RENEWABLE FUELS ASSOCIATION

July 8, 2015

Mary Nichols
Chairwoman
California Air Resources Board
1001 “I” Street
Sacramento, CA 95812

Dear Chairwoman Nichols,

The Renewable Fuels Association (RFA) appreciates the opportunity to comment on proposed regulatory changes associated with the re-adoption of the Low Carbon Fuels Standard (LCFS) (Second Notice of Public Availability of Modified Text, June 23, 2015).

We are encouraged that the Air Resources Board (ARB) is revising several problematic elements of the first 15-day notice (released June 4, 2015) based on feedback from RFA and other interested stakeholders. A number of provisions in the first 15-day notice regarding establishment of fuel pathways were simply unworkable and we commend ARB for taking steps to address stakeholder concerns.

However, while the second 15-day notice represents a marked improvement over the initial proposed modified text, RFA believes ARB must make additional changes to ensure the pathway approval process is efficient and presents minimal administrative burden for both low carbon fuel producers and ARB staff. In addition, RFA again urges ARB to revise its indirect land use change (ILUC) analysis to reflect the best available science and data. Our comments and concerns on the second 15-day notice are detailed below.

1. **We support the new language added to section 95488(a)(2) allowing fuel producers to request re-certification of “legacy pathways” that were certified under prior versions of the LCFS.**

Under the first 15-day notice, the requirement that all low carbon fuel producers with existing certified pathways must entirely re-apply for those pathways was unnecessarily burdensome and duplicative. Thus, we welcome ARB’s proposed modifications to section 95488 to streamline the re-certification process by allowing fuel producers to request re-certification of existing pathways by ARB staff using CA-GREET 2.0. We agree that, in most cases, ARB staff “already has all of the information needed to conduct recertification without any submission of additional data by the applicant…”, and we support the use of a simple, straightforward electronic form through the LRT system to request re-certification. We assume that the key variables that influenced an individual ethanol producer’s existing pathway carbon intensity (CI) score (e.g., natural gas use, transportation distances, ethanol yield, etc.) will be retained by ARB staff for the re-certification using CA-GREET 2.0. However, it is somewhat unclear how

ARB will handle producer-specific inputs in CA-GREET 2.0 that were not included in approved pathway petitions based on CA-GREET 1.8 (e.g., yeast and enzymes). We encourage CARB to include fields for any additional information needed for re-certification on the online form.

2. **RFA supports the proposed prioritization of fuel pathway re-certifications for "batch processing."**

Based on the volumes of distinct renewable fuels delivered to the California market, and the different roles certain fuels have played in helping regulated parties achieve compliance, we agree with ARB's proposed prioritization of fuel types for "batch processing" of re-certification requests.

3. **The description of "Tier 1" fuels in section 95488(b)(1) remains somewhat confusing and ambiguous. ARB should clarify that the "Tier 1" classification applies to specific *fuels* not specific *facilities* or *individual pathways*.**

ARB describes Tier 1 fuels as being "[c]onventionally-produced alternative fuels of a type that has been in full commercial production, excluding start-up or ramp-up phase, for at least three years, and for which certified LCFS pathways have existed for at least three years shall be classified into Tier 1." This language has caused much confusion amongst conventional ethanol producers. Many producers have interpreted this description as applying to individual facilities or specific Method 2 pathways; and some producers who have had an approved Method 2 pathway for fewer than three years have interpreted this language as meaning their fuel cannot be classified as "Tier 1." ARB should clarify that the "Tier 1" classification applies to specific *fuels*—not specific facilities—that have existed commercially for at least three years. In other words, ARB should clarify that all starch-based ethanol produced using conventional methods is "Tier 1" fuel.

4. **"Tier 1" fuels should be excluded from the "Provisional Pathways" requirements described in section 95488(d)(2).**

For unexplained reasons, the second 15-day notice inserted Tier 1 fuels into the section governing provisional pathways. Because ARB is highly familiar with the feedstocks and production technologies associated with Tier 1 fuels, it is completely unnecessary to apply the same provisional pathway conditions to new Tier 1 fuel producers that are applied to new Tier 2 fuels. New facilities producing Tier 1 fuels should receive final approval of their CI scores by the Executive Officer based on one quarter of operational records, as facility operations and the fuel CI would not be expected to change following start-up.

5. **Investment in the development of new "Tier 2" fuels is discouraged by the "Provisional Pathway" requirements described in 95488(d)(2). ARB should allow provisional CI scores to be based on pilot-scale data, rather than requiring operational data for a full quarter of commercial production.**

Developers of new and innovative low-carbon fuels will likely find it difficult to attract financing for scale-up due to ARB's requirement that new "Tier 2" facilities must have operational data for one full quarter of commercial production before even submitting a new pathway petition.

Developers of “Tier 2” fuel facilities are unlikely to raise the necessary capital for construction of commercial-scale facilities without the ability to show potential investors or lenders a provisional CI score that has been approved by ARB.

We agree that ARB can and should verify provisional CI scores using actual operational data once the Tier 2 facility is up and running. Further, if actual operational data indicates that the actual CI of the fuel is higher than the provisional CI score, we agree that the Executive Officer should “adjust the number of credits or reverse any provisional credit in the producer’s account without a hearing.” However, we strongly believe provisional CI scores should be approved on the basis of pilot-scale data provided by Tier 2 fuel developers so that the LCFS regulation encourages—rather than discourages—investment in new and innovative low-carbon fuels.

6. **RFA again urges ARB to revise its indirect land use change (ILUC) analysis to reflect the best available science and data.**

RFA continues to strongly dispute the analyses underlying the ILUC values in ARB’s re-adoption proposal (Table 5). We have commented numerous times on ARB’s most recent ILUC analysis and provided volumes of new information and data from independent sources that support much lower ILUC values for corn ethanol. To that end, we are re-attaching our recent comments to ARB on the staff’s flawed ILUC analysis.

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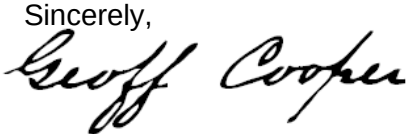
Thank you again for the opportunity to comment and please do not hesitate to contact me with any questions.

Sincerely,



Geoff Cooper
Senior Vice President

RENEWABLE FUELS ASSOCIATION

February 16, 2015

Mary Nichols
Chairwoman
California Air Resources Board
1001 “I” Street
Sacramento, CA 95812

Dear Chairwoman Nichols,

The Renewable Fuels Association (RFA) appreciates the opportunity to provide comment on the California Air Resources Board’s (CARB) Initial Statement of Reasons (ISOR) regarding re-adoption of the Low Carbon Fuel Standard (LCFS). While the proposal for re-adoption marks a slight improvement over the current regulation, we remain deeply concerned by several aspects of the proposal and believe it threatens the long-term durability of the LCFS program. Thus, RFA believes the ISOR needs significant revision before it can be presented to the Board for approval.

Grain-based ethanol has made a substantial contribution to LCFS compliance in the first four years of the program. Indeed, ethanol has accounted for **59% of total credits** generated from 2011Q1 through 2014Q3, and 95% of the ethanol used for compliance has been grain-based ethanol, according to CARB reporting data. If not for the LCFS credits generated by grain-based ethanol, deficit generation would have certainly outpaced credits by now, and compliance with the program would be extremely difficult, if not impossible. Thus, it is not an exaggeration to state that the LCFS has endured so far **only because of the contributions of grain ethanol**. Yet, the ISOR proposes to continue punitive carbon intensity (CI) penalties for grain ethanol and other crop-based biofuels based on purported indirect land use change (ILUC) emissions. If finalized, the proposed re-adoption regulation will make the use of most grain ethanol infeasible for compliance as early as 2016. Why would CARB use flawed and prejudicial analysis to purposely diminish the compliance viability of the low-carbon fuel that has provided the largest volume of credits to date?

As the attached comments show, CARB’s ILUC analysis remains technically and methodologically flawed, and grossly overstates the land use impacts associated with biofuels expansion. A November publication by the Center for Agricultural and Rural Development (CARD) at Iowa State University makes a remarkably important contribution to the debate over ILUC modeling. The report marks the first time that actual land use changes over the past decade (i.e., the period in which commodity crop prices rose to record levels) have been quantified and discussed in the context of CARB’s ILUC modeling results. The CARD/ISU paper, which is discussed in detail in the attached comments, found that “[t]he pattern of recent land use changes suggests that **existing estimates of greenhouse gas emissions caused by**

**land conversions due to biofuel production are too high** because they are based on models that do not allow for increases in non-yield intensification of land use." In essence, the authors found that the primary response of the world's farmers to higher crop prices "…**has been to use available land resources more efficiently rather than to expand the amount of land brought into production**."

The CARD/ISU research was submitted to CARB in early December. However, CARB's ISOR fails to even mention or acknowledge the work in any way. For the first time, we have real-world data that provides important insight into actual market responses to increased biofuels demand and higher crop prices. As described in the attached comments, we believe CARB must take into account the new CARD/ISU research and use it to immediately re-calibrate the GTAP model.

We appreciate CARB's consideration of our attached comments, which also address CA-GREET model revisions and assumptions used in CARB's illustrative compliance scenarios. We welcome further dialog on this subject and look forward to responses to any of the comments offered in the attached document.

Sincerely,

Geoff Cooper
Senior Vice President

RFA RENEWABLE FUELS ASSOCIATION

**COMMENTS OF**
**THE RENEWABLE FUELS ASSOCIATION**
**IN RESPONSE TO THE CALIFORNIA AIR RESOURCES BOARD**
**STAFF REPORT: INITIAL STATEMENT OF REASONS**
**TO CONSIDER**
**RE-ADOPTION OF THE LOW CARBON FUEL STANDARD (LCFS)**

The Renewable Fuels Association (RFA) offers the following comments in response to the California Air Resources Board's (CARB) release of its Initial Statement of Reasons (ISOR) proposing re-adoption of the Low Carbon Fuel Standard (LCFS)

## I. Indirect Land Use Change Analysis

CARB continues to rely on a fundamentally flawed approach to predicting indirect land use change (ILUC) that favors hypothetical modeling results over empirical data, real-world observations, and improved assessment methods.

Nearly six years have passed since CARB originally adopted the LCFS, which included carbon intensity (CI) penalties for certain biofuels for predicted ILUC. In the intervening years since the program was adopted, the scientific understanding of land use change has significantly progressed. Retrospective analyses of global agricultural land use have been conducted, actual market responses to increased demand and higher commodity prices have been observed and characterized, the reliability of predictive economic models has been improved, and new data has emerged to better guide certain modeling assumptions.

Yet, in spite of these advances in the science, CARB continues to rely on the narrow—and completely unsubstantiated—view that "[a] sufficiently large increase in biofuel demand in the U.S. would cause non-agricultural land to be converted to cropland both in the U.S. and in countries with agricultural trade relations with the U.S."

CARB's entire approach to ILUC is founded on the notion that farmers are limited to only two responses to increased demand for crops. While CARB recognizes four potential market responses to heightened demand for crops, its predictive modeling framework essentially allows only two of these responses to play out. The four potential market responses acknowledged by CARB are shown below.

- **Response 1**: "Grow more biofuel feedstock crops on existing crop land by reducing or eliminating crop rotations, fallow periods, and other practices which improve soil conditions";
- **Response 2**: "Convert existing agricultural lands from food to fuel crop production";
- **Response 3**: "Convert lands in non-agricultural uses to fuel crop production"; or
- **Response 4**: "Take steps to increase yields beyond that which would otherwise occur."

CARB theorizes that there is essentially no crop yield response to increased demand (Response 4 above), and an artificially low elasticity value is used to reflect this belief in CARB's economic model. Further, the CARB modeling framework does not allow double-cropping or reduction of fallow/idle cropland; thus, Response 1 above is also eliminated. *As a result, CARB assumes increased demand for crops can only be met through displacement of animal feed and conversion of non-agricultural lands to crop production (Responses 2 and 3 above).* Not coincidentally, Responses 2 and 3 have the most significant GHG impacts.

CARB has produced no evidence whatsoever that such land conversions have actually occurred on a meaningful scale in response to the LCFS or growth in U.S. biofuels demand. Indeed, empirical evidence suggests that demand growth has been primarily met through Responses 1 and 4 above, which are effectively excluded from CARB's modeling framework.

Instead of tuning the modeling framework to reflect these observed market responses, CARB continues to rely on conjectural assumptions and model predictions to penalize biofuels for hypothetical market outcomes. In essence, CARB is using the exact same approach to estimating ILUC emissions that it used six years ago, making only minor adjustments to certain model parameters based on "judgment calls."

RFA believes the principles of sound policymaking and regulation demand that CARB recognize and incorporate the best available science and data in the LCFS process, particularly when empirical data is available to fill important knowledge gaps.

**a. A New Publication by Babcock & Iqbal Has Important Implications for CARB's ILUC Analysis. CARB Should Give Serious Consideration to the Findings of the Paper, and Adjust its ILUC Estimation Methodology Accordingly**

In mid-November, Babcock & Iqbal at the Center for Agricultural and Rural Development (CARD) published Staff Report 14-SR 109, "Using Recent Land Use Changes to Validate Land Use Change Models."[1] The paper (Attachment 1) makes a remarkably important contribution to the debate over ILUC modeling. The report marks the first time that actual global land use changes over the past decade (i.e., the period in which commodity crop prices rose to record levels) have been quantified and discussed in the context of CARB's ILUC modeling results. The report was submitted to CARB staff in early December 2014, yet there is not a single mention of the paper (nor is there a response to its findings) in the ISOR.

Babcock & Iqbal examined historical global land use changes from 2004-2006 to 2010-2012 and determined that "…the primary land use change response of the world's farmers from 2004

[1] Babcock, B.A. and Z. Iqbal (2014), Using Recent Land Use Changes to Validate Land Use Change Models. Center for Agricultural and Rural Development Iowa State University Staff Report 14-SR 109. Available at: http://www.card.iastate.edu/publications/synopsis.aspx?id=1230

to 2012 has been to use available land resources more efficiently rather than to expand the amount of land brought into production."[2] Among other important revelations, the paper shows that key regions where CARB's GTAP analysis predicts biofuels-induced conversion of forest and grassland have actually experienced substantial *losses* of cropland.

Unfortunately, CARB's GTAP analysis does not take into account the methods of intensification (e.g., double-cropping, increases in the share of planted area that is harvested, return of fallowed land to production) that have been observed in the real world over the past decade. According to Babcock & Iqbal, GTAP and other models "…do not capture intensive margin land use changes so they will tend to ***overstate land use change at the extensive margin and resulting emissions***."[3] This finding is corroborated by Langeveld et al (2013) (Attachment 2), who found GTAP and other models have "…limited ability to incorporate changes in land use, ***notably cropping intensity***," and "[t]he increases in multiple cropping have often been overlooked and should be considered more fully in calculations of (indirect) land-use change (iLUC)."[4]

Ultimately, the Babcock & Iqbal work calls into question the plausibility of CARB's GTAP results and demonstrates that CARB's ILUC results are directionally inconsistent with real-world data and observed market behaviors in many regions. The data and discussion presented in the paper challenge the very underpinnings of CARB's analysis and are simply too important for the agency to ignore. Thus, as described more fully in the comments below, we believe CARB should move immediately to calibrate its GTAP model using the real-world land use data made available by Babcock & Iqbal.

**b. Countries and regions where cropland has decreased and/or forestland and grassland have increased over the past decade should be presumed to not have converted pasture or forest to crops in response to biofuel-induced higher prices. CARB should calibrate its GTAP model to reflect the absence of extensive land use change in these countries and regions.**

At the outset, it is important to note that the lack of a "counterfactual case" to compare to the real-world data (i.e., the *ceteris paribus* principle) is not sufficient reason to ignore the Babcock & Iqbal results. CARB has stated that comparing GTAP results to real-world data is "not productive," because it is not possible to compare real-world data to a counterfactual case in which biofuel expansion did not occur. Appendix I to the ISOR further states:

> GTAP-BIO is not predicting the *overall aggregate* market trend—only the incremental contribution of a single factor to that trend. If GTAP-BIO projects reduced exports, for example, this should be understood to mean that exports will be lower than what they would have been in

[2] *Id,* Executive Summary.
[3] *Id,* Executive Summary. (emphasis added)
[4] Langeveld, J. W.A., Dixon, J., van Keulen, H. and Quist-Wessel, P.M. F. (2014), Analyzing the effect of biofuel expansion on land use in major producing countries: evidence of increased multiple cropping. Biofuels, Bioprod. Bioref., 8: 49–58. doi: 10.1002/bbb.1432. (emphasis added)

> the absence of the effect being modeled (increased ethanol production, in this case). It is the difference between predicting an absolute change and a relative change.[5]

This statement by CARB seems to misunderstand the recommendation from stakeholders to consider and integrate empirical data and observed outcomes into CARB's modeling work. *RFA and other stakeholders fully understand that CARB's GTAP modeling exercise is meant to isolate only the impacts of biofuels expansion on land use.* However, empirical data can be useful for checking the directional consistency and general reasonableness of model predictions. According to the Babcock & Iqbal, "…the historical record of land use changes can be used to provide insight into the types of land that were converted…"[6]

Comparing empirical land use data to GTAP predictions is particularly useful in regions where cropland has contracted over the past decade. That is, if cropland in a certain region *decreased* according to historical data, then there is no justification for asserting—as GTAP does—that biofuel expansion caused extensive margin conversion of natural forest and grassland in that region. In other words, if there was no cropland expansion resulting from biofuels expansion *and all other factors combined* (i.e., in aggregate), then there certainly is no rationale for arguing that biofuels expansion in isolation of other factors led to cropland expansion.

That is not to say, however, that biofuels expansion did not have an impact on land use in the region. Indeed, cropland may have contracted *even more* in a "world without biofuels" (i.e., the counterfactual case). In other words, some additional cropland might have gone out of production in the absence of biofuels, and the function of biofuels demand may have been to keep that cropland engaged in production. Thus, the appropriate question for regions that have experienced cropland *contraction* over the past decade is whether there was foregone sequestration because of biofuels—***not*** whether there was extensive conversion of forest and grassland and soil carbon loss because of biofuels. According to Babcock & Iqbal:

> The countries in Figure 8 that either had negligible or negative extensive land use changes **should be presumed to not have converted pasture or forest to crops in response to biofuel-induced higher prices**. Rather, the presumption should be that **any predicted change in land used in agriculture came from cropland that did not go out of production**.[7]

Figure 8 from Babcock & Iqbal is embedded below. Note that many countries and regions for which CARB's latest GTAP analysis predicts extensive change from forest and grassland to crops actually showed cropland losses or no change. This includes Canada, EU, Japan, China, India, Russia, the U.S., and Oceania. Further, the amount of corn ethanol-induced conversion of

[5] ISOR, Appendix I at I-20.
[6] Babcock, B.A. and Z. Iqbal (2014) at executive summary.
[7] *Id*. at 26.

forest and grassland in the U.S. predicted by CARB's GTAP model is two to four times larger than the actual extensive land use change in the U.S. driven by ***all factors in aggregate***.

