasticity of 0.18 instead of the empirically-estimated own price elasticity of forests of 0.005 results in dramatically higher greenhouse gas emissions. The GTAP cross price elasticity of forest with respect to crop price equals

$$\varepsilon_{forest,\,crop} = \theta_{crop}\sigma = -0.7489*0.2 = -0.15$$

This elasticity is 30 times higher than the maximum cross price elasticity that would be possible if the empirically-estimated forest own price elasticity was used in the analysis.

The GTAP cross price elasticity of pasture with respect to crops is also equal to -0.15, which may be close to the value that is consistent with the empirical estimates. This suggests that a model that used empirically based own and cross price elasticities for forest, pasture, and crops would have pasture land being at least 30 times more responsive to crop prices than forest land in a five year horizon. The ratio of responsiveness would be similar for longer time periods, given the very low own return elasticities for forest shown in Figure 2 of Ahmed, Hertel, and Lubowski.

Because the CET supply function is seemingly so fundamental to GTAP, it is not clear how empirically estimated own and cross price elasticities of land transformation could be accommodated. An ad hoc approach could take the total amount of pasture and forest land converted in GTAP and reallocate it between pasture and forest such that the percentage change in pasture is some multiple of the percentage change in forest land. For example, suppose GTAP predicts that U.S. crop acreage expands by 100,000 ha with 45,000 ha

[7] The share of revenue in Ahmed, Hertel, and Lubowski do not sum to one, which implies that "other" land use must be equal to one minus the sum of share to forest, crops, and pasture. The other land use is ignored in this explanation.

coming from forest and 55,000 ha coming from pasture. These estimates would be consistent with the -0.15 cross price elasticities in GTAP. An allocation of pasture and forest land that is more consistent with the empirically consistent cross price elasticities would be 95,000 ha of pasture and 5,000 ha of forest. This would be an ad hoc approach because these ratios would not account for the likely increase in the price of pasture because of the greater loss of pasture, which would limit the amount of pasture that would be converted. So, instead, perhaps lowering the ratio of responsiveness from 30 to 1 to 10 to 1 would be more consistent with a model that used the empirically-estimated cross price elasticities. This might result in 90,000 ha of pasture and 10,000 ha of forest. The magnitude of these changes suggests that making forest land less responsive to crop prices than pasture would result in major reductions in the amount of forest land converted to cropland. This would dramatically reduce estimated greenhouse gas emissions from land use changes in response to expansion of biodiesel.

References

Ahmed, S.A., T. W. Hertel, and R. Lubowski. "Calibration of a Land Cover Supply Function Using Transition Probabilities." GTAP Research Memorandum No. 14. October 2008.

Lubowski, Ruben (2002) "Determinants of Land Use Transitions in the United States: Econometrics Analysis of Changes among the Major Land-Use Categories". PhD Dissertation, Harvard University: Cambridge, MA.

Lubowski, Ruben, Andrew J. Plantinga, and Robert N. Stavins (2006) "Land-Use Changes and Carbon Sinks: Econometric Estimation of the Carbon Sequestration Supply Function", *Journal of Environmental Economics and Management*, 51(2006)

10. APPENDIX 5. BABCOCK IDLE LAND MEMO

Recent Land Use Changes in the United States

Bruce A. Babcock
Miguel Carriquiry

The analysis of CARB indicates that between 0.16 and 0.28 million hectares (0.395 and 0.692 million acres) of U.S. land will be converted to cropland depending on the assumptions of the different scenarios. Averaging across scenarios, 0.21 million hectares of land could be brought into agricultural production. The results indicate that between 40% and 50% of the total expansion of cropland would occur by converting forestland (see Table 1). This short paper presents data on U.S. cropland changes in the last 15 years to see how well this model prediction accords with historical trends.

