Land cover types subgroup

Low carbon fuel standard (LCFS) Indirect land use change expert workgroup

A Report to the California Air Resources Board

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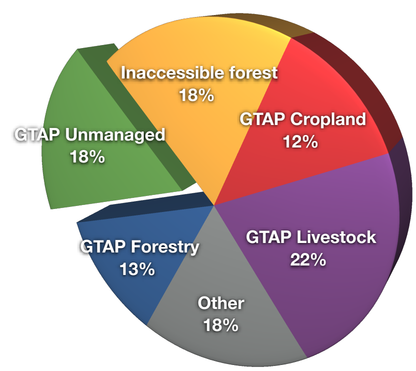
Executive Summary

Our workgroup assessed how the GTAP (Global Trade Analysis Project) model manages land cover conversions and surveyed existing data sources of land cover types and agricultural conversion pathways, environmental quality issues, and yields for newly converted lands. We used this analysis to develop recommendations for near-term modeling updates (within the next four months—led largely by California Air Resources Board (CARB) staff), short-term research (over the next year by CARB staff with some external assistance) and long-term research (requiring significant external assistance/expertise). Note that this is not a ranking of importance. We feel that all our recommendations are important for improving our estimate of carbon emissions associated with the indirect land use change (ILUC) impacts of biofuels. This report is the result of discussions within our subgroup, outside experts and the broader CARB expert working group.

Note that there are many versions of the GTAP model run by different groups using different input data and assumptions. Here we are referring to the GTAP output by Hertel et al. (2009) and the recent update by Tyner et al. (2010), which have both been considered by CARB as part of its implementation of the Low Carbon Fuel Standard (LFCS).

Key findings on land pools and conversion

The problem of unmanaged land. GTAP only considers economically active lands, which means it excludes lands deemed unmanaged/un-priced or inaccessible. This is problematic because cropland and pasture expansion could occur into either category. GTAP's unmanaged lands are 18% of the world's land area according to our preliminary calculations (see section 1.2). Unmanaged lands are particularly prevalent in Brazil and in the U.S., where they could provide a substantial land source for expanding croplands and pasture.



Redefining inaccessible forestland. GTAP's forestry land pool includes forests that are considered economically active and a portion of natural forests, and deems the remaining forests to be "inaccessible". More scrutiny is needed to determine if these forests are truly inaccessible. While forests in Canada's wilderness areas may well be out of reach from agricultural expansion, wild areas in the tropics are being gradually cut away as the agricultural frontier expands.

Refinement and expansion of land pool types. The coarse land pool categories currently in GTAP each contain a huge range of potential carbon emissions. Carbon stocks vary widely within land cover classes at the region/AEZ level. The biggest differences are found between different types of land cover such as forests (~100 to 400 tC/ha) and grassland (~5 to 50 tC/ha), but they also vary greatly within each class according to biophysical conditions and land use history. Wetlands and marginal lands should be explicitly considered. Marginal lands (lands with reduced productivity) are an important consideration because cultivation of these lands may be less likely to displace other land uses and has potential to increase carbon stores with dedicated management and appropriate production scenarios.

Understanding land conversion patterns. Assumptions about the type of land converted for expanding croplands – whether from forests or grasslands – have a huge impact on the estimates of carbon emissions from ILUC. GTAP estimates the supply of land across cropland, forestry, and grazing land (livestock sector) through a Constant Elasticity of Transformation (CET) supply function. Unfortunately, the parameters for this function have been determined using US data not readily extrapolated to other regions around the world.