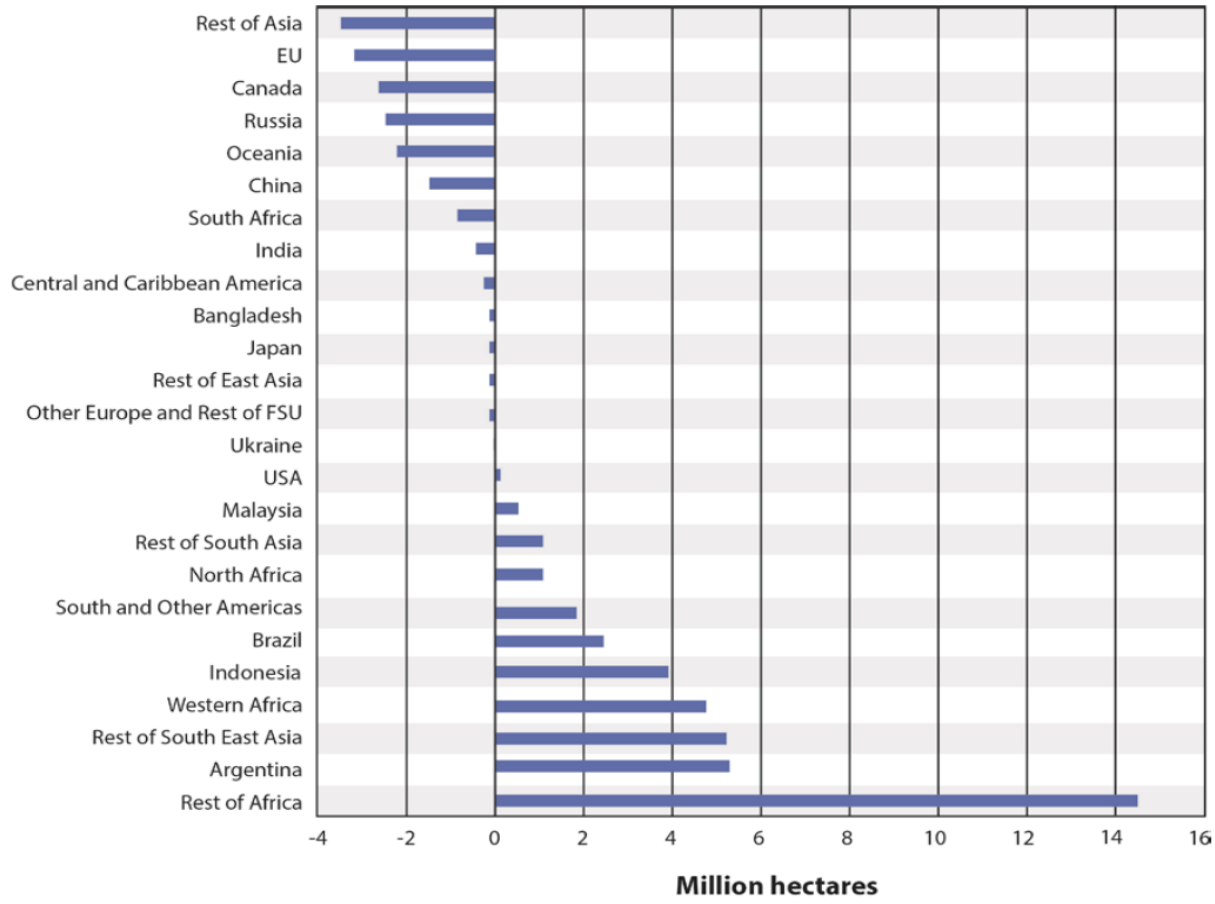



**Figure 8. Change in Arable Land Plus Permanent Crops: 2004–2006 to 2010–2012**

According to Babcock & Iqbal, the land use emissions implications in countries and regions where cropland decreased or stayed the same are that:

> …the type of land converted to accommodate biofuels was not forest or pastureland but rather **cropland that did not go out of production**. Calculation of foregone carbon sequestration depends on what would have happened to the cropland if it did not remain in crops which, in turn, depends on where the cropland is located and the potential alternative uses. **The magnitude of the change in estimated CO2 emissions from cropland that is prevented from going out of production relative to forest that is converted to cropland is potentially large.**[8]

Unfortunately, CARB's GTAP analysis suggests there was conversion of forest and grassland to crops in regions where real-world data show cropland actually contracted. The disagreement

[8] *Id.*

between GTAP predictions and real-world data highlights the implausibility of GTAP results for certain regions. CARB can—and should—correct its analysis to better align with real-world land use patterns. The following section provides a method for calibrating CARB's GTAP model to better reflect observed land use changes.

### c. CARB should use data from Babcock & Iqbal (2014) to immediately calibrate its GTAP model to reflect real-world land use change patterns in key regions.

As stated in the Babcock & Iqbal paper, CARB should not presume that higher crop prices have caused conversion of forest and grassland to crops in countries and regions where cropland has actually decreased over the past 10 years. Thus, we believe CARB should calibrate its GTAP model to disallow forest and grassland conversion in AEZs and regions for which empirical data show forest or grassland expansion and/or cropland contraction. This can be easily accomplished by excluding GTAP predicted land conversions for the countries in Figure 8 of Babcock & Iqbal that show negative extensive change (i.e., loss of cropland). A more detailed method for accomplishing this calibration is available in comments submitted to CARB by Air Improvement Resource on Dec. 4, 2014.[9]

It could be argued that these countries should still be subject to emissions penalties for foregone sequestration, in that biofuels demand may have caused some cropland to remain in production that may otherwise have transitioned to some other use. But this should only be done if it can be demonstrated that the alternative use of the land would have resulted in carbon sequestration that is greater than the sequestration achieved if the land remained engaged in crop production.

For the countries in Figure 8 that *do* show extensive land use change over the past 10 years, CARB can continue to rely on GTAP predictions, but should also conduct more intensive research to better understand the precipitating causes of land conversions at the extensive margin in those countries. For example, while Sub-Saharan Africa (excluding South Africa) shows significant extensive change over the past decade, it is likely unrelated to biofuels expansion in the U.S. According to Babcock & Iqbal, "The extent to which extensive expansion in African countries was caused by high world prices is likely small for the simple reason that higher world prices were not transmitted to growers in many African countries."[10]

In the longer term, CARB should migrate to the soon-to-be-released dynamic version of GTAP that contains updated baseline economic data. Further, CARB should closely monitor efforts to validate and back-cast the new version of GTAP and be prepared to consider new results from these exercises.

### d. CARB's GTAP Analysis Should Adopt CA-GREET2.0 Assumptions for Co-products Displacement Rates

[9] Air Improvement Resources comments available at: http://www.arb.ca.gov/fuels/lcfs/regamend14/air_12042014.pdf
[10] Babcock, B.A. and Z. Iqbal (2014) at 16.

The recently released CA-GREET2.0 model correctly assumes that distillers grains from ethanol production displace both corn and soybean meal in livestock and poultry rations.[11] The total mass of corn, soybean meal, and urea displaced by 1 pound of distiller grains is 1.111 pounds. While this assumption has modest impacts for the direct emissions associated with corn ethanol's lifecycle, the impacts on land use are significant. We have detailed these impacts in many previous comments to CARB, dating back to 2008.

Unfortunately, CARB's GTAP analysis continues to assume 1 pound of distillers grains displaces only 1 pound of corn. This is problematic for at least two reasons: 1) CARB's assumptions and boundary conditions for estimates of direct and indirect emissions should be consistent and uniform, 2) CARB's current GTAP assumptions on distillers grains displacement are simply inconsistent with the reality of how distillers grains are fed.

We are fully aware that there is no simple method for setting displacement ratios in GTAP, as interactions amongst the various sectors in the model are characterized in terms of economic values (e.g., expenditures, receipts, etc.). However, the economic values representing ethanol co-products in CARB's GTAP model are based on the 2004 database. Obviously, there have been significant changes in the distillers grains market since 2004; the ways in which these co-products are traded, priced, and fed have evolved dramatically. As we have discussed in previous comments to CARB, the agency can better reflect real-world feeding practices (i.e., some displacement of soybean meal) by adjusting the economic values associated with co-product trade in GTAP. RFA believes CARB must make this adjustment to ensure consistent boundaries and assumptions across its direct and indirect emissions analysis.

**e. CARB <u>Still</u> Has Not Justified its Proposal to Use a Yield-Price Elasticity Value That is Lower than Recommended by Both Purdue and CARB's Own Expert Work Group. CARB Should Use 0.25 as the Central Value, Not the Proposed Value of 0.185.**

Despite new data and published scientific papers supporting the use of a range for YPE of 0.14-0.53, CARB continues to propose using a range of 0.05-0.35. CARB staff has continued to ignore input from stakeholders, academia, and its own Expert Work Group on this parameter, instead relying on input from paid contractors at UC Davis and its own "expert judgment."

In Appendix I, CARB states that "[a]n expert from UC Davis, contracted to conduct a review and statistical analysis of data from a few published studies also concluded that YPE values were small to zero." Yet, it is quite clear from the brief (and somewhat unclear) report from the UC Davis contractor that the YPE response was examined only over the short term (i.e., 1-2 years).

This is inappropriate and scientifically indefensible, as demonstrated by previous stakeholder comments and remarks from Purdue University. For example, during the March 11 workshop on

[11] The latest version of CA-GREET2.0 is available at: http://www.arb.ca.gov/fuels/lcfs/ca-greet/ca-greet.htm

ILUC, Purdue University Prof. Wally Tyner explained why it is inappropriate to include short-run estimates in the range used for CARB's analysis, stating:

> The yield-price elasticity is a *medium-term elasticity*…and we normally think of that as about 8 years. I personally think, and our group thinks, that any of those papers in the literature that represent one year are *totally irrelevant* to this. They may be fine for a one-year estimate, but a one-year estimate is totally irrelevant. Most of the short-term estimates are very low and most of the medium-term [estimates] were much higher—in the range of the 0.25 that we currently use.[12]

Tyner underscored this point again in a note to CARB following the March 11 workshop: "The yield to price elasticity does not measure changes over one crop year. In fact, ***any estimate done over one year would be totally inappropriate for GTAP and should be excluded from consideration in determining appropriate values for the parameter***."[13]

Babcock and other members of the Expert Work Group's Elasticity Subgroup agreed that the use of a short-run elasticity is inappropriate for the purposes of CARB's GTAP scenario runs:

> …to the extent that existing studies provide reliable one-year estimates, they underestimate the long-run response of yields to price. There are sound theoretical reasons for believing that there are lags in the response to higher crop prices. Farmers have an incentive to adopt higher-yielding seed technologies and other management techniques with higher prices. Switching from one seed variety or technology such as seed-planting populations, may require more than a single season to accomplish. And there are likely five to 15 year lags involved in developing new seed varieties and new management techniques that may be only profitable under high prices.[14]

The Schlenker work, which has served as the basis of CARB's use of inappropriately low YPE values, was critiqued by the EWG's Elasticities Subgroup. The subgroup raised several concerns with the Schlenker data, none of which (to our knowledge) have been adequately addressed by CARB staff. In short, the Elasticities Subgroup found that, "[t]he Roberts and Schlenker (2010) results provide ***no evidence that there is not a price-yield relationship***,

[12] Audio of Prof. Tyner comments are available at: http://domesticfuel.com/2014/03/12/carb-stresses-iluc-update-is-preliminary/. (emphasis added)
[13] See Appendix B of March 11, 2014 RFA comments, available at: http://www.arb.ca.gov/fuels/lcfs/regamend14/rfa_04092014.pdf. (emphasis added)
[14] ARB Expert Work Group. 2011. "Final Recommendations from the Elasticity Values Subgroup." Available at: http://www.arb.ca.gov/fuels/lcfs/workgroups/ewg/010511-final-rpt-elasticity.pdf

they just find evidence that any short-run price yield relationship is overwhelmed by variations in yields caused by weather."[15]

### f. The GTAP model's inability to explicitly consider double-cropping further justifies the use of a higher range of price-yield elasticity values.

As explained by CARB's EWG, "…higher prices give farmers a greater incentive to double crop."[16] Indeed, Babcock & Iqbal adds to the body of empirical evidence that double-cropping has significantly increased during the recent period of higher commodity prices (see also Babcock & Carriquiry[17]). Unfortunately, GTAP simulations do not explicitly allow increased demand for agricultural commodities to be satisfied through increased double-cropping. While we believe the best way to account for the impact of double-cropping is to calibrate the GTAP model to the Babcock & Iqbal data (as described in previous sections), and alternative method would be to raise the yield-price elasticity in regions where double-cropping is known to occur.

The EWG Elasticities Subgroup recommended that the price-yield elasticity parameter could be used to partially account for double-cropping responses. In its final report, the subgroup explained that "the reality of double cropping" *by itself* justified the use of a positive (i.e., non-zero) value for the price-yield elasticity.[18] The subgroup recommended that "…for countries that have the opportunity to double crop, such as the U.S., Brazil, Argentina, and some Asian rice producing countries such as Thailand…an additional increment should be given to the price-yield elasticity."[19] To date, CARB staff has failed to account for increased double-cropping in its GTAP modeling scenarios. At a minimum, 0.25 should be used as an average value, and an additional increment of 0.1 should be added (total = 0.35) for regions where double-cropping is known to occur.

## II. The New CA-GREET2.0 Model Marks a Major Improvement Over CA-GREET1.8b. However, Certain Improvements to CA-GREE2.0 Are Still Needed to Better Reflect the Direct Carbon Intensity of Ethanol Pathways

In general, RFA supports CARB's decision to revise and update its CA-GREET model based on the Argonne National Laboratory GREET1_2013 model. We believe Argonne's GREET1_2013 model contains a number of important improvements and updated inputs that more accurately reflect the current CI performance of corn ethanol and many other fuel pathways. Much has changed since CARB released the original CA-GREET model more than six years ago; ethanol and feedstock producers have rapidly adopted new technologies and practices that have significantly reduced the fuel's lifecycle CI impacts. Thus, it is encouraging to see the CA-

[15] *Id*. (emphasis added)
[16] *Id*.
[17] Babcock, B. A. and M. Carriquiry, 2010. "An Exploration of Certain Aspects of CARB's Approach to Modeling Indirect Land Use from Expanded Biodiesel Production." Center for Agricultural and Rural Development Iowa State University Staff Report 10-SR 105.
[18] ARB Expert Work Group. 2011. "Final Recommendations from the Elasticity Values Subgroup." Available at: http://www.arb.ca.gov/fuels/lcfs/workgroups/ewg/010511-final-rpt-elasticity.pdf
[19] *Id.*

GREET model finally catching up to the actual state of the industry. However, we believe the CA-GREET2.0 model could be further improved by adopting the recommendations below.

### a. CARB Should Reduce Denaturant Content in Fuel Ethanol to 2.49% to Reflect Real-World Conditions

In order to comply with Federal requirements, ethanol producers limit the denaturant content of commercial fuel ethanol to 2.49% or less. GREET1_2013, upon which CA-GREET2.0 is based, appropriately assumes denaturant content is 2%. However, Appendix C to the ISOR specifies that CA-GREET2.0 assumes the non-ethanol content of denatured fuel ethanol is 5.4%, with 2.5% being denaturant, 1% being water, 0.5% being methanol, and 1.4% being "other." While denatured fuel ethanol does contain trace amounts of water (1% or less), methanol and "other" components are generally absent from the fuel or present in amounts below those specified by CARB. Further, CARB assumes that all non-ethanol constituents of denatured fuel ethanol—including *water* and "other"—have the same carbon intensity as CARBOB. This is an unsubstantiated and unfair assumption. CARB should fix the denaturant content at 2.49% and treat any remaining non-ethanol constituents (which would be mostly water) as having the same CI as the ethanol.

### b. CARB Should Include the GREET1_2013 Default Value for Enteric Fermentation Impacts in the Corn Ethanol Pathway

For the CA-GREET2.0 model, CARB is proposing to exclude the GREET1_2013 credit for methane emissions reduction resulting from feeding DDGS. We strongly disagree with this proposal and CARB's rationale for the exclusion. We recommend that CARB adopt the GREET1_2013 methane emissions reduction credit for use in CA-GREET2.0.

CARB states that an "expanded system boundary" would be required for inclusion of methane emission reductions resulting from feeding DDGS to livestock. This implies that CARB views methane emissions reductions as a potential indirect or consequential effect. It could be argued that reduced methane emissions from livestock are a direct effect of corn ethanol expansion (via increased DDGS feeding). Nonetheless, even if we accept the argument that methane emission reductions are an *indirect* effect, CARB has no defensible reason for excluding these emission reductions. That is because CARB *already has expanded the boundary conditions for its corn ethanol pathways to include consequential/indirect effects such as purported land use changes*. CARB has also proposed to include indirect emissions associated with irrigation constraints, and at one point CARB was considering inclusion of hypothetical emissions that would indirectly result from "holding food consumption constant." Thus, CARB is proposing to include a number of potential indirect/consequential emissions sources in the corn ethanol lifecycle, but plans to selectively exclude potential emissions reductions (i.e., credits). This reflects inconsistent and asymmetrical boundary conditions (and possible bias) in CARB's analysis of corn ethanol emissions.

## III. CARB's Compliance Scenario Assumptions Regarding the Availability of Sugarcane Ethanol and Related Credit Generation Seem Highly Implausible

CARB's new compliance scenarios continue to grossly over-estimate the amount of imported sugar-derived ethanol that is likely to be available to the U.S. and California marketplace in the future. As a result, CARB adopts an overly optimistic view of potential LCFS credit generation in the 2015-2020 timeframe.

In Appendix B, CARB states that its sugarcane ethanol estimate is derived from the Food and Agricultural Policy Research Institute's (FAPRI) World Agricultural Outlook. It should be noted that due to budget constraints, FAPRI has not produced a comprehensive World Agricultural Outlook report since 2011. It is unfathomable that CARB would rely on the 2011 FAPRI publication for its projections of sugarcane ethanol availability when more current projections are available from multiple sources.

Indeed, FAPRI itself continues to publish annual "Projections for Agricultural and Biofuel Markets."[20] These projections are published in March of every year. Much has changed in the Brazilian and world sugar and ethanol sectors since 2011, and FAPRI has since significantly revised its outlook for U.S. imports of sugarcane ethanol.

FAPRI's 2014 projections include yearly estimates of U.S. ethanol imports through 2023. FAPRI projects that U.S. ethanol imports will average **182 mg per year** in the 2015-2023 timeframe, with exports never exceeding 197 mg in any single year. *Importantly, these projections include the effects of the California Low Carbon Fuel Standard*. According to FAPRI:

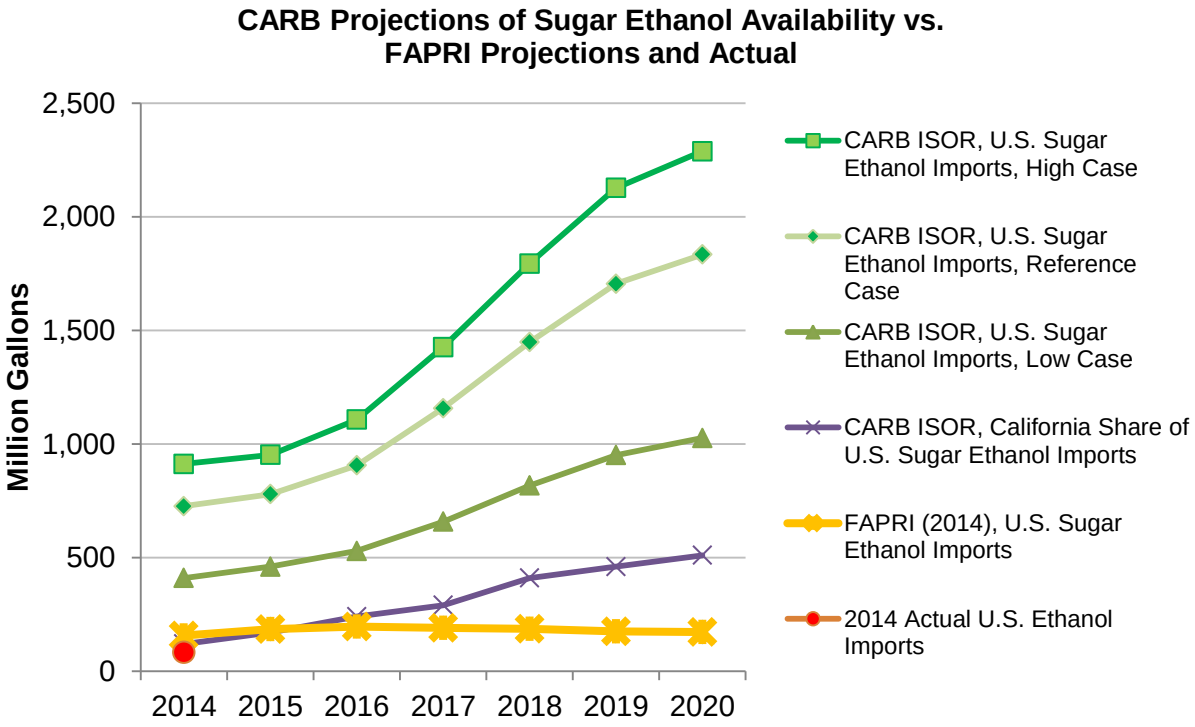
- "Sugarcane ethanol imports from Brazil continue to decline in 2014 before leveling out."
- "Lower RFS requirements for advanced biofuel could imply reduced ethanol imports."
- "However, *low-carbon fuel requirements in California provide some incentive for continued ethanol imports*."