Table 1. Land Used Changes in CARB's Biodiesel Analysis

	A	B	C	D	E	F	G	Mean
U.S. land converted (million ha)	**0.24**	**0.16**	**0.28**	**0.28**	**0.16**	**0.2**	**0.18**	**0.21**
U.S. forest land (million ha)	0.11	0.06	0.13	0.12	0.08	0.09	0.08	0.1
U.S. pasture land (million ha)	0.13	0.1	0.14	0.16	0.08	0.11	0.11	0.12
% of forest on total converted	46%	38%	46%	43%	50%	45%	44%	48%

To put these estimated land use changes into perspective, Figure 1 shows the annual changes in U.S. crop acreage since 2000. The smallest change in acreage is the change from 2002 to 2003 at 0.6 million acres. Thus CARB's estimated changes are quite small relative to the acreage changes that we have actually observed in recent years.

It is useful to see if the changes in cropland shown in Figure 1 are associated with changes in pasture and forest land because CARB's GTAP analysis allocates land between crops, forests and pasture to maximize total returns. We do not have annual data on forest land, but we do have data on hayland (pasture) and CRP land. Figure 2 presents the annual changes in CRP and pasture land to the Figure 1 changes in cropland. Between 2000 and 2001 the sharp drop in cropland corresponds to an increase in pasture and CRP land. And the sharp increase in cropland in 2007 and 2008 corresponds to a decrease in CRP land in 2008 and 2009, although both CRP and crop acres decreased significantly in 2009. But what is notable about Figure 2 is the long-term stability of hayland. And CRP acres have been stable as well with the exception of the significant declines in 2008 and 2009, when increased crop prices led to farmers deciding not to renew their CRP contracts.

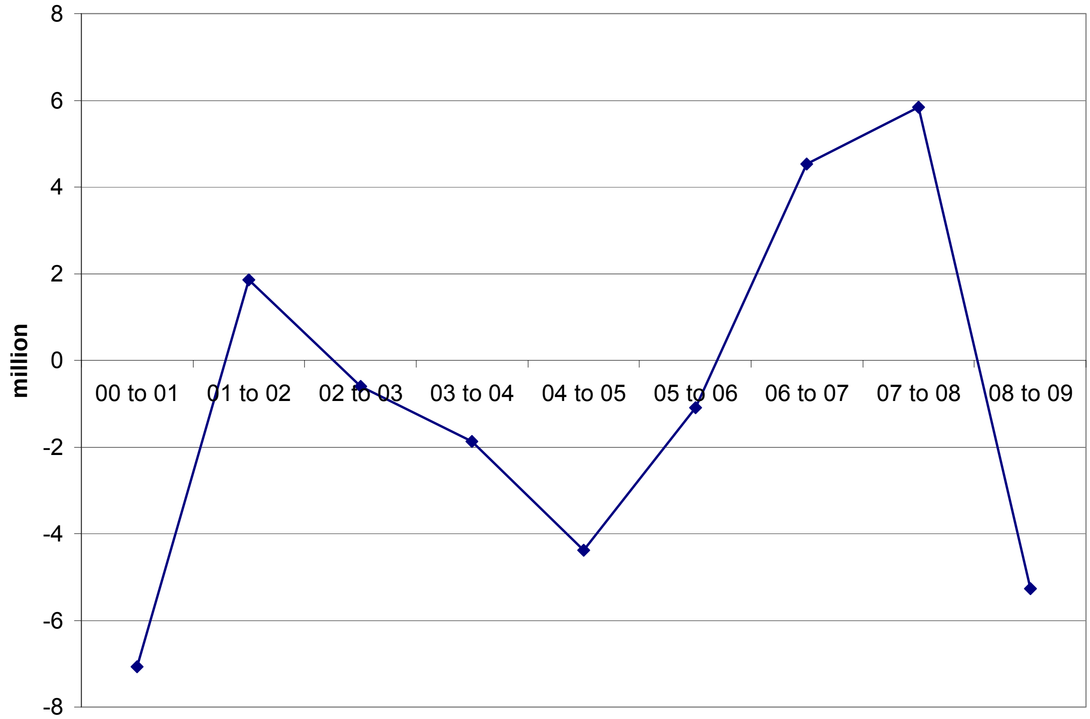

Figure 1. Annual Changes in U.S. Crop Acreage for the 13 Principle Field Crops
Source: FAPRI Agricultural Outlook