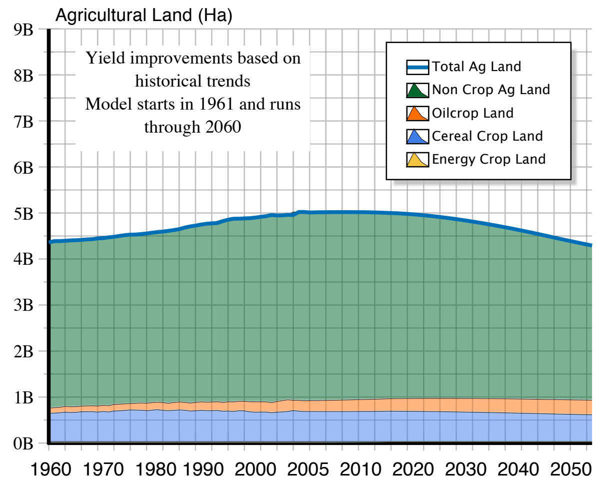
Translating GTAP CET allocations to specific ecosystem changes. The CET function estimates land transitions between the pasture, forestry and cropland categories, but does not estimate what type of forest is converted to cropland or grazing land (e.g., montane forest vs moist deciduous). GTAP currently uses the Woods Hole Research Center (WHRC) database to estimate the ecosystem types and associated carbon stocks. This database should be replaced with updated information from satellite-derived land cover maps such as the GLC2000 to estimate the area of different ecosystems. Important classes such as peatlands should also be added using higher-resolution information for critical regions.

Another key issue is estimating which ecosystem types are more likely to be cleared. It appears that GTAP currently assumes ecosystems are cleared relative to their availability (i.e. in proportion to their area). However, some ecosystem types may be more likely to be cleared than others. Available data should be used to estimate the conversion probability for the different ecosystem types.

Key findings on land yield impacts on land demand

Yield improvement effects on direct land use change. For existing crops—corn and soybeans in the US—the effect of future improvements in crop yields could range from relatively small to very large, depending on whose projection is to be believed. Historical data for yield trends of corn and soybeans suggest that these crops have shown persistent linear increases in yield in the US. In fact, these trends appear to be independent of actual market prices. Applying an exogenous linear yield change in the land use change estimates could easily capture the effect of this long-term trend on direct land use change due to US biofuels production from corn and soybeans. In fact, GTAP modelers in a recent analysis have used this approach for corn ethanol to capture both direct and indirect land use change effects of an exogenous linear global corn yield improvement trend.

Impact of overall agricultural productivity on indirect land use change. The current GTAP analysis used by CARB to estimate ILUC implicitly assumes that land supplies will be constrained and therefore all new biofuels demand will lead to land clearing. This assumption may be too limiting, and we recommend more consideration of the possibility that improved productivity in agriculture could lead to less or even no new land clearing, depending on whether this productivity improvement outpaces growing demand. Both the supply and the demand growth sides of the equation need further evaluation. Pasture intensification and animal production efficiency play the largest role in determining whether net land demand in the future continues to exceed existing supply or eventually declines. The chart on the right illustrates this point. It is based on modeled results for a scenario in which yield and demand trends from 1961 to 2005 are assumed to continue in the future (see section 3.3.4).



Crop yields on new land converted to agriculture. Previous GTAP analysis for CARB was based on the assumption that new land converted to agriculture would be one-third less productive than land already in production for a given crop. This is too crude an assumption to be applied across all land in all regions around the globe. Recent analysis by researchers at Purdue (Tyner et al 2010) has incorporated a new approach to estimating new land yields based on a natural ecosystem model. These results demonstrate the regional specificity of new land yields, and better represent potential yields. This approach still has significant limitations, particularly because it ignores the history of land management, which may lead to significant degradation of the land and loss of productivity. New data will soon be available from the University of Minnesota that may allow for a statistical analysis of regional yields and management practices. This data could provide a more transparent and reliable basis for estimating yields on new land.

Key findings on environmental quality aspects of land use change

Overlaying all of the considerations described in the previous section are set of environmental considerations that are not captured by the analysis of land availability, probability of conversion or potential yields. Many lands should be kept out of use on the basis of environmental factors, including existing soil quality, potential for soil erosion and biodiversity. While not directly relevant to calculating carbon emissions of land use change, these issues deserve explicit attention. Soil quality and erosion data are readily available in the US and have been used to establish criteria for removing land from agriculture under the Conservation Reserve Program. Less data is available for the rest of the globe. Nonetheless, exploring the available data and setting minimum environmental criteria for land availability should be a priority.