Thus, CARB's current 2020 projections (Appendix B reference, high and low cases) of sugarcane- and molasses-based ethanol are roughly 6-13 times higher than FAPRI's current outlook, which *do* take into the account the likely "pull" from the LCFS. Further, total ethanol imports to the entire United States (most of which were sugar-derived) were just 84 million gallons in 2014, compared to CARB's compliance scenario assumption of 410-912 million gallons. In fact, CARB's projection that California would receive 120 million gallons of sugar-related ethanol in 2014 is 42% larger than actual imports to the entire U.S. Of the 84 million gallons imported by the U.S., only 7.96 million gallons—or 9.5% of the U.S. total—entered through California ports. Thus, actual California imports in 2014 were equivalent to just 6.6% of the volume anticipated by CARB.

[20] 2014 FAPRI Baseline available here:
http://www.fapri.missouri.edu/outreach/publications/2014/FAPRI_MU_Report_02_14.pdf

Similarly, CARB's projection that California will receive 510 million gallons of sugar-derived ethanol in 2020 compares to FAPRI's projection that the entire U.S. will receive only 172 million gallons of sugar ethanol that year.

CARB has suggested that higher LCFS credit values could lure larger volumes of sugar ethanol to California than projected by FAPRI. However, empirical data from the past four years show no discernible relationship between credit values and sugarcane ethanol imports to California.[21] It is also worth noting that Brazil is soon increasing its ethanol blend rate, which will further reduce the amount of sugarcane ethanol that is available to export.




We strongly recommend that CARB refine its estimates of sugar-related ethanol and use FAPRI's latest projections of sugarcane ethanol availability when conducting its analysis of potential fuel availability.

* * * * *

Thank you for considering RFA's comments on the ISOR for the re-adoption of the LCFS. We would be pleased to address any questions you may have regarding the contents of these comments or any other issues related to ethanol's role in the LCFS.

[21] See analysis of sugarcane ethanol import response to LCFS credit prices at: http://www.ethanolrfa.org/exchange/entry/the-california-lcfs-and-sugarcane-ethanol-wheres-the-flood/

# APPENDIX A:

Babcock, B.A. and Z. Iqbal (2014), Using Recent Land Use Changes to Validate Land Use Change Models. Center for Agricultural and Rural Development Iowa State University Staff Report 14-SR 109.

# Using Recent Land Use Changes to Validate Land Use Change Models

Bruce A. Babcock and Zabid Iqbal

***Staff Report 14-SR 109***

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For questions or comments about the contents of this paper, please contact Bruce A. Babcock, *babcock@iastate.edu.*

## Executive Summary

Economics models used by California, the Environmental Protection Agency, and the EU Commission all predict significant emissions from conversion of land from forest and pasture to cropland in response to increased biofuel production. The models attribute all supply response not captured by increased crop yields to land use conversion on the extensive margin. The dramatic increase in agricultural commodity prices since the mid-2000s seems ideally suited to test the reliability of these models by comparing actual land use changes that have occurred since the price increase to model predictions. Country-level data from FAOSTAT were used to measure land use changes. To smooth annual variations, changes in land use were measured as the change in average use across 2004 to 2006 compared to average use across 2010 to 2012. Separate measurements were made of changes in land use at the extensive margin, which involves bringing new land into agriculture, and changes in land use at the intensive margin, which includes increased double cropping, a reduction in unharvested land, a reduction in fallow land, and a reduction in temporary or mowed pasture. Changes in yield per harvested hectare were not considered in this study. Significant findings include:

- In most countries harvested area is a poor indicator of extensive land use.
- Most of the change in extensive land use change occurred in African countries. Most of the extensive land use change in African countries cannot be attributed to higher world prices because transmission of world price changes to most rural African markets is quite low.
- Outside of African countries, 15 times more land use change occurred at the intensive margin than at the extensive margin. Economic models used to measure land use change do not capture intensive margin land use changes so they will tend to overstate land use change at the extensive margin and resulting emissions.
- Non-African countries with significant extensive land use changes include Argentina, Indonesia, Brazil, and other Southeast Asian countries.
- Given the lack of a definitive counterfactual, it is not possible to judge the consistency of model predictions of land use to what actually happened in each country. Some indirect findings are that model predictions of land use change in Brazil are too high relative to other South American countries; and model predictions of increasing extensive land use that are larger than what actually occurred are consistent with actual land use changes only if cropland was kept from going out of production rather than being converted from forest or pasture.

The contribution of this study is to confirm that the primary land use change response of the world's farmers from 2004 to 2012 has been to use available land resources more efficiently rather than to expand the amount of land brought into production. This finding is not necessarily new and it is consistent with the literature that shows the value of waiting before investing in land conversion projects; however, this finding has not been recognized by regulators who calculate indirect land use. Our conclusion that intensification of agricultural production has dominated supply response in most of the world does not rely on higher yields in terms of production per hectare harvested. Any increase in yields in response to higher prices would be an additional intensive response.

# Using Recent Land Use Changes to Validate Land Use Change Models

In the mid-2000s prices for major agricultural commodities began a long, sustained increase. Prices increased dramatically due to growth in demand for food and biofuel producers, underinvestment in agricultural infrastructure and technology, and poor growing conditions in major producing regions. Figure 1 shows the percent change in inflation-adjusted prices received by US producers for corn, soybeans, wheat, and rice relative to the previous five-year average.[1] The predominance of negative changes shows that since 1960 average real prices for these commodities have dropped. These figures show that the commodity price boom in the early 1970s resulted in the largest increase in real prices, but the recent increase in prices since 2006 resulted in the longest sustained increase, especially for corn and soybeans. For wheat and rice, real prices increased sharply in the mid-2000s and have stayed high even though the year-over-year increases were not as long lasting as for corn and soybeans. The magnitude of these real price increases after such a prolonged and sustained period of flat or falling prices presents a unique opportunity to quantify how world agriculture responds to incentives to produce more.

The United States, California, and the EU have enacted regulations based in part on model predictions of agricultural supply response to price increases induced by increased biofuel production. The model predictions of land use changes are called indirect land use changes because the predicted changes are due to a modeled response to higher market prices rather than a direct response to the need to grow more feedstock for biofuel production. Thus, for example, the corn used to produce corn ethanol in the United States was met by US corn production; however, the diversion of corn from other uses increased corn prices and crop prices of other commodities that compete with corn for market share and land. Because corn and other commodities are traded on world markets, prices in other countries also increase. The response in the US and in other countries to these higher prices is what the models measure.

[1] Prices are average annual prices received by US farmers adjusted by the US CPI.

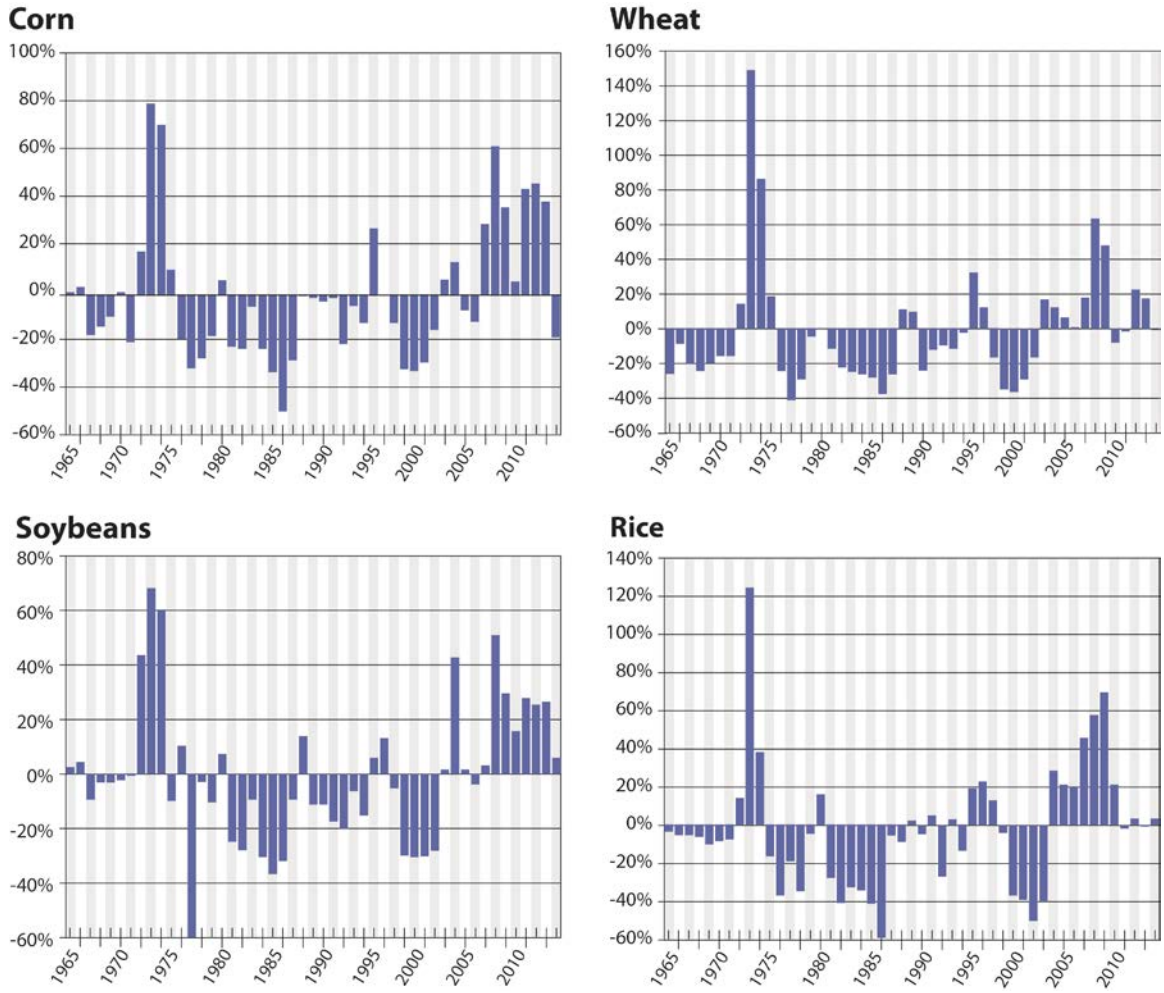


**Figure 1. Deviations in Real US Commodity Price Levels from Lagged Five-Year Average Measuring World Land Use Changes**

Some portion of the higher prices since the mid-2000s was caused by increased bio-fuel production. For example, Fabiosa and Babcock (2011) estimate that 36% of the corn price increase from 2006 to 2009 was due to expanded ethanol production. Carter, Rausser, and Smith (2010) estimate that 34% of the corn price increase between 2006 and 2012 was due to the US corn ethanol mandate. This implies that a portion of the actual response of land use since this price increase is due to US ethanol production. Other factors such as crop shortfalls and other sources of increased demand account for the rest of the price increase.

Because indirect land use is a response to higher market prices, model predictions of land use change should be similar whether the higher prices came from increased biofuel

production, increased world demand for beef, or from a drought that decreased supply in one or more major producing areas. This implies that the pattern of actual land use changes that we have seen since the mid-2000s should be useful to determine the reliability and accuracy of the models that have been used to measure indirect land use. The purpose of this paper is to look at what has happened over approximately the last 10 years in terms of land use changes and to determine whether and how these historical changes can provide insight into the reliability of model-predicted changes in land use. We address the following questions in this paper:

- How has cropland changed around the world in approximately the last 10 years?
- What were the major drivers of observed land use changes?
- When can actual land use changes be compared with model predictions?
- What can be said about the types of land that were actually converted?

## How Has Harvested Area Changed Since 2004?

The most complete source of data on annual cropland is from the Statistics Division of FAO (FAOSTAT), which measures annual harvested area by crop and country. These data have been widely used to measure the impact of biofuel production on expansion of land used in agriculture (Roberts and Schlenker 2013) and to calibrate the land cover change parameter in the GTAP model (Taheripour and Tyner 2013). Figure 2 shows the change in harvested land according to FAO. The data are smoothed by calculating the change in harvested area as the average in 2010, 2011, and 2012 minus the average in 2004, 2005, and 2006. The earlier period measures harvested area before the large increase in price. The later period represents harvested area after prices had increased substantially. India, China, Africa, Indonesia and Brazil had the largest increase in harvested land. These data seem to suggest that these countries had the largest increase in land conversion; however, harvested land is not equal to planted land. Harvested land will deviate from planted land when a portion of planted land is not harvested and when a portion of land is double or triple cropped.

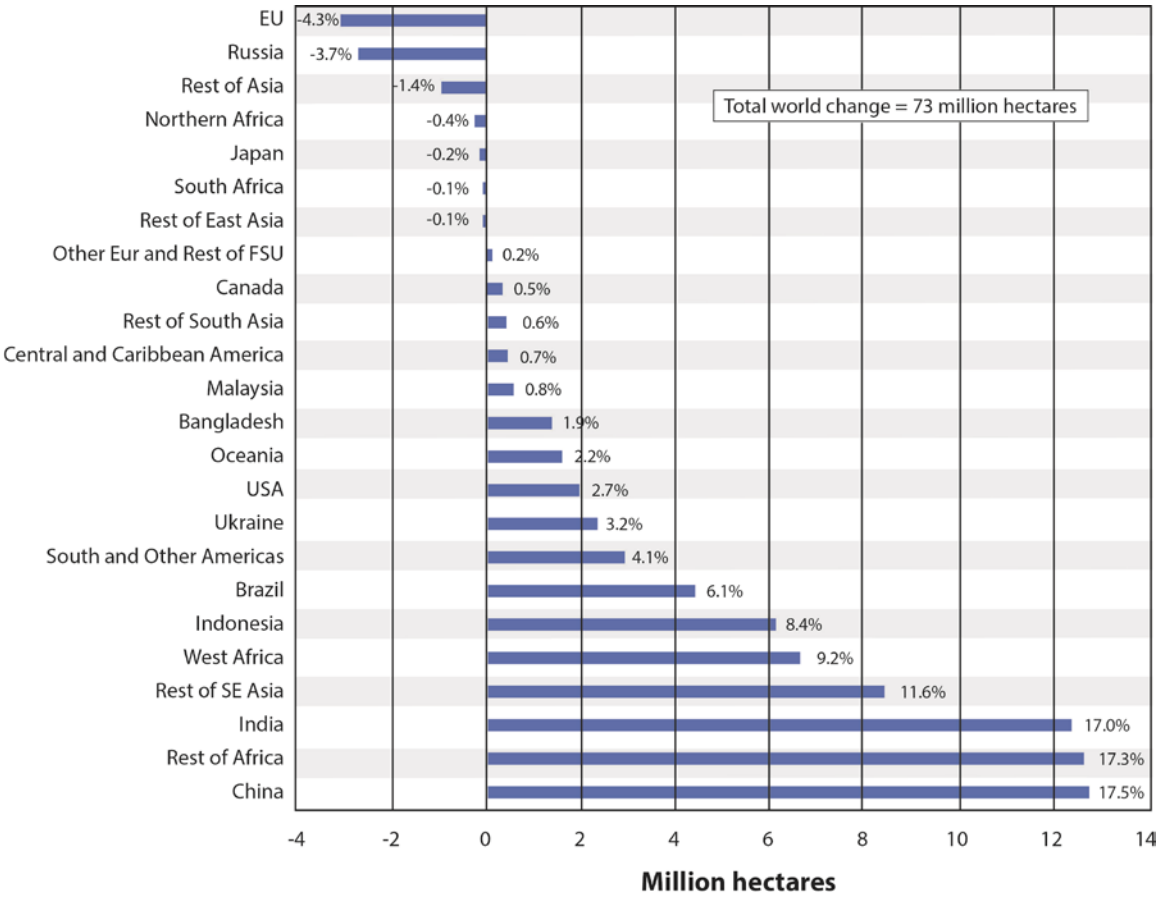


**Figure 2. Change in Harvested Land 2010–2012 Average Minus 2004–2006 Average and Country's Share of Total World Change**
*Source:* FAOSTAT

Suppose that a portion of land that is planted to a first crop is not harvested and that a portion of first crop land that is harvested in a country is double-cropped, which simply means that a second crop is planted on land that was already planted to a crop in the same year.[2] By definition, total harvested land, $H$, equals total harvested land from the first crop, $H_1$, plus total harvested land from the second crop, $H_2$. Total harvested land from the first crop equals total land planted to the first crop, $P_1$ minus land that was planted but not harvested, $a_1$. Thus we have in any year t

$$P_{1,t} = H_t - H_{2,t} + a_{1,t}$$

[2] Throughout this article land the phrase double crop should be interpreted as two or more crops being grown on a single parcel of land.

For the purpose of greenhouse gas emissions from land use changes, it is most relevant to calculate the change in planted area between two time periods $t = T$ and $t = 0$. Thus, we have

$$P_{1,T} - P_{1,0} = (H_T - H_0) - (H_{2,T} - H_{2,0}) + (a_{1,T} - a_{1,0})$$

If second crop acreage has increased over time, then use of FAO data on total harvested land overstates land use change by this amount. If the change in first crop land that is not harvested also increases over time, then at least some portion of this upward bias in measuring land use change is overcome. If, instead, the amount of unharvested land has decreased over time then the upward bias is increased. A more in-depth examination of data available for a few countries gives insight into the extent to which use of FAO harvested area data provides a good indication of land use changes.

### United States

Figure 3 illustrates that reliance on harvested area as an indicator of land use change can lead to a large bias, and shows annual changes in harvested and planted land to corn in

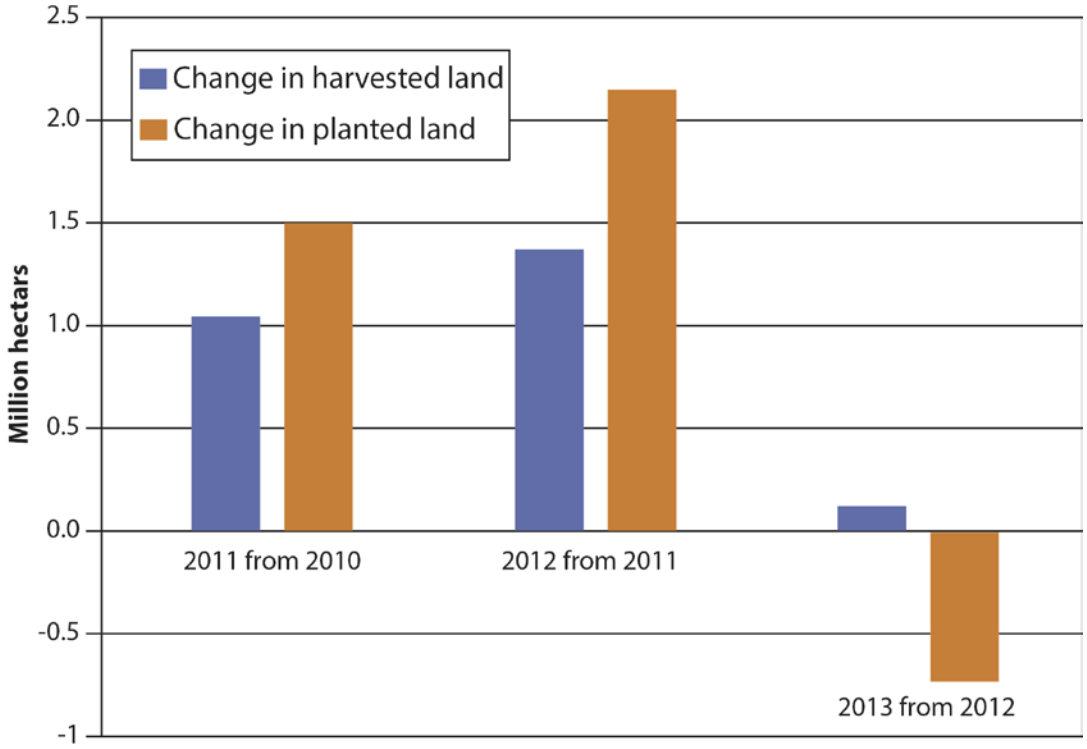


**Figure 3. Annual Change in Harvested and Planted Corn Land in the United States**

the United States from 2011 to 2013. A widespread drought in the United States resulted in an increase in the amount of planted land that was not harvested. Thus in 2012, use of harvested land to measure land use change understates land use change, whereas in 2013, it overstates land use change. Taking average changes over some time period will reduce the impact of an outlier like 2012, but it will not eliminate it. Thus, use of 2012 harvested data in the United States will tend to understate land use change relative to an earlier period and overstate it relative to a later period. Because data on US planted land is available from USDA's National Agricultural Statistics Service, it makes much more sense to use these data rather than FAO harvested land data.