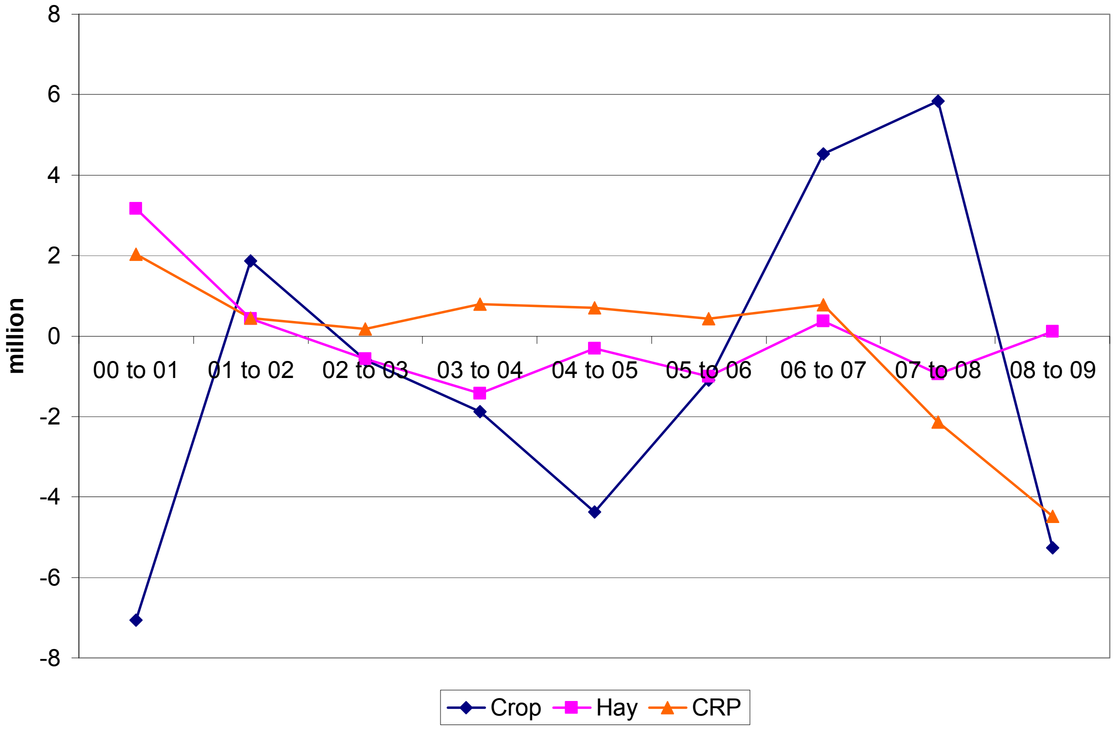

Figure 2. Annual Changes in U.S. Land Devoted to Crop, CRP and Hay

The data in Figure 2 suggests that there is some negative correlation between cropland and land enrolled in CRP and hayland, but the magnitude of the changes in cropland are much larger than the changes in either CRP or hayland. Because total land in the United States does not change, what land use category is changing along with cropland? Because CARB allocates acreage between crops, pasture, forest, and other (typically industrial land) the answer from CARB's modeling perspective is that one of these categories must be increasing or decreasing. From a data and accounting perspective, the first place to look is to account for changes in double-cropped acreage.

Figure 3 overlays the annual change in double cropped acres on the change in cropped acres. As shown, the large expansion of crop acres in 2007 and 2008 were partly accomplished by increasing double cropped acres. The correlation coefficient between the change in double cropped acres and the change in crop acres over this time period is 0.8. This suggests that the first adjustment that should be made in accounting for how the U.S. expands or contracts crop acreage is to subtract double cropped acreage from total crop acreage. Figure 3 shows that the annual change in crop acreage is significantly reduced by such a subtraction. The standard deviation of annual cropland changes from 2001 to 2009 drops from 4.37 to 3.32 million acres by this subtraction.