Recommendations Related to Land Pools and Conversion

Near-term:

- Update the GTAP land cover database using the most recent SAGE/M3 agricultural data and satellite-based land cover maps.
- Assess and improve methods to estimate the area of inaccessible forest, particularly in the tropics where the current approach is weakest.
- Update the area estimates for each ecosystem type using a satellite-based land cover map rather than the WHRC database. These should be coordinated with biomass (above ground) and soil (below ground) carbon estimates.
- Increase transparency and precision in defining the land database to clarify assumptions and data sources.

Short-term:

- Identify rough-cut conversion probabilities for ecosystem types using available data so that we can estimate the carbon stocks from land most likely to be cleared.
- Consider developing regional look-up-tables or modifiers that can help adjust CET function results and account for critical non-economic factors in specific regions.
- Estimate the proportion of total cropland that is idle/fallow/abandoned for each region.
- Consider methods to account for pasture intensification and price responses in Brazil.

Long-term:

- Investigate methods to improve CET function / land allocation that will account for regional differences and move beyond applying data for the U.S. to all regions.
- Refine conversion probabilities for ecosystem types by identifying those areas most likely to be cleared in each region to help improve estimates of carbon emissions
- Develop methods to allow GTAP to access some portion of the unmanaged land pool (i.e. grassland, shrubland, savanna)
- Address issues of marginal and underutilized lands within cropland, livestock and unmanaged land categories
- Consider adding a separate marginal land pool
- Develop estimates of forest accessibility for each region to refine the area of the forestry pool accessed in GTAP

Recommendations Related to Yields

Near-term:

- Correct the methodology used by GTAP modelers to permit an accounting for background yield changes. This can be done by exogenously including a time dependent yield trend in the analysis for corn, soybean and other major grain and oilseed crops.

- Animal production systems represent the largest agricultural land use. The uncertainty about future demand growth and future supply efficiency improvements for animal products is a critical problem for establishment of land use change impacts for biofuels. We therefore recommend that CARB study recent trends in pasture intensification and livestock production efficiency to better understand their role in future land use change.
- Adopt and where appropriate, modify the TEM approach used by Tyner et al 2010 for estimating AEZ-specific yields for new land pools brought into agriculture.

Short-term

- Adopt a modeling framework that allows for the dynamic nature of land use change. A dynamic model can fully incorporate time dependent changes such as technology driven yield improvements and food demand (influenced by the dynamics of economic and demographic change). This could be done using a dynamic version of GTAP.
- Evaluate alternative approaches to calculating yields on new agricultural lands based on statistical analysis of climate and management factors using updated datasets from Monfreda et al 2008.

Long-term

- Develop system dynamics models that can capture time and rate dependent effects.

Recommendations Related to Environmental Quality

Near-term:

- Begin defining in economic and environmental quality terms what could potentially qualify as “marginal” lands that could potentially be used in GTAP and how they would be accessed.

Short-term:

- Investigate what needs to be included and what can realistically be done to really improve the "detail" of the model, especially with respect to US production.
- Investigate what it would take for GTAP to incorporate environmental quality parameters and land cover types from SSURGO and the NLCD into the internal workings of GTAP.
- Get a much better definition of what does and what does not constitute 'marginal' acreage with respect to geo-climatic parameters as well as land-based agronomics.

Long-term:

- Determine how soybeans (and other crops) are accounted for in cropping rotations and moved into other land pools in GTAP and does their movement onto other lands make agronomic sense?

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1. GTAP land pools—types of land available for conversion

The area and types of land cover categories (i.e. land pools) available for conversion in GTAP have important implications for estimates of ILUC emissions. Here we focus on the GTAP land cover database described in Lee et al. (2005), which is used to estimate the area of the different land cover types considered by GTAP. We discuss the origins of the data, focusing on needed refinements and additions.

1.1. Spatial resolution

The GTAP land database disaggregates land use by political regions stratified by agro-ecological zones (AEZ) (Figure 3). There are 18 AEZs created by Navin Ramankutty by aggregating the FAO / IIASA AEZ database into six regions with similar lengths of growing periods and then using temperature and growing degree days to further stratify these into three climate zones—tropical, temperate and boreal climate (Lee et al. 2005). Each AEZ has broadly similar agro-ecological characteristics including precipitation, temperature, soil type, and terrain conditions. Thus, each AEZ has roughly similar land use potential and constraints to help improve modeling of competition and mobility between crop, livestock and forestry sectors. Ultimately, it would be ideal to have a spatially explicit model that operates on a grid to better account for variability in land use and biophysical conditions.