### Brazil

Brazil is another country that collects data on both harvested and planted land.[3] In addition, Brazil collects data on land that is double cropped. Figure 4 shows total harvested land and total harvested land from double cropped land. The axes have been set to the same scale to show that a large proportion of the increase in Brazilian harvested land is a result of increased double cropping. The change in total harvested land from 2004–2012 is 5.4

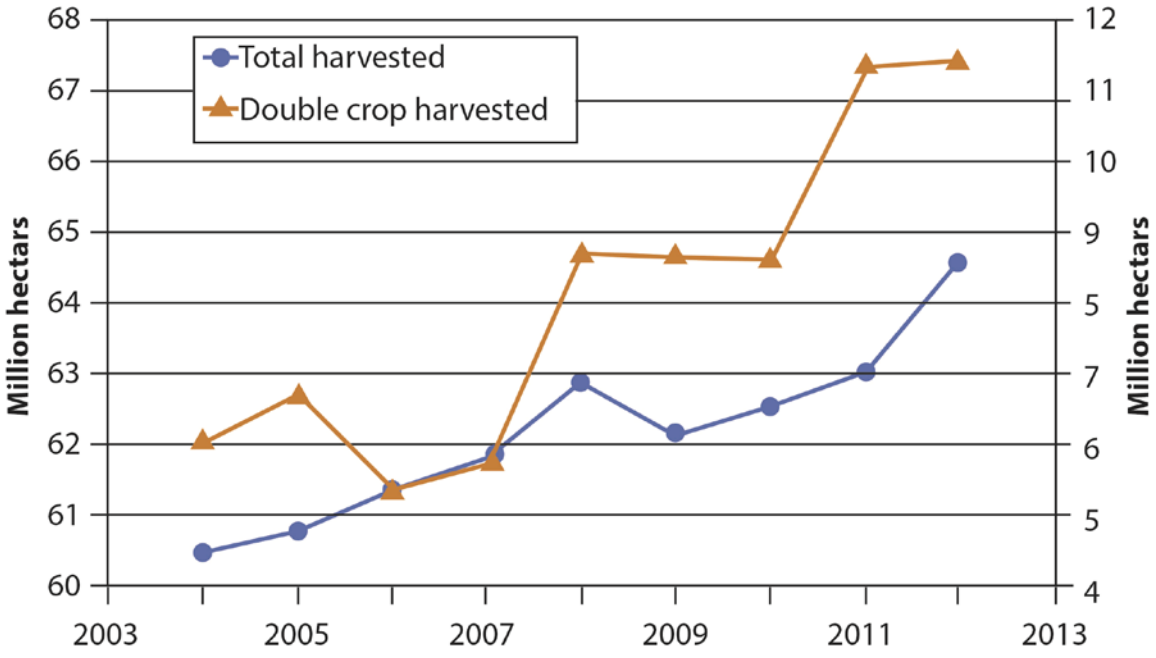


**Figure 4. Brazil Harvested Land Data**

[3]Brazilian IBGE data is available at http://www.sidra.ibge.gov.br/bda/pesquisas/pam/default.asp?o=27&i=P

million hectares. The change in double cropped land is 4.1 million hectares. Thus, more efficient use of land accounts for 76% of the change in harvested land in Figure 4.

### India

Figure 2 shows that India increased harvested area by 6.8% from 2004–2006 to 2010–2012 which is 12.4 million hectares. Given India's long agricultural history it seems unlikely that so much land would be suitable for conversion to crops in such a relatively short time. India collects data on both planted and harvested land as well as double cropped land (India Ministry of Agriculture). Figure 5 shows that the variation in multiple crop area explains most of the variation in total planted area, which includes double cropped area. Subtracting double cropped area from total planted area shows that net planted area decreased by 147,000 hectares between 2004–2006 and 2010–2012. What then accounts for the increase in harvested area? Figure 6 shows that the proportion of planted area that is harvested has increased dramatically over this time period. An examination of previous years' data shows that the wide gap between planted and harvested

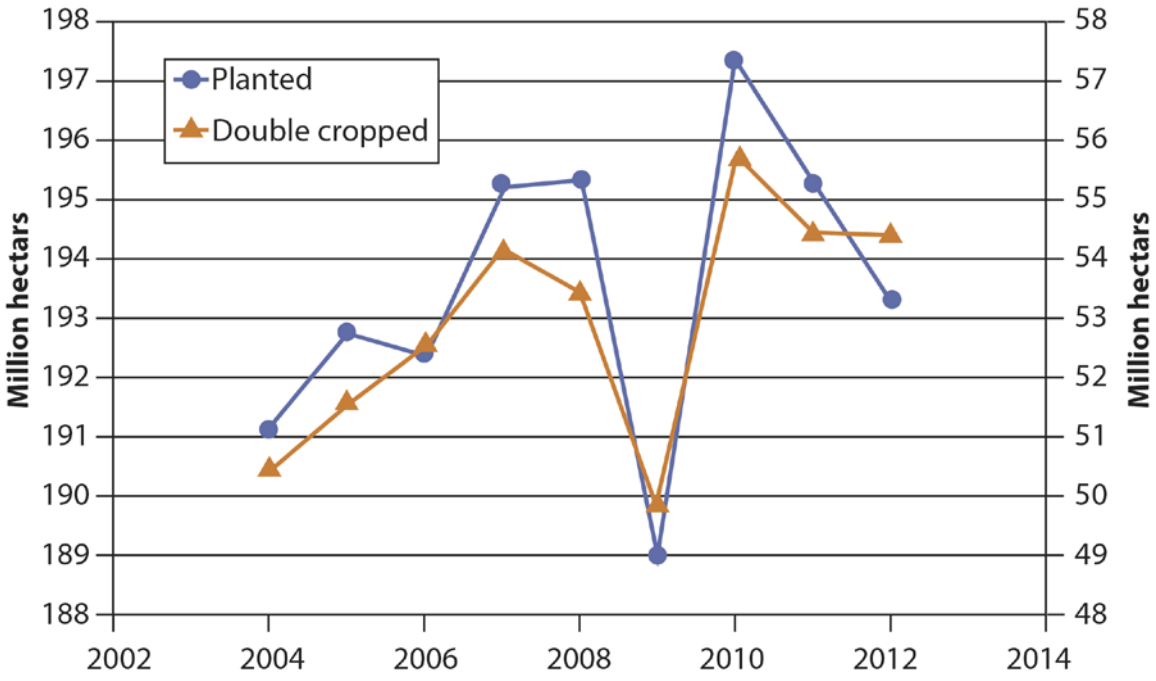


**Figure 5. Total Planted and Multiple Crop Area in India**

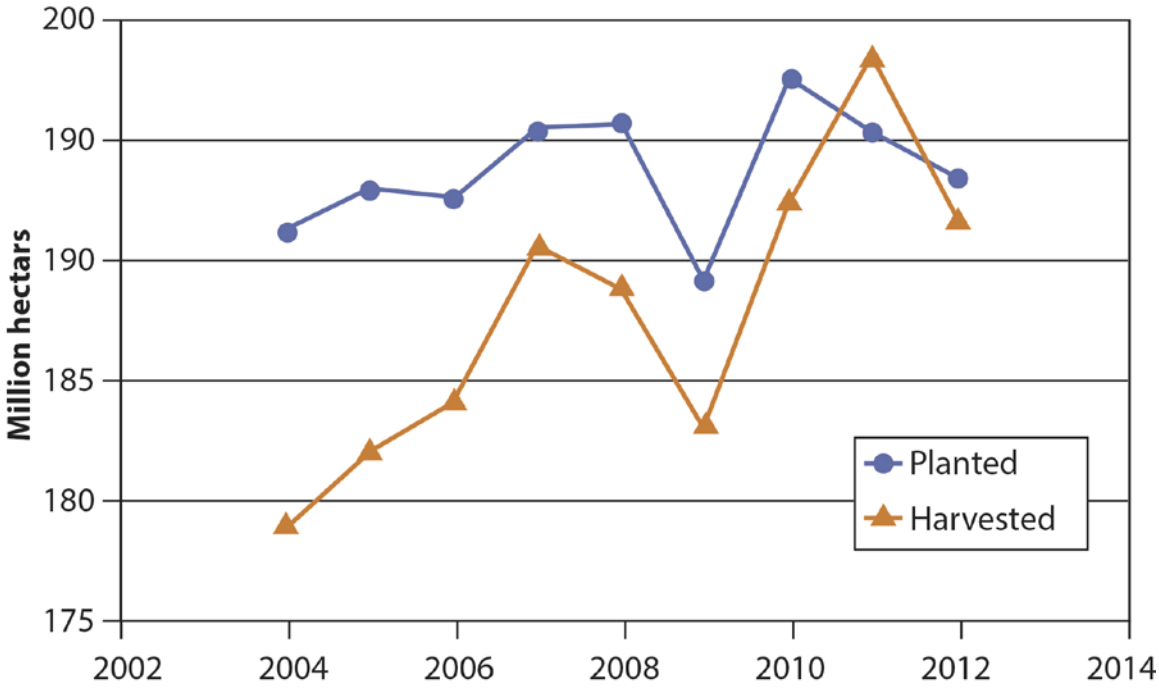


**Figure 6. Total Planted and Harvested Area in India**

area shown in Figure 6 from 2004 to 2006 was typical. For example, the 2004–2006 gap averages 10.6 million hectares, and the gap from 1992 to 2000 averages 10.4 million hectares. The average gap in 2010 and 2012 is 3.4 million hectares. Thus, an increase in double cropped area accounts for about 3.5 million hectares of the increase in harvested area, and a decrease in non-harvested area accounts for another 7 million hectares. Thus, all of the increase is harvested area is accounted for by intensification of land use. One reason why non-harvested area has increased so much is the 6 million hectare increase in irrigated area from 2004 to 2011. More irrigation allows a greater proportion of planted area to grow to maturity, thereby making it worth harvesting. In addition, India increased support prices and input subsidies in the mid-2000s to combat stagnant growth in the agricultural sector. These actions, combined with the expansion of irrigation, increased the opportunity cost of not harvesting land.

### China

FAO harvested area data shows an increase of 8% from 160 million hectares to 173 million hectares from 2004–2006 to 2010–2012. Figure 2 in Cui and Kattumuri (2012) shows that

total cultivated land in China dropped from about 130 to about 122 million hectares from 1996 to 2008. The four reasons cited for the loss of agricultural land are urbanization, natural disasters, ecological restoration, and agricultural structural adjustment, with restoration and urbanization accounting for about 80% of losses. Cui and Kattumuri (2012) claim that the loss of agricultural land slowed down in 2004 and 2005 only because of "…stringent land protection policies" (p. 14). Based on this conclusion, it seems that economic forces in China were trying to reduce cultivated land, not increase it, in the mid-2000s. If correct, then it seems highly unlikely that a significant portion of the increase in harvested area was caused by an increase in the amount of land cultivated. If both FAO harvested area data and data used by Cui and Kattumuri (2012) are correct, then at least 38 million hectares of harvested area came from double cropped land in 2004–2006 and 51 million hectares of harvested area came from double cropped areas in 2010–2012.

### Sub-Saharan African Countries

Figure 2 shows that sub-Saharan African countries have been large contributors to increases in harvested land. With some exceptions, much of African crop production is carried out by small-scale producers without use of modern technologies. While differences exist between countries, typically most production is consumed domestically and most commercial trade occurs between adjoining African countries (Minot 2010). Sub-Saharan African countries account for 34 of the top 50 countries in the UN data base in terms of population growth rates in 2010.[4] The average population growth rates for these 34 countries in 2010 was 2.93%. Leliveld et al. (2013) show that food production in Tanzania has just about matched population growth and that almost all of the food production increase has been due to an increase in the amount of land planted. Although it is possible to plant more than one crop in many African countries by developing shorter-season varieties and better management (Ajeigle et al. 2010), a lack of access to technology and capital is one defining characteristic of traditional agriculture in sub-Saharan Africa, so there is no evidence that double cropping is widely adopted. Thus, the change in harvested land shown in Figure 2 for African countries is likely a better measure of the change in planted land than in other countries.

[4] Population growth rates are available at http://data.worldbank.org/indicator/SP.POP.GROW/countries?display=default

### Indonesia

Figure 7 shows the change in area harvested from 2004–2006 to 2010–2012 for the top eight crops and for all other crops in Indonesia according to FAOSTAT. As shown most of the expansion has occurred in rice and palm oil fruit. Because perennial crops do not generally produce more than one crop per year, the extent to which FAO harvested land data overstates the change in planted land is limited. Adding the change in harvested land of palm, rubber, coffee, coconuts, and cocoa together accounts for 54% of the change in harvested area. According to USDA-FAS (2012) the availability of suitable rice-growing land is severely restricted in Indonesia. Most of the increase in harvested rice area that has been achieved has come about from investment in irrigation facilities that allow two or three crops of rice to be planted on the same land rather than a single crop. The extent to which intensification explains the 1.4 million hectare increase in rice harvested area shown in Indonesia cannot be determined by harvested area data alone. However, given that Indonesia is one of the world's most densely populated countries, and 1.4 million hectares represents a 12% increase in harvested production, it is unlikely that a significant portion of this 1.4 million hectares is new land. According to USDA-FAS (2012) about

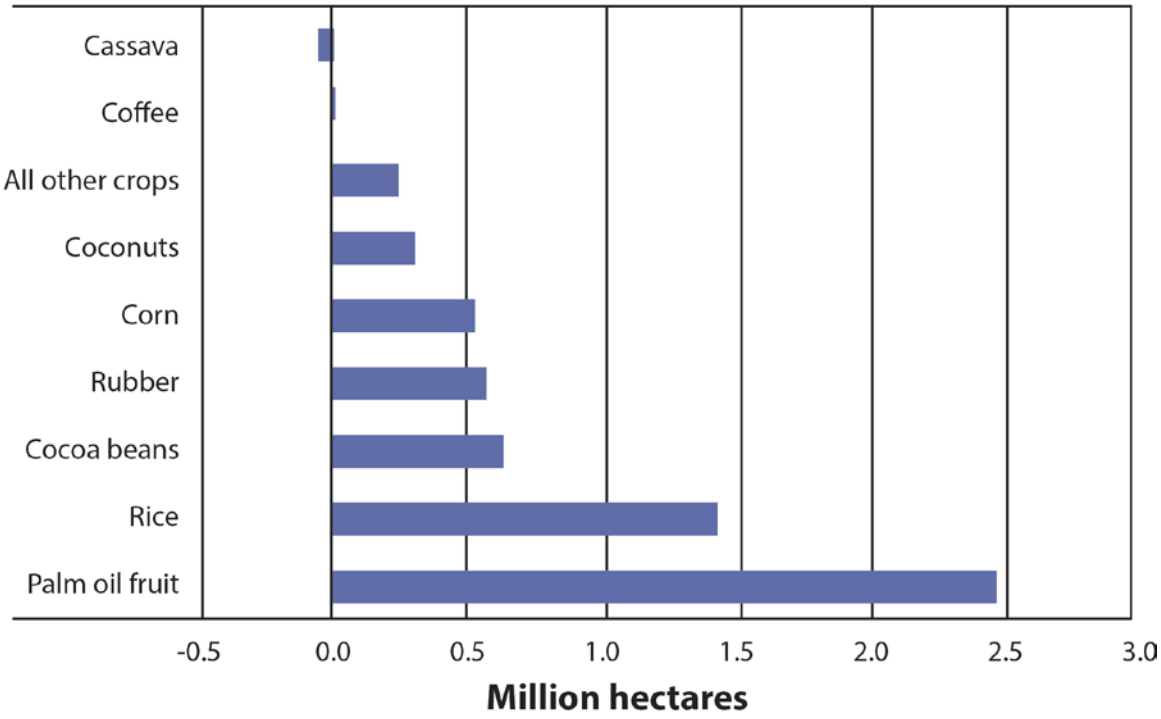


**Figure 7. Change in Harvested Area by Crop for Indonesia as Reported by FAO**

50% of Indonesian rice area grew rice in both the rainy and dry seasons in 2011, which implies that there is significant room for harvested area growth with greater irrigation. Thus it is likely that most of the increased rice area in Indonesia is accounted for by increased double and triple cropping.

Swastika et al. (2004) explain that most corn production in Indonesia is grown on land that produces two crops. Corn is typically grown with tobacco, cassava, another corn crop, or sometimes with rice. Given land constraints in Indonesia and the significant expansion of palm oil production, which has been accomplished by converting forestland and cropland (Susanti and Burgers 2013; Koh and Wilcove 2008), it is likely that a significant portion of the corn production increase came about by increasing double cropped area.

## An Alternative Measure of Land Use Change

Use of harvested area to measure land use change can lead to a large bias in estimates of how much land has been converted to crops from other uses. While this may be an obvious point, it is too often missed in analysis of land use changes. Reliable country-specific data, such as in the United States, that can measure the change in net planted area should be used when available. Where it is not available, land cover data can be used. For global coverage FAOSTAT data on arable land and land planted to permanent crops are available. The FAO definition of arable land is "the land under temporary agricultural crops (multiple-cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen gardens, and land temporarily fallow (less than five years). The abandoned land resulting from shifting cultivation is not included in this category."[5] This definition is different than the common meaning of arable land—land that is capable of producing a crop rather than land that is actually in crop production. Adding FAO's measure of arable land to land that is in permanent crop provides a measure of land use that is appropriate to use in determining the amount of new land that has been brought into production. Figure 8 reproduces Figure 2 using this measure with the exception of the United States, for which USDA's NASS planted area data is used. For the United States, total planted area of principal field crops minus double crop area is

[5] http://faostat.fao.org/site/375/default.aspx

used instead of FAOSTAT data because FAOSTAT reports a 9 million hectare loss in total cropland because of a sharp reduction in temporary pasture.

The implications of Figure 8 are strikingly different than Figure 2. Furthermore the Figure 8 data is much more consistent with the country-specific data in China, India, Brazil, Indonesia, and Africa. Figure 8 data suggest that the net change in global cropland over this period is 24 million hectares. African countries increased cropland by 20 million hectares. Other countries with more than a million-hectare increase include Argentina, Indonesia, Brazil, Rest of Southeast Asia, Rest of South Asia, and South and Other Americas. Countries with significant reductions in cropland include the EU, Canada, China, Russia, and South Africa.