The question then becomes whether changes in actual planted acreage adjusted for double cropping are accounted for by changes in pasture and CRP land. A scatter plot of the annual changes (with the annual change in crop acres shown on the horizontal axis) is shown in Figure 4. If there exists a strong negative relationship between pasture land and cropland, then most of the points should be in the southeast and northwest quadrants.

However, only three of the nine points appear in this quadrant with the two most prominent changes occurring in 2008 and 2001.

Figure 3. Accounting for Changes in Double Cropped Acres

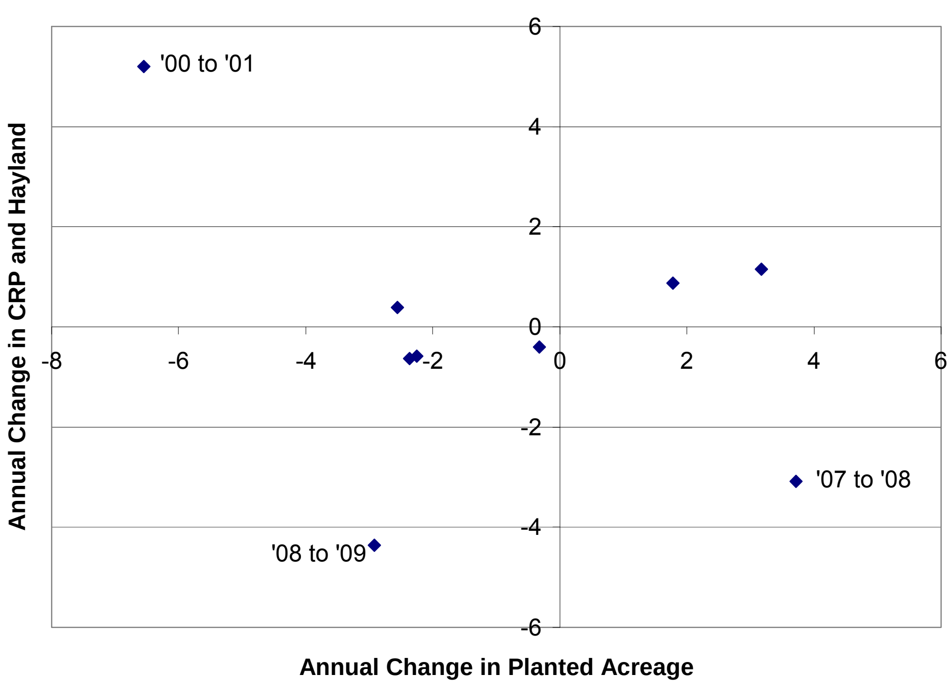

Figure 4. Relationship Between Cropland Changes and Pasture Changes

One conclusion that can be drawn from Figure 4 is that the annual fluctuations in crop acreage are not highly correlated with annual fluctuations in pasture land. What this suggests is that some other land use is absorbing the annual changes. This could be either changes in forest cover, urban land, or it could be that idle crop land moves in and out of production as economic conditions warrant.

Insight into whether the land use changes that we have seen since 2000 are consistent with a stock of idle crop land can be obtained by looking at Figure 5, which shows the annual flux of cropland not accounted for by double cropped acres, CRP land, and hayland. A positive number means that land is flowing out of cropland and potentially into idle cropland. A negative number means a potential reduction in idle cropland. As shown, if Figure 5 does measure flux in idle cropland, then 2002, 2007 and 2008 reduced the stock of idle land, and the remaining years increased the stock. One question that is raised, in this limited time period, was there enough flow of land into the stock of idle cropland to offset the flows out of the stock? This question is answered by looking at the level of the stock of idle cropland, (Figure 6), which is simply the sum of the Figure 5 flux. As shown, the deficit in crop acres (not accounted for by changes in pasture, CRP, or double cropping) in 2002 and 2003 were greater than the reduction in crop acres in 2001. Thus, either the stock of idle cropland in 2000 was greater than zero, or some other category of land needed to be converted into cropland. The increase in crop acres in 2007 and 2008 could have been accommodated by the reduction in crop acres in 2004, 2005, and 2006. And the 2009 reduction in crop acres has seemingly rebuilt up the stock of potentially idle land. Whether the deficits in the stock of idle land in 2002 and 2003 could have been accommodated by an earlier buildup in idle land is revealed by Figure 6, which treats the stock of idle cropland as being zero in 1996, instead of in 2000. As shown, there was a large reduction in cropland in 1998 that could have created enough of a reserve of idle land to accommodate the 2002 and 2003 deficits.