In the meantime, however, developing specific land pools, accessibility criteria, and elasticities for each region/AEZ rather than using global approaches would help maximize GTAP's spatial resolution. Currently, the land pools are estimated using a global dataset with a single set of elasticities to determine land allocation across all regions (discussed below). Region-specific information would help account for key differences based on national policies, land use practices and environmental conditions.

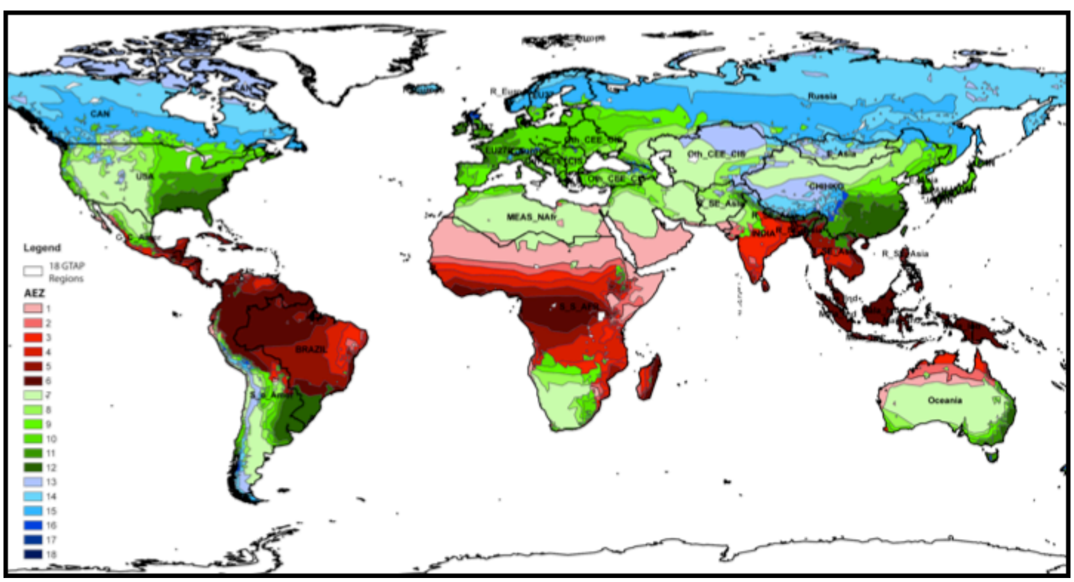


Figure 1. The regional distribution of the 18 Agro-ecological zones (AEZS) used by GTAP

1.2. Data sources and definitions for GTAP land pools

The GTAP land pool database determines the area of land pools available for conversion. Note that all GTAP papers reference the Lee et al. (2005) paper to describe the land cover database but it does seem that some updating has occurred since the paper was published. We focused our review on what is described by Lee et al. (2005) because that is what is cited and available, but recognize that data improvements have likely been made.

The land cover and cropland data originally developed at the Center for Sustainability and the Global Environmental (SAGE) at the University of Wisconsin-Madison form the core of the GTAP land pool database (Ramankutty et al. 2005). The global distribution of major crops, circa 2001, was derived by compiling crop harvested area and yield statistics from national and sub-national sources and redistributing them into a global, satellite-derived land cover map using a data fusion technique (Ramankutty and Foley 1998, Leff et al. 2004, Ramankutty et al. 2005). The census data was state or county level in many cases, rather than the more coarse-resolution FAO country level data. The world's grazing lands, circa early 1990s, were based on Foley et al. (2003) and National Geographic maps (2002).

Note that the SAGE data has now grown into the "M3" cropland dataset and is continually being updated and improved with higher resolution and more recent data (e.g., Ramankutty et al. 2008, Monfreda et al. 2008). We recommend updating the cropland and grazing land data used by GTAP to reflect improvements made over the last several years. Navin Ramankutty has made updates (pers comm.), but it is not clear if the Hertel et al (2010) or Tyner et al (2010) runs have used this revised database.