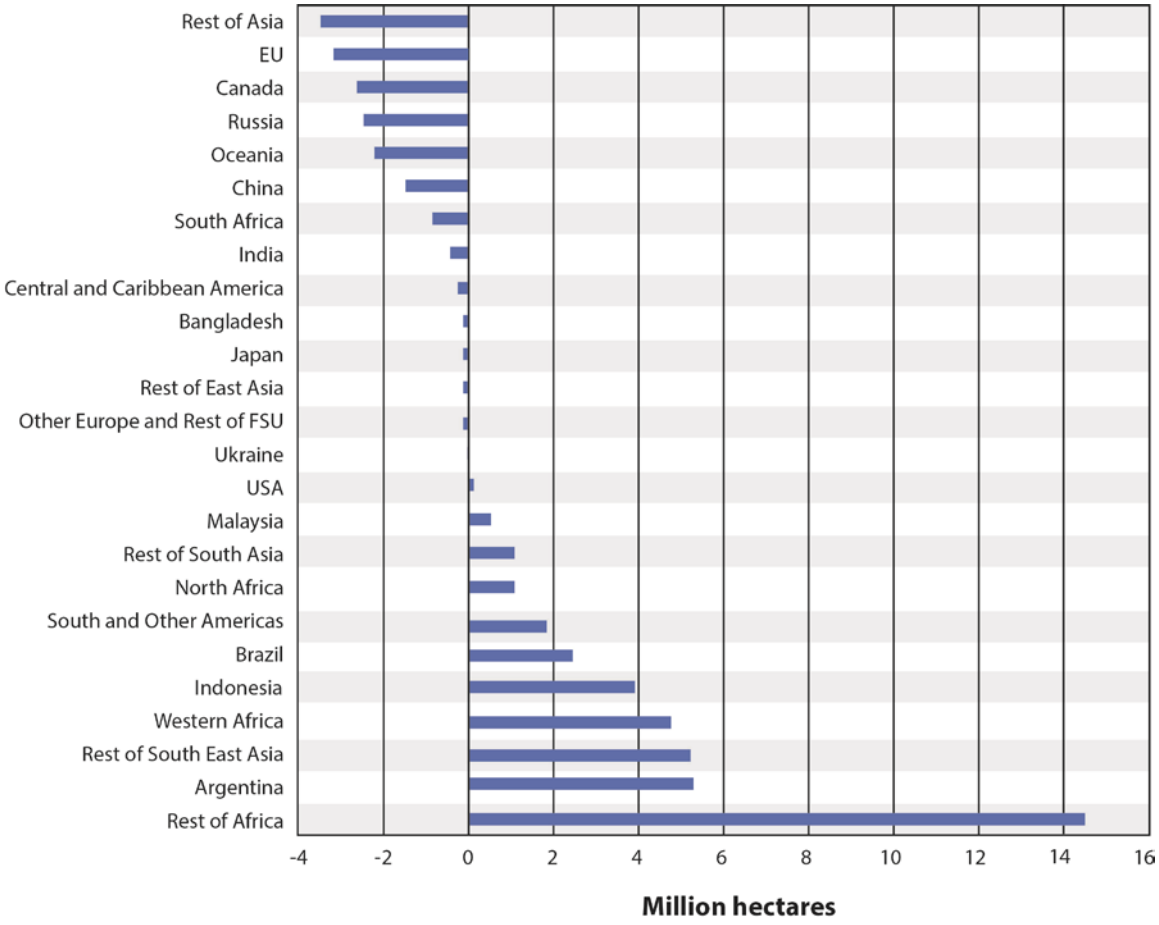


**Figure 8. Change in Arable Land Plus Permanent Crops: 2004–2006 to 2010–2012**

The data in Figures 2 and 8 can be used to determine the relative importance of land use changes at the intensive and extensive margin. Intensive margin changes are changes in double cropped area and a reduction in land that is available to plant but that is not harvested. The total change in harvested area in Figure 2 is the sum of extensive changes and intensive changes to land use. Thus, intensive changes equal the total change in harvested area from Figure 2 minus the changes in cropland given in Figure 8.[6] Both intensive and extensive changes are shown in Figure 9. Countries are sorted from the left according to their level of extensive acreage changes.

Most of the change in land use in African countries and Argentina is at the extensive margin. Most or all of the response in the developed world, India, China, South Africa, and the rest of Asia is at the intensive margin. The response in Indonesia and Brazil is mixed.

## Major Drivers of Recent Land Use Changes

Broadly speaking, the land use changes shown in Figure 9 are consistent with a model of the world in which countries that have available land to convert to agriculture will have relatively more extensive land use change than countries that have long histories of agricultural development and limitations on available land. Thus, one major driver of recent land use changes is the availability of land to convert to agriculture. Most developed countries, along with China and India, have little land available, however, countries in Africa and South America have abundant land resources. There are striking differences, however, in land use indicated by Figure 9 that must be due to other drivers.

Growing demand for soybean imports was a major driver of land use decisions in Argentina, Brazil and the United States. The increased demand for soybeans resulted mainly from China's decision to meet its domestic needs for soybeans through imports rather than domestic production. This decision freed up resources in China to devote to production of other commodities and led to much higher soybean area in Argentina, Brazil, and the United States. Higher demand for high-protein foods in China and other developing countries increased the demand for soybean meal.

[6]One other use of this measure as an indicator of the amount of land that is used in agriculture is OECD-FAO (2014) when total agricultural land is discussed.

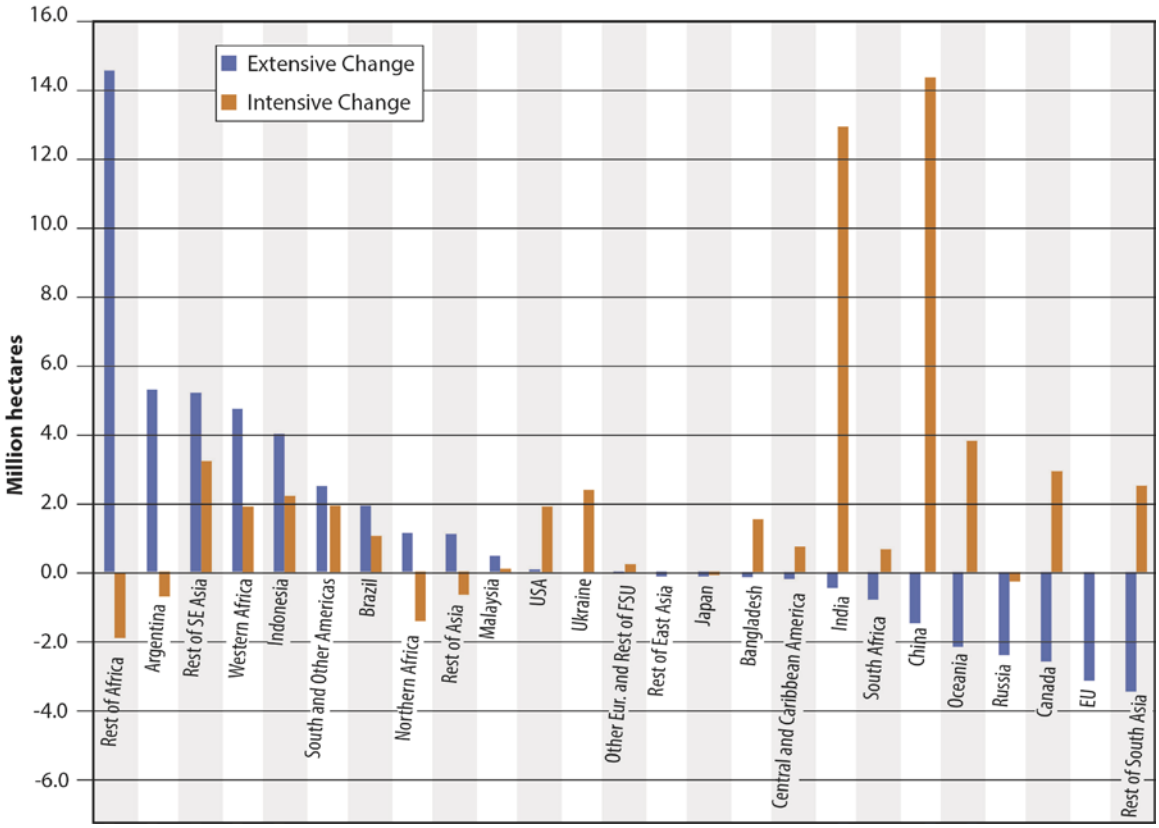


**Figure 9. Extensive and Intensive Land Use Changes: 2004–2006 to 2010–2012**

Increased demand for vegetable oils for food production, cooking, and biodiesel increased the demand for soybean oil.

Brazil responded to this increased soybean demand by expanding soybean area, however, a second crop of corn was planted on a good portion of expanded soybean acreage. This expansion in double cropping reduced the amount of corn area planted to the first crop of corn. Thus, Brazil expanded at both the extensive and intensive land use margins.

Argentina also expanded soybean area, but it did so at the extensive margin rather than by intensifying land use. The prime soybean production areas in Argentina are farther south than in Brazil, which shortens the time period available for double cropping. However, a second crop of soybeans can be planted in Argentina after winter wheat is harvested in December. One explanation for a lack of intensification is that Argentine area planted to wheat has declined from about 6 million hectares in 2005 to 3.6 million hectares in 2012. This decline simply means that there is less land available for double cropping soybeans after wheat. Therefore, if soybean area needs to increase, less wheat

land means less land available for double cropping, thus, soybean first crop area by definition must increase. The decline in wheat area has been mainly driven by government policy interventions in the form of export taxes and export subsidies that were implemented in a way that favored soybeans over corn and wheat (Nogues 2011). This suggests that government policy is what caused a lack of an intensive land use response in Argentina, in contrast to the significant intensive response shown in Figure 9 in Brazil and other South American countries.

As discussed, Indonesian expansion of palm production was accomplished at least in part at the extensive margin. This expansion resulted from increased investment drawn to the industry due to higher profit margins caused by higher prices and higher yields. The higher prices resulted from an overall increase in demand for vegetable oil, driven by increased demand for food production, cooking oil, biodiesel, and other uses. The data show that Indonesian expansion of rice and corn harvested area was done at the intensive margin because the area devoted to perennial crops in Figure 7 is greater than the total extensive expansion shown in Figure 9.

Sugarcane and soybeans account for nearly all of the land expansion in Brazil. Increased sugarcane production was used to meet growing demand for sugar and to meet growing domestic demand for ethanol. The number of flex vehicles in Brazil grew by 20 million from 2005 to 2012. If all of these vehicles used ethanol, Brazilian consumption of ethanol in 2012 would have exceeded 24 billion liters just from these vehicles, and additional consumption would have come from the 15 million gasoline vehicles in Brazil. Actual consumption in Brazil was about 18 billion liters.[7] These figures demonstrate that the growth in sugarcane area was primarily driven by the Brazilian government policy that increased the sales of flex vehicles in Brazil. The expansion in Brazilian soybean area was driven by increased world demand for soybean imports, which was mainly driven by China, as previously discussed. The ability to plant a second crop of corn after soybean due to adoption of shorter-season soybeans and agronomic advances reduced the amount of new land that was needed to accommodate this expansion.

[7] All figures on Brazilian vehicle numbers and ethanol consumption were obtained from UNICA: http://www.unicadata.com.br/?idioma=2

In China, India, and most of the developed world, agricultural land resources are limited. Limited land resources means that expansion at the extensive margin is costly relative to expansion at the intensive margin. Thus, we see a large response in both China and India at the intensive margin rather than the extensive margin. Cui and Kattumuri (2012) argue that Chinese intensification would have been even greater but for the government policy objective of maintaining a minimum of 120 million hectares of land in agriculture. India's intensification was facilitated by government investment in irrigation facilities and price subsidies that increased agricultural profitability (OECO-FAO 2014).

The lack of a large extensive response in Ukraine, Russia, and other FSU countries is somewhat surprising given the availability of land. The lack of response at the extensive margin could be due to a lack of investment in the agricultural sectors of these countries.

How much of the changes in land use shown in Figure 9 can be attributed to high commodity prices cannot be known precisely without observing an alternative history in which the run-up in commodity prices did not occur. Economic theory suggests that some portion of the changes in Figure 9 came about because of high prices in those countries where high world prices were transmitted to farmers. However, some of the changes in land use would have occurred even if prices had remained constant at their 2004–2006 levels.

The extent to which extensive expansion in African countries was caused by high world prices is likely small for the simple reason that higher world prices were not transmitted to growers in many African countries. Minot (2010) concludes that domestic grain prices in Tanzania bear little relationship to world prices. In a more complete study, Minot (2011) studies price transmission in multiple markets in Ethiopia, Ghana, Uganda, Zambia, Mozambique, Tanzania, Kenya, South Africa, and Malawi. Of the 62 markets studied, he found that only 13 showed a statistically significant long-run relationship with world prices. He found some evidence of a linkage in large urban centers and in coastal markets, which is consistent with markets in cities and in coastal ports being more integrated with world markets. However, given his overall findings, these limited linkages to world prices did not find their way through to rural areas where most crops are grown. With such weak evidence supporting price transmission to rural areas one can conclude that the main driver of land expansion in many African countries was not higher world prices.

## Empirical Measures of Land Use Changes

Aggregating land use changes across all countries, the aggregate world extensive change was a net increase of 24 million hectares from 2004–2006 to 2010–2012. The aggregate world intensive land use change was 49.1 million hectares. Thus, across all countries, more intensive use of existing land was double the change from more extensive use of land. Outside of African countries, the aggregate intensive change in land use was almost 15 times as large as extensive changes. This wide disparity between more intensive use of land and more extensive use means that the reliability of current models used to estimate indirect would be dramatically increased if they were modified to account for non-yield intensification of land use.

The recent historical changes in land use can provide some guidance about the effect of dramatically higher prices on land use change over an eight-year period. An estimate of the amount of extensive land use change that can be attributed to higher commodity prices can be made under fairly restrictive assumptions.

First is assuming that land use change at the extensive margin due to high prices is zero in those countries or regions in Figure 9 that had negative extensive changes. This assumption implies that the forces that caused countries to lose agricultural land during this time would have caused the same amount of loss even without the high prices. Clearly, it would seem that at least some land in these countries was kept in production from the high prices, so this assumption understates land use change at the extensive margin. From a greenhouse gas perspective, this assumption is equivalent to saying that the net amount of carbon sequestration that would have occurred on land that was kept in production by high prices in these countries is negligible.

Second is assuming that all the extensive margin changes in Figure 9 in countries and regions that have positive changes are due to high world prices. This too is an extreme assumption because some land would have been brought into production even if commodity prices had not increased. Thus this assumption overstates the response of land use at the extensive margin.

If we include extensive changes in Africa, then world extensive land use changes equals 41.2 million hectares, which represents a 2.68% increase over the average level of land in production in 2004–2006. If we assume that the extensive land use changes in

Africa were primarily caused by internal domestic food demand from growing populations and income, and they would have occurred even without high world commodity prices, then the extensive land use increase equals 20.7 million hectares or 1.35%.

It is instructive here to make a rough estimate of the response of the world extensive margin to aggregate higher commodity prices. The average real prices of corn, soybeans, wheat, and rice received by US farmers increased by 123%, 85%, 59%, and 47% respectively in 2010–2012 relative to 2004–2006. A simple average of these price increases is 78%. With this real price increase, the elasticity of the world extensive margin is 0.034 if African extensive response is included, and 0.017 if the African extensive response is not included.

Similarly, if the intensive response in countries and regions where the response is negative is set to zero, then the aggregate intensive response to high prices is 49.1 million hectares if we attribute all the intensive response to higher prices. Without the African country response, the aggregate response is 47.2 million hectares. The resulting elasticities of intensive response are 0.041 and 0.039. Thus, if we attribute all the African extensive land use changes to high prices, then the world intensive elasticity is 19% higher than the extensive elasticity. If none of the African response is attributed to higher prices than the non-African intensive elasticity is almost three times as great as the extensive response.

These rough estimates demonstrate that the primary land use change response of the world's farmers in the last 10 years has been to use available land resources more efficiently rather than to expand the amount of land brought into production. This finding is not new and is consistent with the literature that finds significant option value in waiting to convert land (Song et al. 2011). OECD-FAO (2009) recognized that intensive land use change has been the driving force behind higher production levels, however, this finding has not been recognized by regulators who calculate indirect land use. Note that our measure of more efficient land use does not include higher yields in terms of production per hectare harvested. Any increase in yields would be an additional intensive response. Rather the intensive response measured here is due to increased multiple cropped area, a reduction in unharvested planted area, a reduction in fallow land, and a reduction in temporary pasture. Because greenhouse gas emissions associated with an intensive

response are much lower than emissions caused by land conversions (Burney, Davis, and Lobell 2010), ignoring this intensive response overstates estimates of emissions associated with land use change because most of the land use change that has occurred is at the intensive rather than extensive margin.

## Comparison of Actual Land Use Changes with Model Predictions

Model predictions of land use change from increased biofuel production are conceptually appealing. This is because the effects of higher biofuel production on land use are measured in isolation—the effects of everything else that influences agriculture are held constant. Thus, the effects of biofuel production alone can, at least conceptually, be measured. The way that the models assume increased production impacts land use is through higher prices. Thus, if the actual changes in land use in Figure 9 were the result of a response to the large increase in commodity prices that actually occurred, then it seems reasonable to compare model predictions to the actual changes that occurred. However reasonable this seems, we simply do not know with certainty what land use changes would have occurred without the increase in commodity prices. What needs to be compared to model predictions is the difference in land use with the commodity price increase relative to what it would have been without the commodity price increase.

What information then can be gleaned from a comparison of model predictions with actual changes? At one extreme, if none of the observed changes in extensive land use were the result of high prices, then we know that indirect land use is not empirically important because land use changes are caused by other forces. At the other extreme, if extensive land use would have stayed constant at base period levels if prices had not increased then all of the observed changes resulted from high prices. In this case it would be valid to judge the accuracy of model predictions with observed changes, because both would be caused by price responses. Reality likely falls somewhere in between these two extremes in that land use in 2012 would have been different than in 2004 even without the price increase, and that at least some portion of the observed changes we see can be attributed to higher prices. Taheripour and Tyner (2013) use observed land use changes as a guide to selection of a key model parameter in GTAP in an attempt to reconcile model predictions with observed changes. Hence, they assume that observed changes in

land use are a useful guide to determine how the GTAP model should predict how land use changes in response to a change in commodity prices.

The two most widely used international models used in the United States to predict land use changes associated with increased biofuel production are GTAP and FAPRI (Gohin 2014). Both models allowed crop yields to respond to higher prices, and neither model allowed land use intensity, as measured here, to increase. Given that the primary way that non-African countries have increased effective agricultural land was through intensification, both models have an upward bias in their predictions of land use change at the extensive margin in non-African countries.[8]

Figure 10 shows the predicted increases in cropland from the FAPRI model that was used by the Environmental Protection Agency to determine greenhouse gas emissions

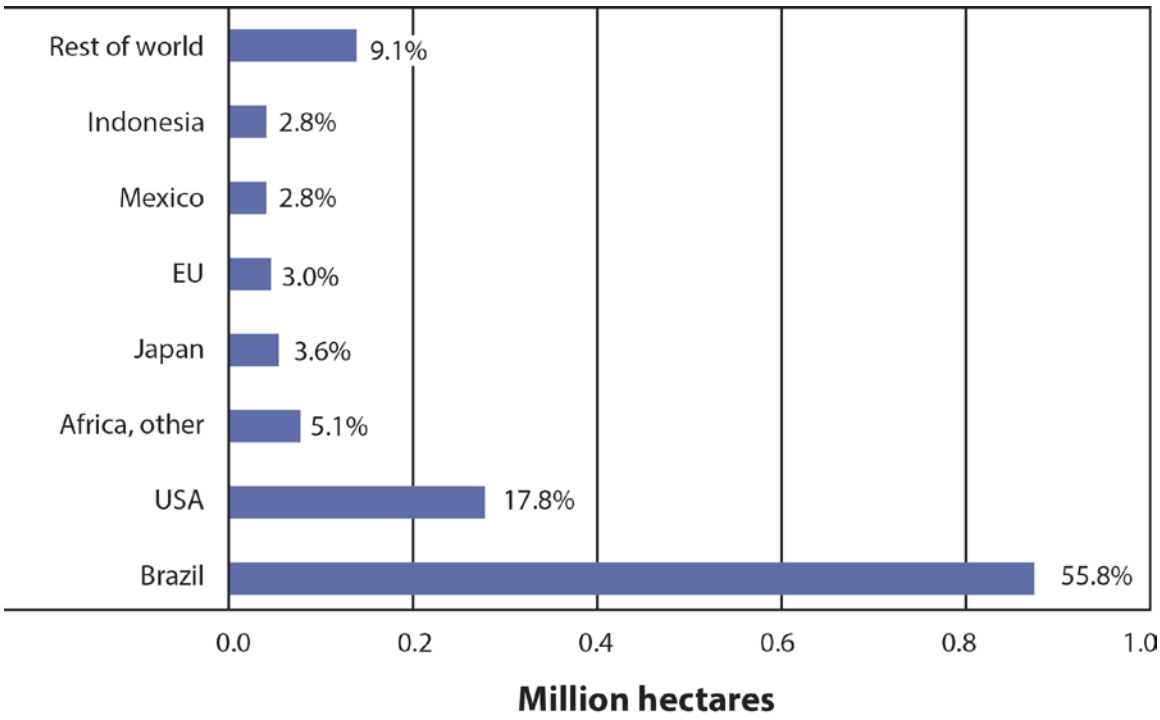


**Figure 10. Predicted Land Use Change in EPA "All Biofuel" Scenario: Hectares and Share of World Total**

[8] One way that production per unit of agricultural land can increase in the GTAP model is through its yield elasticity, therefore at least some of the upward bias in GTAP's prediction of extensive land use changes is offset by using a yield elasticity value that is higher than can be supported empirically.

associated with land use changes from increased biofuels. What is illustrated is the difference between EPA's "Control Case" that includes levels of biofuels in the RFS and EPA's "AEO Reference Case," which contains lower levels of biofuels (EPA 2010). This scenario simulated increases in many different biofuels including biodiesel made from vegetable oil and waste greases, corn ethanol, sugarcane ethanol, and cellulosic ethanol. How these land use changes were calculated is that the FAPRI predictions of land use in the AEO Reference Case were subtracted from the predictions in the Control Case. The total predicted world change in land use is 1.45 million hectares.