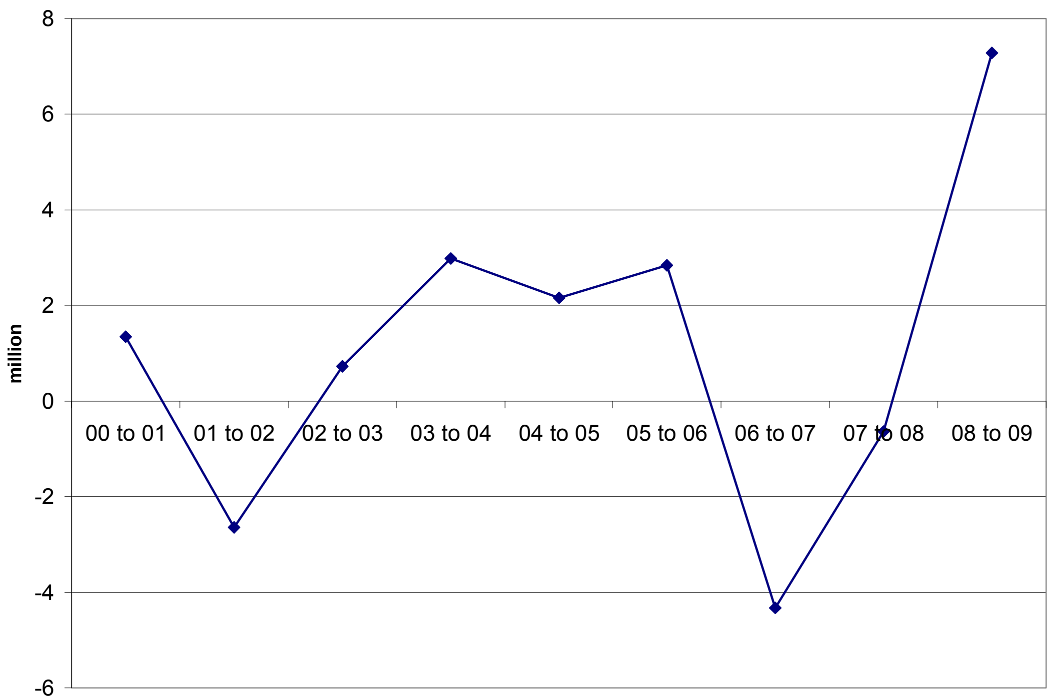

Figure 5. Potential Flux of Idle Cropland

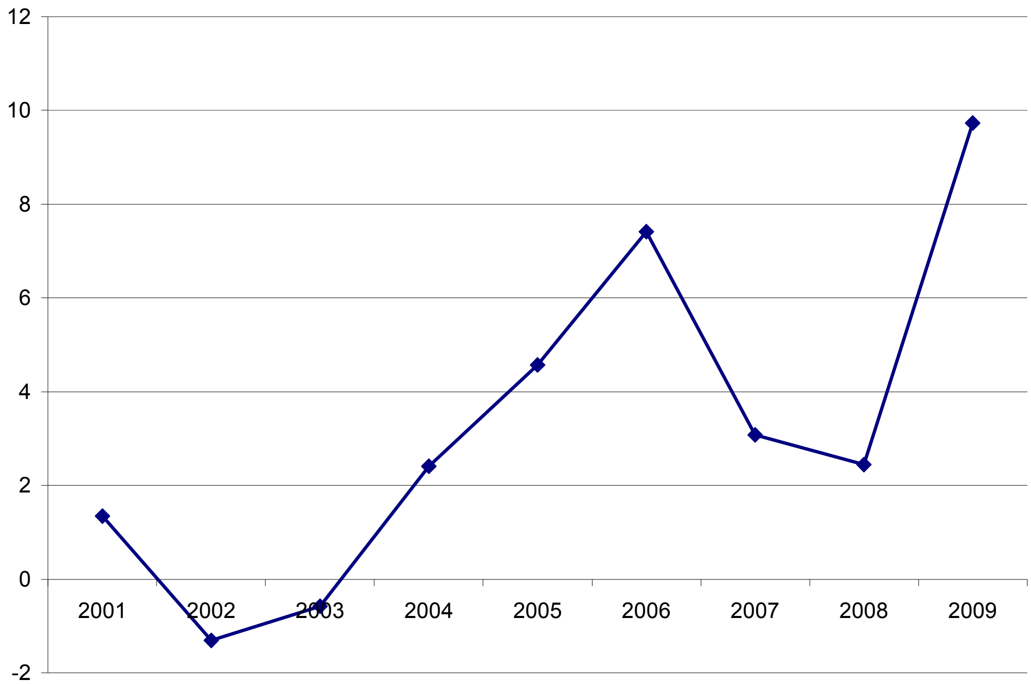

Figure 6. Potential Stock of Idle Cropland Assuming No Idle Land in 2000

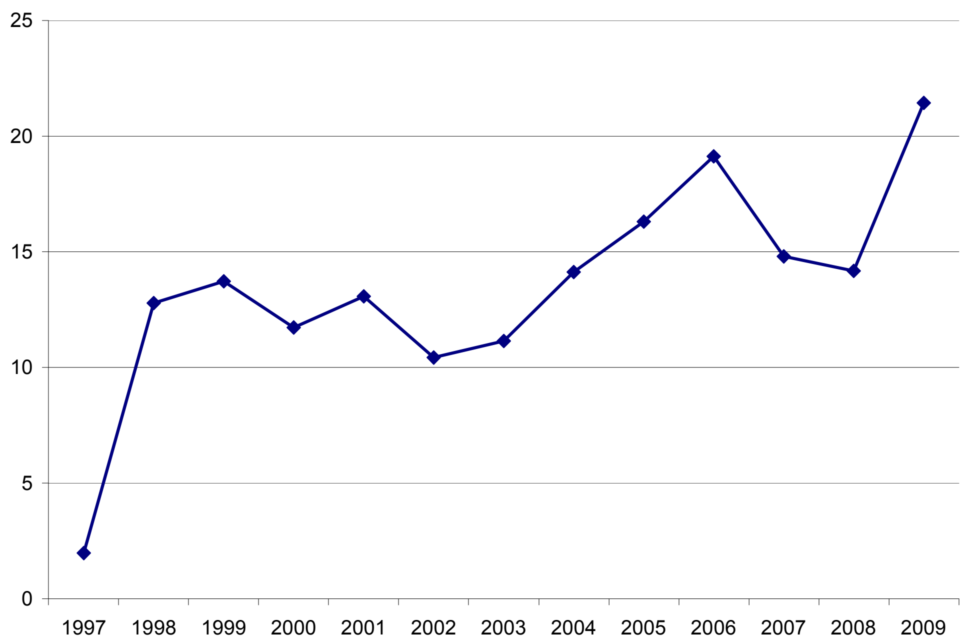

Figure 7. Potential Stock of Idle Cropland Assuming No Idle Land in 1996

Figure 7 shows that it was possible to meet all demands for crop land out of land that was previously idled. Of course, this assumes that the land that moved out of crops (and that did not move into pasture or CRP) did not move to urban land or forests. If a large portion of the land attributed to idle cropland in Figure 7 became forest or if houses were built on it, then it would not have been available to meet the demands for cropland in 2007 and 2008.