The non-agricultural land cover area was estimated from the SAGE land cover map, which relied on a satellite-based land cover map circa 1992, making this data nearly 20 years old at this point (Lee et al. 2005; Figure 2).

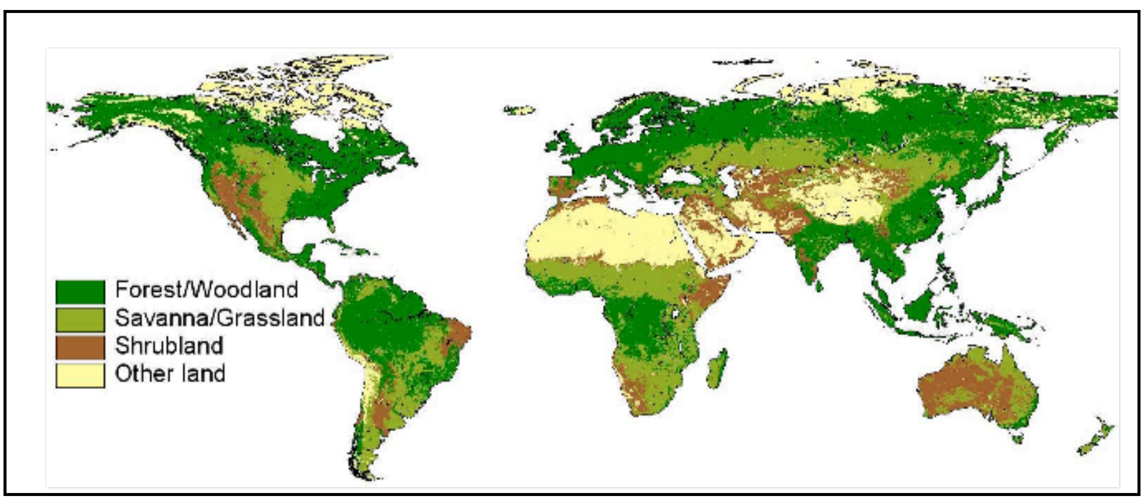


Figure 2. Coarse mapping of non-agricultural land circa 1992

There are land cover maps available circa 2000 and 2005 that have been highly vetted and could be used to update the base land cover data (e.g., GLC2000, MODIS Land Cover Products). We recommend updating to a more recent land cover database to account for additions and subtractions to the land pools including the roughly 13 million ha of tropical forest cleared each year, afforestation in Asia, and agricultural abandonment in Eastern Europe (FAO FRA 2010, FAOSTAT).

Our immediate recommendation is to increase transparency and precision in defining land databases to clarify assumptions and data sources. There is great confusion regarding what is excluded or included in the GTAP land database, and this is making it challenging to move discussions forward. Below we provide definitions related to GTAP land pools and attempt to highlight points of potential confusion. Additional discussion on all definitions can be found in the sections that follow. Please note that there is no specific category for degraded or fallowed land as discussed below.

- **Cropland pool** includes land under temporary crops, meadows for mowing or pasture, gardens, market and land temporarily fallow (less than five years) as well as permanent crops. These lands are accessed by GTAP. The location, area and yield were determined by the SAGE cropland data, circa 2000.
- **Livestock pool** includes permanent pastures are defined as by the FAO: land used permanently (5 years or more) for herbaceous forage crops, either cultivated or growing wild (wild prairie or grazing land). The dividing line between this category and the category 'Forests and woodland' is rather indefinite, especially in the case of shrubs, savannah, etc., which may have been reported under either of these two categories. The location, area and yield were determined by the SAGE cropland data, circa 2000.
- **Forestry pool** includes production forests (aka timberlands) as well as natural forests deemed accessible. Inaccessible forests were excluded. The SAGE land cover map, circa 1992, determined the general area and location of forests. Brent Sohngen's Global Timberland modified the SAGE information to estimate the area of production forests and accessible natural forests.
- **Inaccessible forests** are defined as forestland unlikely to be cleared because it would not be economically viable to clear them. These are not accessed by GTAP. The location and area of unmanaged lands are based on the work by Brent Sohnghen and described in detail below. Note that forests are the only land cover type labeled as "inaccessible" by GTAP.
- **Unmanaged lands** are defined as shrubland, grassland, and savanna. These lands are not accessed by GTAP. The location and area of unmanaged lands were estimated using the SAGE land cover map, circa 1992.
- **Other lands** are defined as lands unlikely to ever be cultivated and include tundra, rock, ice, and desert. These lands are not accessed by GTAP. Other lands were estimated using the SAGE land cover map, circa 1992.
- **Marginal lands** are sometimes defined as lands on the economic margin that could potentially be converted in response to a price increase, as well as lands that have in the past demonstrated reduced productivity (as we use the term here). Note that marginal (aka reduced productivity) lands are not explicitly included by