What is striking about Figure 10 is the concentration of predicted land use change in Brazil and the United States. These two countries account for almost 75% of the total predicted change in land use, with Brazil alone accounting for more than half of all change in the world at the extensive margin. In the AEO Reference Case total cropland in Brazil is increasing, thus the predicted increase in area must come from conversion of land that would have been devoted to other uses.

The first valid comparison that can be made between the CARD-FAPRI model prediction and what actually occurred is that the predicted land use change in Brazil due to higher prices is far too high relative to land use changes that actually occurred at the extensive margin in Argentina and other South American countries. As shown in Figure 9 Argentina and other South American countries together increased land use at the extensive margin by almost four times as much as did Brazil. The CARD-FAPRI model results used by EPA predicted almost no land use change in Argentina and other South American countries due to higher prices. It is notable that the CARD-FAPRI model predicted that growth in Brazil cropland from 2002 to 2009 would be about 9.1 million hectares, whereas Argentina's growth would be 3.7 million hectares in the Reference Case. Thus, the larger increase in agricultural area in Argentina that actually occurred cannot be attributed to the model being right about predicting a larger baseline increase in Argentina than in Brazil. The first conclusion one can draw from this comparison is that the CARD-FAPRI model dramatically over-predicted land use change in Brazil relative to Argentina and other South American countries.

The CARD-FAPRI prediction that the United States would account for about 18% of the world's increase in extensive land use seems inconsistent with the large changes that

occurred in African countries and Argentina. The only way that the US land use prediction is consistent with the historical record is if cropland in the United States would have dropped by a large amount in the absence of the large price increase. The CARD-FAPRI model predicted that US crop area would decline in both the Reference and Control Cases.

The CARD-FAPRI model includes some South African production and a limited number of other crops in a limited number of African countries. The CARD-FAPRI model implicitly assumes that most of African agricultural production of major crops is isolated from world markets. As discussed above if this isolation is in fact a correct characterization of African agriculture, then the large land use changes in African countries shown in Figure 9 would have occurred even without the high commodity prices. The only other conclusion that can be drawn regarding African countries is that the CARD-FAPRI model underpredicts land use changes there to the extent that land use in African countries responded to world prices.

The commodity price increases that led to the Figure 10 predicted changes in land use were a 3.1% increase in corn prices and a 0.8% increase in soybean prices. These simulated price changes are dwarfed by the actual price changes that have occurred as shown in Figure 1. The FAPRI model prediction of a small increase in extensive land use in Japan and the EU due to small changes in price seems inconsistent with the fact that land use in Japan has been largely unchanged over the last 10 years and the EU has experienced a decline in land use. Again, it is not possible to know the extent to which a small increase in world commodity prices would have kept a small amount of land in production in the EU.

The small model-predicted change in Indonesia in extensive land use is generally consistent with observed changes if we assume that no changes would have occurred except for the higher market prices that actually occurred and not from government development priorities.

Figure 11 shows predicted land use changes by the GTAP model. [9] GTAP predicts that 38% of land use changes occur in the United States. As discussed, although

[9] GTAP model predictions of land use changes associated with biofuels vary across publications. Figure 11 land use change predictions were taken from Hertel et al. (2009) which were published about the same time that California's Air Resources Board was making their determination of greenhouse gas emissions from land use change that relied on GTAP model predictions. For the purposes of this paper, we assume that the

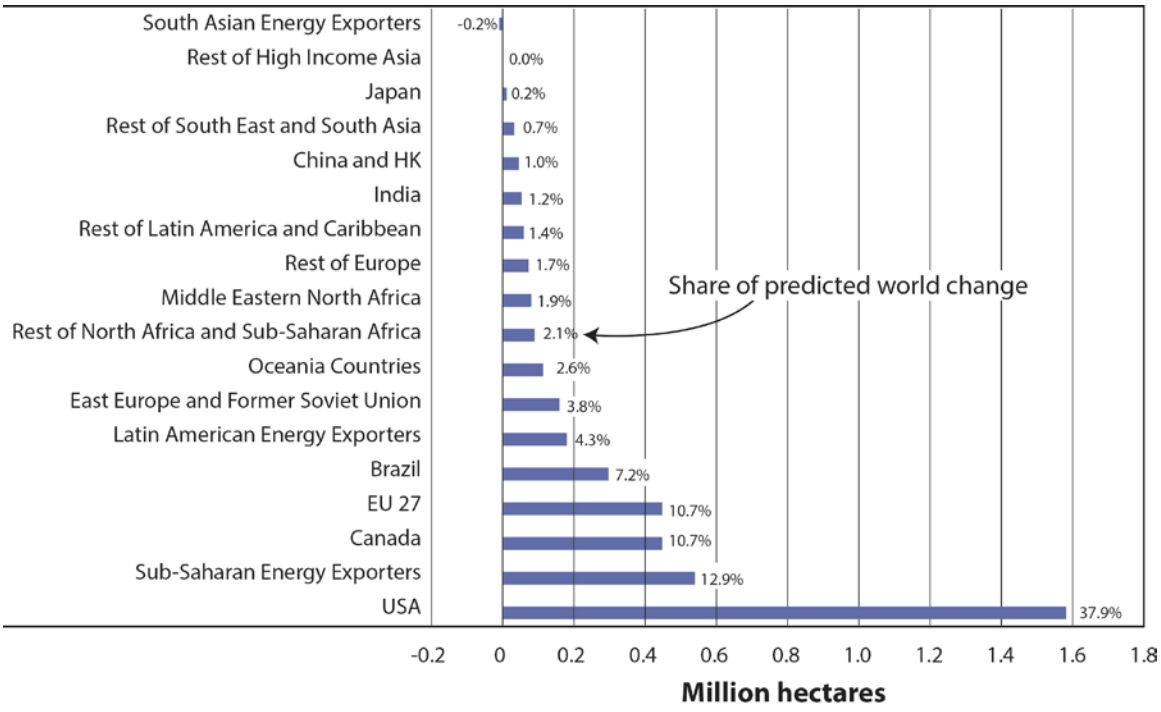


**Figure 11. GTAP Predictions of Indirect Land Use Change from Corn Ethanol**
*Source*: Hertel et al. (2009)

this seems like a large over-prediction of the US contribution, it is not possible to say this prediction is inconsistent with the recent historical data given that we cannot observe what land use would have been without the price increase. However, for this prediction to be true, the fairly small price increase simulated by GTAP would have kept a sizeable amount of land in production in the United States.

As with the CARD-FAPRI model, GTAP over-predicts the land use change for Brazil relative to other Latin American countries assuming that the baseline in Hertel et al. (2009) shows Brazil's area increasing more than agricultural area in the rest of Latin America. This baseline level of data was not available for inspection but GTAP's baseline was developed using 2001 data that incorporates land use changes that occurred in previous years. Brazil's agricultural land was expanding in this prior period, so it is reasonable to assume that Brazil's land use in the baseline was increasing more than in

Figure 11 land use changes are consistent with those used by California. There exist many GTAP-based estimates of land use change due to biofuels. An alternative estimate was provided by Tyner (2010). First and Second Generation Biofuels: Economic and Policy Issues, Presented at the Third Berkeley Bioeconomy Conference, June 24, 2010, http://www.berkeleybioeconomy.com/wpcontent/uploads//2010/07/TYner%20Berkeley%20June%202010.pdf.

other South American countries. This would imply that the predicted change in Brazil relative to the rest of Latin America is too large.

Despite the large discrepancies between model predictions and the actual land use changes that have occurred since 2004 it simply is not possible to conclude with certainty that the model predictions have been proven wrong and should be disregarded. For example, the Hertel et al. (2009) prediction that large land use changes from output price increases resulting from US corn ethanol production would occur in the United States, Europe, and Canada seems inconsistent with the fact that cultivated land decreased in the EU and Canada and stayed constant in the United States despite price changes that were many times larger than those predicted by the model. However, it could be that the amount of actual land reduction that would have occurred in the EU and Canada would have been much larger without the commodity price boom and that if actual land use changes were calculated relative to what would have happened without the price impact then the GTAP model predictions would be consistent with what we observe. Thus, without being able to observe the alternative history that did not contain the commodity price boom, it is not possible to conclude with certainty that the model predictions are wrong. As Babcock (2009) pointed out, economists who run models to predict future land use changes are in the enviable position that skeptics of the predictions will find it difficult to use the actual land use change data to prove that the model predictions were wrong. However the historical record of land use changes can be used to provide insight into the types of land that were converted assuming that the model predictions are correct.

## Using the Historical Record to Guide Estimates of Land Conversion

Table 1 below presents some GTAP results that were used by California's Air Resources Board to calculate $CO_2$ emissions associated with land conversion due to corn ethanol production. By regressing emissions on the amount of land converted, it is possible to obtain a rough estimate of how each of the four land conversions affect estimated emissions separately. Table 2 provides the regression results.

An increase in land conversion increases GTAP's estimates of emissions. Conversion of a million hectares of forest increases emissions much more than conversion of pasture. How to interpret these coefficients is that a one million hectare increase in, for

**Table 1. GTAP Model Predictions of Land Conversion and Associated GHG Emissions**

| | Forest Converted | | Pasture Converted | | |
|---|---|---|---|---|---|
| **Scenario** | **U.S.** | **ROW[a]** | **U.S.** | **ROW** | **LUC Emissions** |
| | *million hectares* | | | | *$gCO_2e/MJ$* |
| A | 0.70 | 0.34 | 1.04 | 1.96 | 33.6 |
| B | 0.36 | 0.01 | 0.79 | 1.53 | 18.3 |
| C | 0.82 | 0.64 | 1.19 | 2.83 | 44.3 |
| D | 0.81 | 0.08 | 1.31 | 2.34 | 35.3 |
| E | 0.48 | 0.52 | 0.66 | 1.35 | 27.1 |
| F | 0.46 | 0.27 | 1.00 | 2.10 | 27.4 |
| G | 0.40 | 0.15 | 0.92 | 2.18 | 24.1 |

*Source:* Provided by staff at the Renewable Fuels Association
[a]ROW means Rest of World

**Table 2. Impact on $CO_2$ Emissions of a Million Hectare Increase in Land Conversion**

| **Land Type Converted** | **Impact on Emissions** |
|---|---|
| | *$gCO_2e/MJ$* |
| US Pasture | 6.17 |
| ROW Pasture | 3.08 |
| US Forest | 22.69 |
| ROW Forest | 14.41 |

*Source:* Estimated from Table 1.

example, US pasture to crops, leads to a 6.17 increase in emissions measured by grams $CO_2$ per MJ of gasoline energy replaced by corn ethanol. Across all seven scenarios the average prediction of forest conversion in the United States is 0.58 million hectares.

Multiplying 0.58 by 22.69, which is the coefficient relating conversion of forest to emissions, results in an estimate of the average contribution of US forest conversion to the final $CO_2$ emission number. The result is that GTAP estimates that conversion of US forests contributes 13.06 $gCO_2/MJ$ or 43% of total estimated emissions.

As shown in Figure 8, US cropland did not appreciably increase at the extensive margin in response to higher prices on average in 2010–2012 relative to 2004–2006.[10] As

[10] A more detailed examination of US data is provided in the next section, which shows there is some evidence of an increase in planned area to be planted from 2007 to 2013. The 2004–2006 and 2010–2012 time periods were used to make US data consistent with available data for other countries.

discussed in the previous section, it is not possible to conclude whether the GTAP model prediction that US cropland would be 1.6 million hectares higher due to higher prices is inconsistent with what actually happened, because it could be that US cropland would have declined from 2004 to 2012 if the higher prices had not occurred. For example, if US cropland would have declined by 5 million hectares if the high prices had not occurred, then the GTAP prediction that 1.6 million of these hectares would have been kept in production is consistent with the historical record. More formally, a necessary condition for consistency of the model prediction of an increase in US cropland due to higher prices is that US cropland would have declined by at least the amount of the model prediction were it not for the higher prices that actually occurred.

So suppose that there would have been a 5 million hectare decline in US cropland were it not for the higher prices and the GTAP prediction is correct that 1.6 million hectares of this land would have been kept in production because of higher prices caused by corn ethanol production. This means that the type of land converted to accommodate biofuels was not forest or pastureland but rather cropland that did not go out of production. Calculation of foregone carbon sequestration depends on what would have happened to the cropland if it did not remain in crops which, in turn, depends on where the cropland is located and the potential alternative uses. The magnitude of the change in estimated $CO_2$ emissions from cropland that is prevented from going out of production relative to forest that is converted to cropland is potentially large. For example, from Table 2, converting one million hectares of grassland instead of forest would reduce land-based $CO_2$ emissions by 11.3 $gCO_2e/MJ$ in the rest of the world and by 16.5 $gCO_2e/MJ$ in the United States. If foregone carbon sequestration is less than the amount of carbon lost from converting pasture to crops then the magnitude of the emission reduction would be larger.

The countries in Figure 8 that either had negligible or negative extensive land use changes should be presumed to not have converted pasture or forest to crops in response to biofuel-induced higher prices. Rather, the presumption should be that any predicted change in land used in agriculture came from cropland that did not go out of production. From Figure 11 this would include Canada, the EU, Russia, the Ukraine, and India.

The countries in Figure 8 that had significant extensive land increases cannot be presumed to have only kept cropland in production because of biofuels. Whether the

expanded cropland due to the portion of the actual price increase attributable to biofuels expansion came from cropland that would have gone out of production or from pasture is an accounting decision. For these countries that expanded extensive land use, the historical pattern of where in the country the land use expansion occurred provides insight into the type of land that was converted to crops.

Brazil is one country that expanded extensive land use and has data on where this expansion occurred. Figure 12 shows each state's share of extensive land use change in Brazil measured by the change in the 2010–2012 average from the 2010–2012 average.[11] Not surprisingly extensive land use increased the most in Mato Grosso. Expansion of sugarcane area in Sao Paulo explains its increase. The states of Goias, Maranhao,

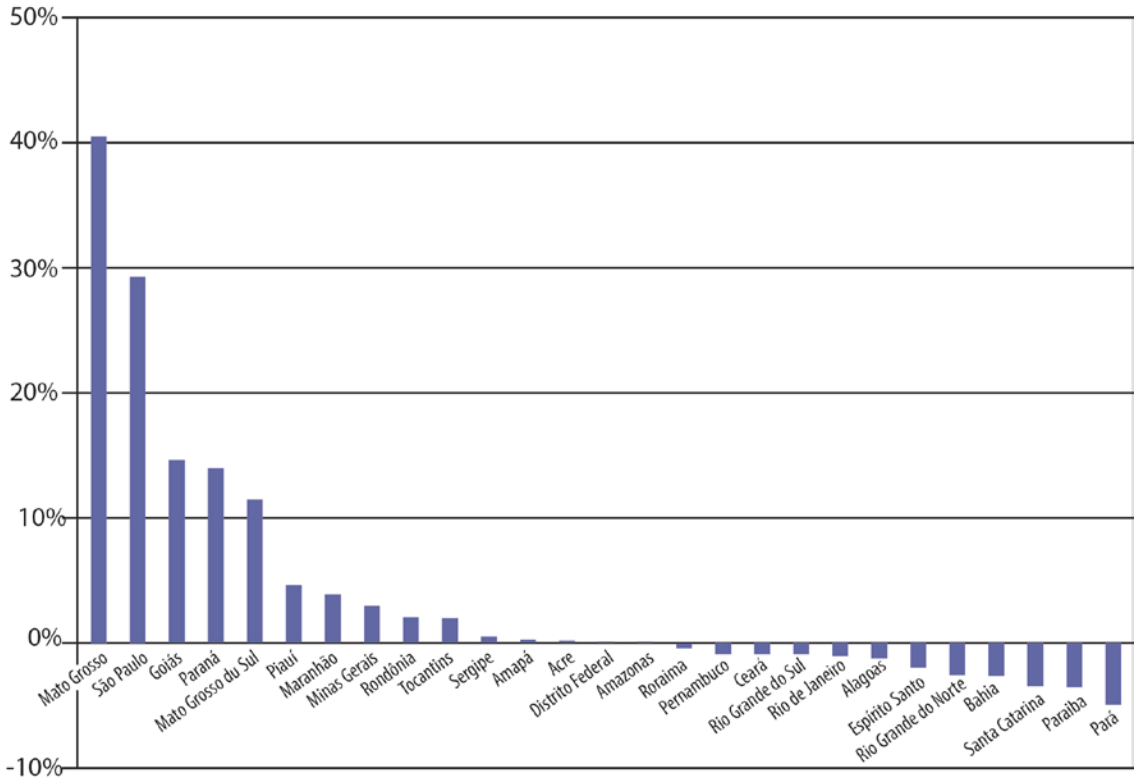


**Figure 12. State Share of Brazil's Change in Extensive Land Use from 2004–2006 to 2010-2012.**

[11]Only land that was planted to crop was considered in calculating each state's share of extensive land use change. The cropland planted data comes from the IBGE website: http://www.sidra.ibge.gov.br/bda/acervo/acervo9.asp?e=c&p=PA&z=t&o=11. Total planted cropland in Brazil is less than FAOSTAT data on arable land plus permanent crops that was used to determine extensive and internsive land use changes in Figure 10 and 11.

Tocantins, and Piaui all have large land areas in the vast Brazilian Cerrado biome which has also seen large-scale development (The Economist). Rondonia is the only state in the Amazon biome that shows an increase in cropland. Where cropland has expanded in Brazil (and in other countries where data allows) can be used as a guide to determine if model predictions of the type land converted are accurate.