Recent trends for U.S. land use as measured by the National Resource Inventory (NRI) are shown in Table 2. The NRI provides nationally consistent data at several points in time for the 1982-2003 period. Total land covered in Table 2 is constant (at 1.938 billion acres) for all the NRI survey years, and thus the reallocation of land across uses can be assessed. The data indicates that forest and developed area have been consistently expanding over the 20 year period covered. At the same time, pasture and crop areas have declined over time. These observations have been made in the literature. According to Alig et al. (2004), while in recent decades forests have been the largest source of land converted to developed uses, these losses are more than offset by displacement of cropland and pastures (by forests). In this line, Alig et al. (2004) writes "*Movement of land between forestry and agriculture in the last two decades has resulted in net gains to forestry that have offset forest conversion to urban and developed uses in area terms*." (p 229).

Table 2. Total Surface Area by Land Cover/Use by Year

Year	Cropland	CRP Land	Pastureland	Rangeland	Forest Land	Other rural land	Developed land	Water areas	Federal land
	Million acres								
1982	419.9	0	131.1	415.5	402.4	48.2	72.9	48.6	399.1
1992	381.3	34	125.2	406.8	403.6	49.4	86.5	49.4	401.5
1997	376.4	32.7	119.5	404.9	404.7	50.4	97.6	49.9	401.7
2001	369.5	31.8	119.2	404.9	404.8	50.1	105.2	50.3	401.9
2003	367.9	31.5	117	405.1	405.6	50.2	108.1	50.4	401.9
Changes in consecutive reports									
1992-1982	-38.6	34	-5.9	-8.7	1.2	1.2	13.6	0.8	2.4
1997-1992	-4.9	-1.3	-5.7	-1.9	1.1	1	11.1	0.5	0.2
2001-1997	-6.9	-0.9	-0.3	0	0.1	-0.3	7.6	0.4	0.2
2003-2001	-1.6	-0.3	-2.2	0.2	0.8	0.1	2.9	0.1	0
Changes by year for different NRI intervals									
1992-1982	-3.86	3.40	-0.59	-0.87	0.12	0.12	1.36	0.08	0.24
1997-1992	-0.98	-0.26	-1.14	-0.38	0.22	0.20	2.22	0.10	0.04
2001-1997	-1.72	-0.23	-0.07	0.00	0.03	-0.07	1.90	0.10	0.05
2003-2001	-0.80	-0.15	-1.10	0.10	0.40	0.05	1.45	0.05	0.00
Average[a]	-1.17	-0.21	-0.77	-0.09	0.22	0.06	1.86	0.08	0.03

[a] Average is since 1992, to avoid confounding effect of CRP introduced in the first interval.
Source: Calculated by authors based on the 2003 Annual NRI report. http://www.nrcs.usda.gov/technical/NRI/2003/national_landuse.html

Hence, history indicates forests advancing over cropland. This is suggestive suggests that at least some portion of the loss of cropland shown in Figure 7 could be accounted for by an increase in forest land. However, note that the increase in forest land seems to have decreased after 1997, so the magnitude of the change in cropland in Figure 7 does not seem like it could have been converted to forest. Note that the increase in urban land from 1997 to 2003 is about equal to the decrease in cropland over the same period, and that the NRI decrease in cropland is much less than the Figure 7 decrease in cropland. Thus it seems plausible at least that some portion of the Figure 7 cropland was urbanized and most of the remainder remained as cropland, as reported in the NRI, but was not planted.

This examination of land use changes shows that the abstraction used by the GTAP model which allocates land between pasture, forests should be altered to include a land category which better accounts for the likelihood that there is a relatively large amount of cropland that moves in an out of crops as economic conditions meet. This change would better reflect the reality of cropland changes since 1997 and it would result in a more accurate estimate of the greenhouse gas emissions from U.S. land use changes because conversion of idle cropland in active incurs few emissions. Of course, the data requirements of making such a change are not trivial, as this brief examination of the data suggests. The feasibility of implementing such a change in modeling structure outside the U.S. and perhaps Europe presents an even larger challenge. But this is the type of data that is needed to facilitate the type of analysis that is required to accurately estimate actual land use changes from expanded biofuels.