## A More Detailed Look at US Extensive Area Data

Figure 13 shows what has happened to one measure of US cropland from 1993 to 2013. This measure is area planted to US principle crops as measured by USDA-NASS, less double cropped harvested area, plus fallow cropland. This measure reached its peak in 1996. In 2007, this measure increased after a long downturn, suggesting some impact of higher prices. However, in 2010 it fell below 130 million hectares before increasing in 2011 and 2012. It is somewhat surprising that total land in agriculture has not increased more than indicated since 2006 because land enrolled in the Conservation Reserve

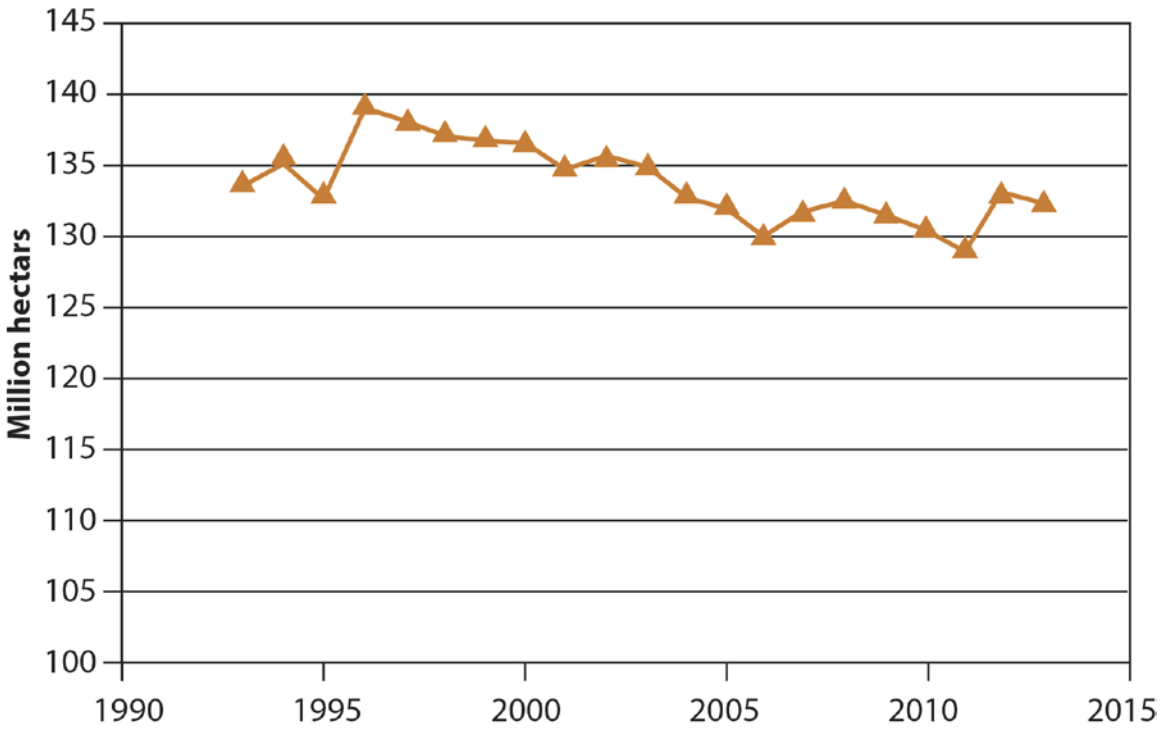


**Figure 13. US Cropland Since 1993**

Program (CRP) declined by 4 million hectares from 2007 to 2013. One explanation for a lack of response in this measure of land use could be an increase in area that is reported as prevented planting area.

The US crop insurance program creates an incentive for farmers to report area that they had planned to plant but were not able to due to adverse weather. This land is called prevented planted acres. Farmers who buy crop insurance receive a crop insurance payment on these acres. Aggregate data on the amount of prevented planted acres can be added to the Figure 13 data to measure how much land US farmers intend to plant each year. Data on the area designated as prevented planting area are available since 2007.[12] Figure 14 shows the change in CRP land since 2007 (grey line), the change in US cropland since 2007 (blue line calculated from Figure 13), and the change in intended planted land since 2007 (orange line). It is striking how close the change in intended

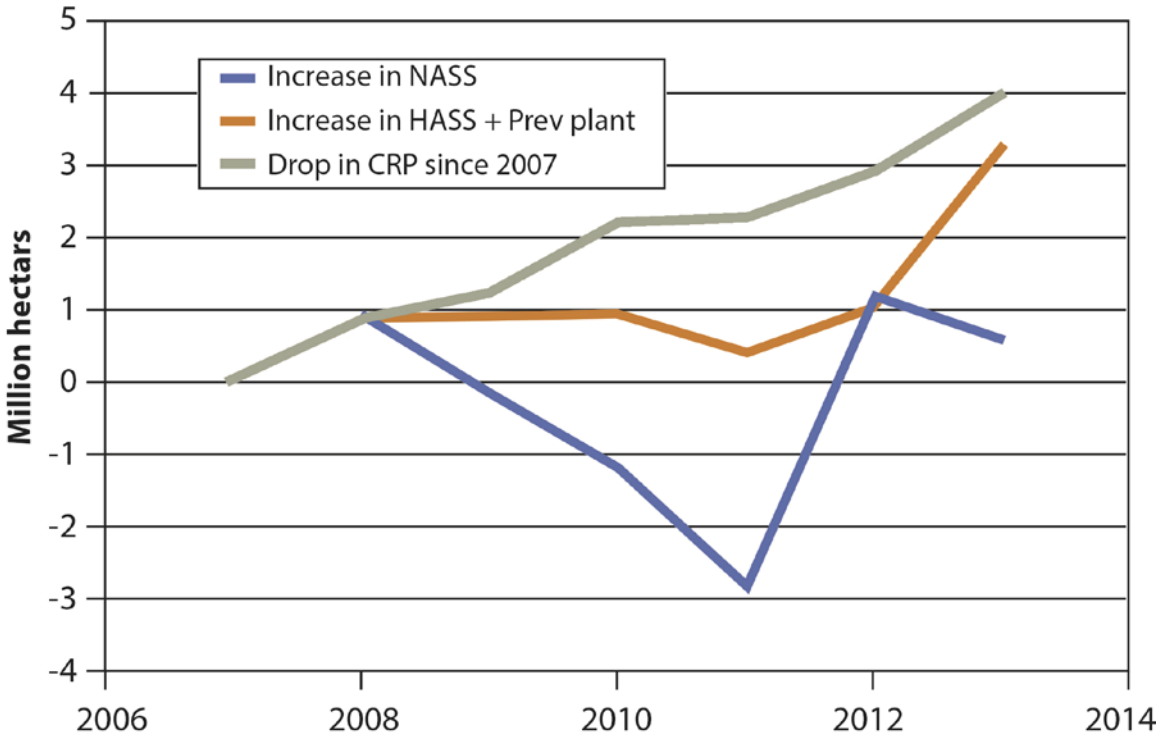


**Figure 14. CRP Land Showing up as Increased Prevented Planting Acres**

[12] Prevented planting has been part of the US crop insurance program before 2007 but data on total area designated as prevented planting are not readily available.

planted land is to the reduction in CRP, and it is also striking how little of the land that is no longer enrolled in CRP shows up as land in production.

What can be concluded from this more detailed examination of extensive land use in the United States is that the data seem to indicate a reversal of a long-term trend of declining total US cropland since 1996 beginning in 2007—the first crop planted in response to significantly higher prices for US corn and soybeans. The large reduction in land enrolled in CRP is much greater than the amount of land that is reported as being in productive use in crop production. This suggests that there is an abundance of ex-CRP land that is available for planting or that a large proportion of ex-CRP land has not yet been available for crop production and is being reported as having been prevented from being planted. The data are consistent with any increase in extensive land use since prices increased in 2006 as coming from a stock of available land that had been planted to crops previously or from land that was enrolled in CRP. This finding is consistent with USDA (2013), which found that the only net contributor to US cropland from 2007 to 2010 was a reduction in CRP land. There was no net increase in cropland from conversion of forests, from conversion of urban land, or from conversion of pasture.

## Conclusions

That countries primarily responded to higher world prices by intensifying land use rather than by converting land from forests and pastures should not be surprising. Many countries, such as China and India, simply do not have available land to bring into agriculture. In countries with land suitable for crops, the investment and other transaction costs of developing new land make the process quite costly relative to the cost of increasing the intensity of land use. In addition, the value of waiting to invest in land conversion projects is large, which leads to a significant delay in land conversions.

The pattern of recent land use changes suggests that existing estimates of greenhouse gas emissions caused by land conversions due to biofuel production are too high because they are based on models that do not allow for increases in non-yield intensification of land use. Intensification of land use does not involve clearing forests or plowing up native grasslands that lead to large losses of carbon stocks.

The recent data on land use changes reveals the importance of policy in determining land use decisions. In Argentina, higher export taxes and quotas on corn and wheat relative to soybeans caused soybean area to increase and wheat area to decrease. The drop in wheat area limits the availability of land on which soybeans can be double cropped which means that expansion of soybeans can only take place by replacing existing crops or by expanding onto new lands. In Brazil, increased enforcement of laws restricting clearing of forests and the resulting drop in the rate of deforestation is consistent with Brazil expanding land use at both the intensive and extensive margin.

It might be argued that recent data are a poor indicator of what we should expect to happen if more time passes because supply response is always larger in the long-run than in the short-run. Land conversion takes time but the time gap used here to measure land use change is long enough to allow a significant amount of change to happen. In addition, the incentive to expand agricultural supply between 2006 and 2012 was as strong as any period since at least 1960. Furthermore, if the recent sharp declines in commodity prices continue then the incentive to expand supplies in the future will be muted.

We plan on extending our analysis of land use changes by attempting to develop a statistical model to explain more systematically why some countries expanded land use more at the extensive margin and others expanded more at the intensive margin. Such a model could provide better insights into the role that policy, price transmission, and resource availability plan in determining agricultural supply response. Improved understanding could be useful to future attempts at estimating greenhouse gas emissions caused by extensification of agricultural production.

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FAO: Area harvested: http://faostat3.fao.org/download/Q/QC/E
FAO: Land Cover: http://faostat3.fao.org/download/R/RL/E
USA: USDA-NASS: http://quickstats.nass.usda.gov

# APPENDIX B:

Langeveld, J. W.A., Dixon, J., van Keulen, H. and Quist-Wessel, P.M. F. (2014), Analyzing the effect of biofuel expansion on land use in major producing countries: evidence of increased multiple cropping. Biofuels, Bioprod. Bioref., 8: 49–58. doi: 10.1002/bbb.1432.

Modeling and Analysis

Biofpr Biofuels Bioproducts & Biorefining

# Analyzing the effect of biofuel expansion on land use in major producing countries: evidence of increased multiple cropping

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Abstract: Estimates on impacts of biofuel production often use models with limited ability to incorporate changes in land use, notably cropping intensity. This review studies biofuel expansion between 2000 and 2010 in Brazil, the USA, Indonesia, Malaysia, China, Mozambique, South Africa plus 27 EU member states. In 2010, these countries produced 86 billion litres of ethanol and 15 billion litres of biodiesel. Land use increased by 25 Mha, of which 11 Mha is associated with co-products, i.e. by-products of biofuel production processes used as animal feed. In the decade up to 2010, agricultural land decreased by 9 Mha overall. It expanded by 22 Mha in Brazil, Indonesia, Malaysia, and Mozambique, some 31 Mha was lost in the USA, the EU, and South Africa due to urbanization, expansion of infrastructure, conversion into nature, and land abandonment. Increases in cropping intensity accounted for 42 Mha of additional harvested area. Together with increased co-product availability for animal feed, this was sufficient to increase the net harvested area (NHA, crop area harvested for food, feed, and fiber markets) in the study countries by 19 Mha. Thus, despite substantial expansion of biofuel production, more land has become available for non-fuel applications. Biofuel crop areas and NHA increased in most countries including the USA and Brazil. It is concluded that biofuel expansion in 2000–2010 is not associated with a decline in the NHA available for food crop production. The increases in multiple cropping have often been overlooked and should be considered more fully in calculations of (indirect) land-use change (iLUC). © 2013 Society of Chemical Industry and John Wiley & Sons, Ltd

Keywords: biofuels; land use change; iLUC; food vs. fuel; ethanol; biodiesel; co-products; Brazil; USA; EU; China.

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## Introduction

Increased biofuel production has led to criticism and concerns about food availability while it is feared that rising demand for cropland will lead to deforestation, grassland conversion and increased Greenhouse Gas (GHG) emissions from these land use changes. The main criticism is based on expected impacts of biofuel production following the introduction of dedicated biofuel targets and policies.[1–3]

Commonly used economic models in biofuel policy evaluation include multimarket partial equilibrium models such as the FAPRI-CARD, ESIM, and IMPACT model, and computable general equilibrium (CGE) models such as the Global Trade Analysis Project (GTAP), LEITAP and the Modeling International Relationships in Applied General Equilibrium (MIRAGE) model. Most models were originally developed to evaluate agriculture or climate policies and were later adapted to incorporate biofuel production.[4–6] This has consequences for the way the models have been implemented. Early applications, for example, did not consider generation of co-products (by-products of the biofuel production process which are mostly used as animal feed)[1,7] while second-generation biofuel production technology, at least in early applications, was not included.[4]

Other restrictions include limited ability to adjust to accelerations in yield improvement[7] or to changes in crop rotation.[9] Most models do not consider double-cropping (cultivation of two or more crops on the same plot within a given year), while changes in fallow or other unmanaged land can only be accommodated to a limited extent,[8] which is considered a significant drawback of model results.[7] Changes in programs offering farmers compensation for not cultivating arable land (Conservation Reserve Program (CRP) in the USA and Set-Aside in the EU), for example, were often not adequately represented. Further, models do not fully incorporate impacts of trade policies (e.g. preferential biofuel imports[8]), crop tillage,[10] or agro-ecological conditions in crop production areas.

While the exact consequences of these limitations remain unclear, there is a risk that relevant changes in crop production patterns, partly triggered by biofuel policies, may not be sufficiently covered in the analysis. Scenarios for future crop production published by the Food and Agriculture Organization (FAO) suggest that increasing cropping intensity will be an important source of additional crop biomass. According to Nachtergaele *et al.*,[11] cropping intensity is projected to increase by a total of 4% in developing countries between 2006 and 2050. For developed countries, however, the forecast increase is 7%. Global average is projected to increase by 6%.

Central to the debate on the impact of biofuel production is the question to what extent current policies are causing alienation of land from food and feed production. At the core is the way increased biomass requirements are to be met by area expansion, yield improvement or by increased cropping intensity. Bruinsma[12] estimated that 80% of the projected growth in crop production in developing countries up to 2050 would come from intensification in the form of yield increases (71%) and higher cropping intensities (8%). Higher shares are projected in land-scarce regions such as South Asia and the Near East/North Africa where increases in yield would need to compensate for the expected decline in the arable land area. Arable land expansion will remain an important factor in crop production growth in many countries of sub-Saharan Africa and Latin America; although less so than in the past.

Given the large (albeit possibly temporary) increases in crop prices, the general expectation that biofuels will permanently push up demand for food crop biomass plus the fact that farmers in the past have shown to be able to respond effectively to changes in crop demand might have to be moderated. Especially the projected increases in cropping intensity may be on the low side. Using data for 1962–2007, OECD-FAO[13] for example calculated that half of the realized increases in the harvested area were attributable to increased cropping intensity (the other half have been related to area expansion).

More recently, reduction of (fodder and) CRP area and increased double-cropping have been reported for the USA.[14] For example, about 16% of 2008 corn and soybean farms had brought new acreage into production since 2006. This new, formerly uncultivated, land accounted for approximately 30% of the reported farm's expansion in total harvested acreage. Most acreage conversion came from uncultivated hay. Some 15% of corn and soybean farms reported a harvested acreage (summing up all crops) exceeding their arable area in 2008, implying an increase in double-cropping. These farms reported greater expansion in harvested biofuel crop acreage than other farms, suggesting double-cropping is a quick and effective strategy to generate additional biofuel crop biomass.

Given the above limitations, economic model impact assessments of biofuel policies should be considered with care. Consequences of the limitations on the modeling outcome are difficult to assess but they may be considerable. The introduction of co-products in a GTAP evaluation of US and EU biofuel policies, for example, was

 

assessed to reduce the need for land conversion with 27%.[6] According to Croezen and Brouwer,[15] scenarios including second-generation biofuel technologies resulted in land-use requirements that were 50% lower as compared to scenarios which did not include lignocellulosic biofuel conversion technologies.

In summary, the use of estimates of biofuel scenarios based on incomplete information could generate misleading estimates. Another risk is the inadequate input use, which could give an incorrect impression with respect to day-to-day crop management practices such as input use efficiency. Consequently, perspectives for (sustainable) biomass production for biofuel and food/feed applications may be estimated incorrectly.

With a view to improving the accuracy of data for evaluations of biofuel policy impacts, this paper assesses data from different sources of biomass production of eight major biofuel producers. We analyze biofuels and feedstock increases of major biofuel feedstocks between 2000 and 2010, and their impacts on land use in Brazil, the USA, the EU, China, Indonesia, Malaysia, South Africa, and Mozambique. Together, these countries represent a large majority of global biofuel production. Local conditions for crop and biofuel production will be described in a generalized way. In order to determine the impact of biofuel policies, production volumes will be compared to those of 2000, clearly before most countries introduced biofuel-related policy measures. An important distinction will be made between the amount of biomass (crop feedstocks) that is used to generate biofuels, the amount of land that is needed to produce the biomass, and the average number of harvests that can be generated from arable land (resulting from the prevalence of fallow and double-cropping in a given region). The paper will make use of the following concepts:

- Harvested area: the crop area that is harvested in a country or region in a given year. This differs from the amount of arable land, as land may be harvested several times, while fallow land is not harvested at all.
- Agricultural area in a given country or region. This includes arable land (cultivated with arable crops, i.e. food and feed crops), permanent grassland and agricultural tree crops (fruits, beverages, stimulant crops)
- Cropping intensity: the ratio of harvested crop area to the amount of arable land.*

The relation between these concepts is the following equation:

- Harvested area = arable area * cropping intensity (1)

In our analysis, we estimate land and biomass balances. Based on the volume of biofuels produced, the equivalent amount of biomass and the required area of land is calculated. These estimates are based on detailed material collected and analyzed for a book on biofuel crop production systems currently in preparation. The review is organized as follows. First, it describes available land resources in the study countries. Next, it presents biofuel production in 2010 which is compared to that in 2000. Implications of biofuel expansion for land use are given, as are other changes in land use that have been observed. This is followed by a discussion and some conclusions.

## Land resources

An overview of land cover and land use in the study countries is presented in Table 1. China, Brazil, and the USA are the largest countries, Brazil having the largest forest area (nearly 40% of the study countries total). Agricultural area is high in China, the USA and (on a relative scale) the EU, Mozambique, and South Africa. Most arable land is found in the USA, China, and the EU, permanent grasslands being important in China (hosting more than one-third of the study area grassland), the USA, and Brazil. We calculated cropping intensity, expressed as the sum of all harvested crop area during a given year divided by the total arable land (the Multiple Cropping Index or MCI). MCI was originally introduced as a measure for cropping intensity of tropical farming systems,[16] but can be calculated for temperate regions as well.[12] MCI in the study countries varies between 0.53 in South Africa, 1.45 in China. It is around 0.8 in Brazil, the USA, and the EU.

## Biofuel production

Sugarcane is the predominant feedstock for ethanol production in tropical regions (Table 2). In temperate areas, ethanol is mostly made from cereals (corn in the USA and China, wheat in the EU and China). Main biodiesel feedstocks are soybean (Brazil, USA), rapeseed (EU), and oil palm (Indonesia and Malaysia). There are other feedstocks of minor importance, such as castor beans in Brazil, sunflower in the EU and Jatropha in Mozambique, but these are not included in the analysis.

Large differences exist in the way fields are prepared for biofuel production. There are a number of practices which

*Note: this is not similar to the intensity of crop production (amount of inputs used per ha or amount of yield realized per ha).

 

**Table 1. Land cover and land use (million ha).**

| Region | Land area | Forest | Agricultural area | Permanent grassland | Arable area | Multiple Cropping Index (-) |
|---|---|---|---|---|---|---|
| Brazil | 846 | 520 | 273 | 196 | 50 | 0.86 |
| USA | 914 | 304 | 411 | 249 | 160 | 0.82 |
| EU | 418 | 157 | 187 | 68 | 107 | 0.84 |
| Indonesia and Malaysia | 214 | 115 | 62 | 11 | 25 | 1.21 |
| China | 933 | 207 | 519 | 393 | 111 | 1.45 |
| Mozambique | 88 | 39 | 49 | 44 | 5 | 1.08 |
| South Africa | 121 | 9 | 97 | 84 | 13 | 0.53 |

Source: FAOSTAT (2013).[18]

**Table 2. Biofuel production chains included in the analysis.**

| Region | Feedstock | Biofuel | Field preparation | Input use |
|---|---|---|---|---|
| Brazil | Sugarcane | Ethanol | Pre-harvest burning is phased out | Moderately low |
| Brazil | Soybean | Biodiesel | Mostly no-till | Low |
| USA | Corn | Ethanol | Mostly plowed | High |
| USA | Soybean | Biodiesel | Half under no-till | Moderately low |
| EU | Wheat | Ethanol | Plowing | High |
| EU | Rapeseed | Biodiesel | Plowing | High |
| EU | Sugarbeet | Ethanol | Plowing | Moderately high |
| Indonesia and Malaysia | Palm oil | Biodiesel | Pre-harvest burning | Moderately low |
| China | Corn | Ethanol | Plowing | Very high |
| China | Wheat | Ethanol | Plowing | Very high |
| Mozambique | Sugarcane | Ethanol | Pre-harvest burning | Moderately high |
| South Africa | Sugarcane | Ethanol | Pre-harvest burning | High |

determine the performance of the biofuel production chain including pre-harvest burning of sugarcane leaves and plowing for arable crops. Burning leaves of sugarcane is common practice before manual harvesting in order to avoid injuries to laborers. This causes a considerable loss of leaf material and soil organic matter, while emissions of particulate matter cause a threat to the laborers' lungs. This practice is gradually being phased out in Brazil where mechanical green harvesting is becoming more common. Plowing arable fields, causing loss of soil carbon, is common in the EU and in China, but less so in the Midwest of the USA and soybean cultivation in Brazil, who have adopted conservation agriculture. Use of fertilizers and agro-chemicals is highly variable. Input use in feedstock production is low to moderately low in Brazil and in the USA (corn), Indonesia, Malaysia and Southern Africa. It is high in the production of cereals (USA, EU, and China) and rapeseed. Sugarbeet holds an intermediate position.

The main output data are presented in Table 3. Crop yield is high for sugarcane (Brazil, South Africa), sugarbeet, and oil palm. Cereal yields are high for corn in the USA, but less so for corn and wheat in the EU and China. Rapeseed and soybean yields are modest. Ethanol yields are highest for sugarbeet, and sugarcane (Brazil). Highest biodiesel yields were observed for oil palm (Indonesia, Malaysia). Generation of co-products is also quantified, as these can be applied in the livestock industry. Major biofuel crops are well established feed crops, which holds especially for corn and soybean. Co-products considered in this study include dried distillers' grains with solubles (DDGS), soy meal, rapeseed meal, beet pulp, and palm meal. It was decided to use a simple mass balance approach to distinguish between crop biomass used for biofuel production and for feed applications. Biofuel land claims were calculated by allocating a share of total land use according to the ratio of total crop feedstocks used for biofuels. Co-product yields were calculated using conversion data and converted into tons per ha equivalent

 

**Table 3. Crop, biofuel and coproduct yields.**

| Region | Feedstock | Crop yield (ton/ha) | Biofuel yield (l/ha) | Biofuel yield (GJ/ha) | Co-product yield (ton/ha) |
|---|---|---|---|---|---|
| Brazil | Sugarcane | 79.5 | 7200 | 152 | – |
| Brazil | Soybean | 2.8 | 600 | 18 | 1.8 |
| USA | Corn | 9.9 | 3800 | 80 | 4.2 |
| USA | Soybean | 2.8 | 600 | 18 | 1.8 |
| EU | Wheat | 5.1 | 1700 | 37 | 2.7 |
| EU | Rapeseed | 3.1 | 1300 | 43 | 1.7 |
| EU | Sugarbeet | 79.1 | 7900 | 168 | 4.0 |
| Indonesia and Malaysia | Palm oil | 18.4 | 4200 | 90 | 4.2 |
| China | Corn | 5.5 | 2200 | 46 | 2.9 |
| China | Wheat | 4.7 | 1700 | 36 | 2.5 |
| Mozambique | Sugarcane | 13.1 | 1100 | 23 | – |
| South Africa | Sugarcane | 60.0 | 5000 | 107 | – |

Source: crop yields calculated from FAOSTAT (2013),[18] biofuel and co-product yields calculated from literature.

which allows better comparison. Co-product yields are high for corn (USA), oil palm, and sugarbeet. Yields are low for rapeseed and soybean, while no co-products for the food or feed market are generated by sugarcane-ethanol.

Ethanol production in the study countries, amounting to 17 billion litres in 2000, rose to 86 billion litres in 2010 (Table 4). Most of the increase was realized in the USA, which was responsible for a production of 50 billion litres in 2010. Brazil is the second-largest producer with 28 billion litres, followed by the EU and China. Increases have been relatively high in China, the USA, and the EU. Biodiesel production rose from 0.8 to 15 billion litres. The EU is the highest producer, followed by Brazil and the USA. Indonesia, Malaysia, Mozambique, or South Africa are not producing significant amounts of biofuels, although they may be important producers in their respective regions. Biofuel production in the study countries (86 and 15 billion litres of ethanol and biodiesel, respectively) represents 97% and 77% of the global total production level. Thus, conclusions of global significance can be drawn from the analysis of the study countries.

**Table 4. Biofuel production in the study countries (billion l).**

| | Ethanol | | | Biodiesel | | |
|---|---|---|---|---|---|---|
| | 2000 | 2010 | Increase | 2000 | 2010 | Increase |
| Brazil | 9.7 | 27.6 | 17.9 | Neg. | 2.1 | 2.1 |
| USA | 6.1 | 49.5 | 43.4 | Neg. | 2.1 | 2.1 |
| EU | 1.5 | 6.4 | 4.9 | 0.8 | 10.3 | 9.5 |
| Indonesia and Malaysia | N.i. | N.i. | N.i. | Neg. | 0.2 | 0.2 |
| China | Neg. | 2.1 | 2.1 | Neg. | 0.4 | 0.4 |
| Mozambique | Neg. | 0.02 | 0.02 | Neg. | 0.05 | 0.05 |
| South Africa | Neg. | 0.02 | 0.02 | Neg. | 0.05 | 0.05 |
| *All* | 17.3 | 85.6 | 68.3 | 0.8 | 15.1 | 14.3 |

Notes: N.i. = not included; Neg. = negligible.

## Land use

Land used for biofuel expansion was calculated by dividing increased biofuel production presented in Table 4 by biomass to biofuel conversion rates taken from literature. Since 2000, biofuel expansion in the study countries has claimed an additional 25 million ha of cropland (Table 5). As 11 million ha is allocated to co-products, net biofuel expansion amounts to 14 million ha. Over 85% of area expansion occurred in the USA, where increased biofuel production has occupied over 5 million ha, and in the the EU and Brazil. Co-product generation is relatively high in the USA and the EU. The main crops used to produce biofuels (corn, wheat, soybean, and rape), are dominant feed crops whose nutritive characteristics have long been known. Low co-product ratio in Brazil is explained by the high share of sugarcane, whose residues are mostly used in the production of biofuels or electricity (co-generation). Vinasse is recycled and used as fertilizer.

Since 2000, countries of the study area have seen a net decline in agricultural area by 9 million ha. Loss of agricultural area in the USA, the EU, China, and South Africa amounted to 31 million ha, which is mostly compensated

 

**Table 5. Net changes in land availability.**

| | Increased land requirement (mln ha) | Associated with co-products (mln ha) | Net biofuel area increase (mln ha) | Changes in agricultural area (mln ha) | Extra harvested area due to increased MCI (mln ha) | Change in NHA (mln ha) |
|---|---|---|---|---|---|---|
| Brazil | 4.9 | 1.8 | 3.1 | 12.0 | 4.9 | 13.8 |
| USA | 11.0 | 5.9 | 5.1 | –3.5 | 10.9 | 2.3 |
| EU | 6.6 | 3.2 | 3.4 | –11.5 | 3.6 | –11.2 |
| Indonesia, Malaysia | 0.02 | 0.01 | 0.01 | 8.9 | 2.0 | 10.9 |
| China | 2.2 | 0.4 | 1.8 | –13.4 | 20.3 | 5.1 |
| Mozambique | 0.13 | 0.03 | 0.1 | 1.3 | 0.9 | 2.0 |
| South Africa | 0.12 | 0.04 | 0.1 | –2.7 | –1.2 | –4.0 |
| All | 24.9 | 11.4 | 13.5 | –9.0 | 41.5 | 19.0 |
| Global total | | | | –47.8 | 91.5 | |

by expansion of agricultural land in Brazil (plus 12 million ha), Indonesia/Malaysia (plus nine million ha), and Mozambique. Net global loss of agricultural area amounted to 48 million ha. In many cases, loss of agricultural area has been much larger than net expansion of biofuel area. This was the case in the EU, China, and South Africa. It is only in the USA that biofuel expansion is the dominant cause of agricultural land use loss.

Increasing the cropping frequency on arable land – reflected by an increase of the MCI – allows farmers to increase the harvested area on shrinking agricultural areas. This has facilitated *additional* crop harvests equivalent to 42 million ha. More than half of this expansion was realized in China, where government policy has been oriented toward improving (maintaining) food production capacity. MCI also added considerable harvested areas in the USA, Brazil, the EU, Indonesia, and Malaysia. The role of MCI in improving agricultural output since 2000 can hardly be overemphasized. Global increases, equivalent to 92 million ha of harvested crops, have been more than sufficient to compensate for losses of agricultural area.

Improvement of MCI in all but one case is more than sufficient to compensate for expansion of biofuel area: this is the case in Brazil (where MCI generated 5 million ha while biofuels required 3 million ha – a positive balance of nearly 2 million ha), the USA (11 *vs.* 5 million ha), EU (0.2 million ha balance), Indonesia/Malaysia (plus 2 million ha), China (19 million ha) and Mozambique (0.8 million ha). South Africa, which noted a decline of MCI, is the exception to the rule of increased cropping intensity.

The combined effect of biofuel expansion, changes in agricultural area, and improvement of MCI generally is positive. Together, countries included in the study increased harvested area for non-biofuel purposes of 19 million ha. This increase allowed improved availability of crop production for traditional food, feed, and fiber (FFF) markets. Net FFF area increased in most of the cases, except for the EU and South Africa.

## Discussion

Following changes in biofuel policies in the course of the first decade of the twenty-first century, a strong expansion in biofuel production was observed in the USA, the EU, China, and many other countries. The 34 study countries realized an increase in ethanol production of 68 billion litres and 14 billion litres of biodiesel in 2010 as compared to 2000. These increases, however, were not sufficient to fully satisfy biofuel policy objectives in the USA and the EU. China, Indonesia, and Malaysia have adjusted policies in response to substantial consumption of food cereals and high palm oil prices, respectively. For the near future, further expansion of biofuel production is expected especially in the USA, Brazil, Argentina, and the EU. Smaller, but significant, development may be expected elsewhere.

Land devoted to biofuel production was calculated at 32 million ha in 2010, an increase of 25 million ha as compared to 2000. Of this increase, 11 million ha can be allocated, using standard conversion rates, to co-products. This means that nearly half of the increase in biofuel area in fact is used to generate crop biomass for the livestock feed market. Clearly, ignoring co-product generation in early biofuel impact assessments has led to an overestimation of land requirements, in most cases by 40% or more. The contribution of feed co-products is relatively high in the USA, China, and the EU due to the large share of cereals with high feed yields. It is low in Brazil where ethanol production is dominated by sugarcane which generates no

 

feed co-products. However, it should be noted that the co-generation of electricity from sugar cane residues has not been included in the calculations.

Biomass used for biofuel production, calculated from biofuel literature and FAO statistics, amounted to 527 million ton in 2010. This is an increase of 334 million ton, of which 80 million tons is for co-product generation. Biofuel expansion therefore required 254 million tons of crops. Area expansion, amounting to 25 million ha (including co-products), has been relatively stronger due to a shift from high yielding (ton per ha) sugarcane to cereals like corn and wheat and to oil crops like soybean and rapeseed all which have much lower yields than sugarcane. Implications for land use will, however, also depend on the role of yield improvement. In literature, different assumptions on yield improvement can be found. For US corn, for example, Searchinger *et al.*[19] assumed a maximum of 20% yield improvement in 30 years. Others have suggested that a considerable share of corn used in biofuels in the USA could be generated by yield improvements.[20] One should be extremely careful comparing crop yields as these tend to show large year-to-year variations. However, US corn yields calculated from FAOSTAT data suggest that a significant part of these yield improvements already has taken place between 2000 and 2010. Indicative yield improvements (3-year averages) during this period of sugarcane in Brazil and wheat in the EU have been 17% and 11%, respectively.

The changes in land use that were reported are most revealing. The loss of agricultural area due to urbanization, etc., in industrial countries (USA, EU, South Africa) is two times larger than biofuel expansion (31 *vs.* 14 million ha). Expansion of agricultural area in other countries (Brazil, Indonesia, Malaysia, and Mozambique) amounted to 22 million ha. Changes in intensification of arable cropping are even larger. On a global scale, the MCI increased by 7% in a period of ten years. This may not seem high, but as it applies to an area of 1.4 billion ha, the implications are enormous. In the study area, improvement of cropping intensity has been variable. It rose by 14% in China, 10% in Brazil and Mozambique, and 4% in the EU. Other countries take an intermediate position.

For the entire study area, 42 million ha of crop harvested area has been generated. Consequently, the reduction of unutilized arable land (CRP in the USA, set-aside in the EU plus fallow) and an increase in double-cropping has been sufficient to generate nearly three times the amount of biofuel land expansion. Both fallow reduction and double-cropping seem to have been largely ignored in the debate so far which is a serious omission. Improved MCI was identified as a major source of increased harvested area by OECD-FAO,[12] but the consequences for land availability vis-à-vis future biofuel expansion tend to have been overlooked. Bruinsma[11] focused mainly on yield improvement. Economic models used in evaluation of biofuel policies appear to have neglected the potential contribution of MCI.

In the future, MCI may be expected to show further increases. The magnitudes will, however, depend on crops and farming systems. Tropical regions have a larger potential for double-cropping (provided sufficient water is available). Cereals and pulses, having relatively short growing cycles, provide good perspectives. Sugarcane, occupying land year round, has limited potential for increased MCI. Climate change may, however, also offer new opportunities for temperate regions, for example, when temperatures in spring allow early harvesting of winter cereals.[17]

The approach that was followed has a number of advantages. Calculating full biomass balances allowed the assessment of biofuel feedstocks available for animal feed and – consequently – gives a realistic assessment of the amount of feedstocks required for biofuel production. Requirements of biofuel production for biomass and land resources were calculated with local data, thus incorporating a realistic assumption of cultivation practices, crop rotations, yields, and conversion efficiencies. The use of full land balances has put land demand for biofuels in perspective, integrating many processes which affect land requirement and changes in land use. Limitations of the approach are related to the large number of data that are needed. Data on crop rotations and cultivation practices often have a local nature which makes it difficult to obtain a more generic picture at the national level. Data on double-cropping and biomass to biofuel conversion are extremely difficult to obtain while the exact relation between biofuel production and increased MCI needs to be investigated. Calculations, finally, have been restricted to major biofuel feedstocks.

Notwithstanding these limitations, the implications of the findings are substantial. The impact of the increases in cropping intensity can hardly be overemphasized. On the one hand, observed MCI improvement since 2000 demonstrates that projected biofuel crop areas (estimated up to 50 million ha in 2050) can easily be compensated. In one decade, enhanced cropping intensity generated as much as 92 million ha of extra harvested crops worldwide. This is surprisingly high, and the consequences are clear. While biofuel production may occupy a significant amount of crop land in the future, there are strong drivers of crop area expansion which may be able to generate similar – or larger – additional harvested areas

 

in biofuel countries. Thus, there is little reason to expect that biofuel expansion will lead to substantial reductions of area of food/feed production. For the first decade of the twenty-first century, net harvested area for traditional (non-biofuels) biomass markets in the study area increased by 19 million ha.

The outcomes of this study are relevant to the debates related to biofuel production. Our review clearly shows that biofuel expansion has not been the major factor causing land-use change. Loss of arable land due to urbanization, etc., has claimed over twice as much land. This loss is almost certainly permanent, which is not the case for biofuel production. Further, increased intensity of arable land use has generated more than sufficient harvested area to fully compensate biofuel expansion. This makes claims of land-use changes caused by biofuel expansion (as caused by biofuel policies) less convincing.

Consider, for example, projected land use change caused by EU biofuel policies. In 2020, an additional area of 0.5 million ha has been projected to be devoted to biofuels in Brazil.[2] Only 15% of this is associated with deforestation. These are small figures, which suggest that the role of biofuel expansion as a major driving force for deforestation in Brazil needs to be reconsidered (26 million ha of forest was lost since 2000). Projected land-use change due to EU policies should also be compared to the increase of MCI observed in Brazil, generating almost (five million ha or) *ten* times the amount lost to EU biofuel exports in just one decade. In the light of these figures it is hard to imagine that biofuel policies alone are the dominant source of land-use change or deforestation.

The food *versus* fuel debate, further, needs to be enriched. While biofuel expansion in the study area has claimed 14 million ha of arable land, this area is more than compensated for by increased cropping intensity. FAOSTAT data clearly show that harvested area for food/feed markets has increased. They also show that biomass availability for food and feed applications has gone up. Further, it is not biofuel expansion but loss of agricultural land due to urbanization, etc., that is the major threat to land (biomass) availability. All this needs to be considered in the debate. The outcomes of this study show that it is essential for policy impact analyses to use statistical data to check model projections. Further, the analysis should be based on full – and not partial – biomass and land balances. Initial restrictions in model applications, ignoring co-product generation, seem to have given strongly misleading conclusions. Excluding double-cropping or cropping intensity in biofuel policy analysis has been another limitation which has had a major impact on the results. It is suggested, therefore, to incorporate local and national data on crop cultivation (e.g. crop rotations) in assessment studies of biofuel policies.

Keeney and Hertel[8] indicated that forecasting environmental impacts of biofuel policies requires both careful model formulation as well as sufficient empirical knowledge of supply and demand. Currently, only a few key parameters (e.g. yield elasticity, acreage response elasticity) determine the outcome of land-use change modeling studies. It should be checked to what extent popular analytical models correctly predicted adjustments in crop production and land-use practices. Essential elements that may have been lacking include changes in fallow and double-cropping, accelerations in yield improvement, and loss of agricultural land due to urbanization, infrasructure and industry.

Special attention is merited for cropping intensity, as well as non-biofuel crop yield improvement.[7] In this process, predicted changes in crop production and land use should be critically evaluated. Keeney and Hertel,[8] for example, predicted an increase of crop production to coincide with a reduction of forest and pasture areas in the USA, the EU, and Latin America. FAO statistics have shown that, during the last decade, forest area in the USA and EU has *increased* while grassland area remained constant in the USA and in Brazil.

The implication of this analysis for estimations of GHG emissions from biofuel production is potentially substantial. Very high assessments of carbon releases due to indirect land-use changes[2,18] have been used to underpin adjustments in biofuel policies in the EU. This review shows that a careful reconsideration of the generally assumed view that biofuels are important causes of indirect land use change is in place. Whereever feasible, this should be done using observed – rather than modeled – data.

## Conclusion

This review addressed the impact of increased biofuels production on land use in major biofuel producing countries using full land balances based on land and crop statistics. Biofuel expansion is often considered a major threat for biomass availability for food and feed production and an important source of land use change. However, this analysis based on FAO statistics on crop production and land use in the period 2000 to 2010 shows that the impact of biofuel expansion on land use has been limited. An increase of 14 million ha was noted in 34 major biofuel producing nations over a period of a decade.

 

During the same period, increased cropping intensity generated over 42 million ha of extra crop land – three times the biofuel expansion. Further, an area of 31 million ha of agricultural area was lost (amongst other due to urbanization) in the USA, the EU, China, and South Africa. Consequently, there are strong drivers for expansion of land availability for traditional food and feed markets which has led to increased food and feed crop area. With the exception of the USA, biofuel expansion has not made up more than a quarter of the total loss of agricultural land.

This information should be considered in discussions on food vs. fuel debate and land-use change caused by biofuel policies. Existing frameworks need to be reconsidered. For example, biofuels *cannot* be identified as the most important or single global cause of land-use change. Other drivers have caused more (and more permanent) loss of agricultural area including process of urbanization, infrastructure development, tourism and even conversion into nature (an additional 8 million ha of forest have been established in the USA and the EU since 2000). Observed changes in land use caused by biofuel policies are very small in comparison to other changes.

Models used to evaluate biofuel policies should be enriched by incorporating more and better information on (changes in) land use and local cropping patterns, as well as differences in current and potential productivities in different agro-ecologies and farming systems. Finally, the relation between increased multiple cropping and biofuel production should be further investigated.

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