GTAP. Marginal lands are likely a component of all land pools but are not specifically associated with the unmanaged land pool.

1.3. Fallow and idle croplands and pasturelands

The SAGE cropland data, circa 2001, follows the FAO definition of croplands, which includes land under temporary crops, meadows for mowing or pasture, gardens, market and land temporarily fallow (less than five years) as well as permanent crops. Thus, GTAP does not distinguish between those areas where cropland is actively cultivated versus those lands where croplands are idle, fallowed, recently abandoned or enrolled in the conservation reserve program (CRP) as is practiced in the U.S. For example, the USDA data estimates US cropland at 434 million acres but only 310 million are being used to produce crops (i.e. 29% not actively cultivated in 2002). GTAP estimates the total cropland pool for the US was 454 million acres based on the SAGE cropland data, circa 2001, but without any distinction between what was fallowed, cultivated or potentially underutilized.

The SAGE pastureland data, circa 2001, follows the FAO definition of permanent pastures, which includes lands used permanently (5 years or more) for herbaceous forage crops, either cultivated or growing wild (wild prairie or grazing land). The dividing line between this category and the category 'forests and woodland' is vague, especially in the case of shrubs, savannah, etc., which may have been reported under either of these two categories. The livestock pool includes pastureland with a range of conditions and uses, and includes some under-performing lands where production could be easily intensified. For example, Brazil has large expanses of low productivity pasture that are rarely grazed by cattle or abandoned all together. These lands could have large increases in yields (via increased cattle densities) or be used for new cropland. The rents for the livestock sector are based on beef prices only rather than the prices of cattle and cattle slaughter, which means they may not be responsive enough to ongoing land management changes such as those recently observed in Brazil (see Nassar et al 2010 for detailed discussion). Consequently, GTAP may be underestimating the potential to produce commodities within existing croplands as defined by the SAGE cropland data.

Tyner et al. (2010) did begin addressing this issue by adding land pools for CRP in the US and cropland-pasture in Brazil. However, the most recent model runs were not successful in accessing the CRP lands. Care needs to be exercised when accessing these lands or lands of this type that were originally removed in large part for environmental quality reasons and the effect of placing new cropping scenarios on them. We recommend continued effort to consider fallow-cropping patterns in each country and special consideration of Brazil's underutilized pasturelands where cattle production has intensified in recent years (Nassar et al. 2010). Locating accurate data on the ratio of fallow to active cropland will be challenging though, as reporting on fallow land to FAO is sporadic and many countries have limited data (FAOSTAT). Some countries such as the U.S., and Canada have high quality national data sources that could be used.

It is also important to consider the environmental condition of unproductive, fallowed and abandoned agricultural areas. Lands are sometimes fallowed for agronomic or environmental reasons because fallowing helps retain soil moisture and restore soil tilth due to local geo-climatic conditions (e.g., soils, precipitation, etc.). Some fallowed lands may not be appropriate for cultivation and thus unlikely to be used for active production. Crop yields may be higher or lower than other types of land due to previous land use and history of fallow so this should also be considered.

1.4. Unmanaged lands

GTAP only considers economically active lands, which means it excludes lands deemed unmanaged/un-priced or inaccessible. This is problematic because cropland and pasture expansion could occur into either category. GTAP's unmanaged lands consist of shrubland, grassland and savanna (Lee et al. 2005) and cover 2.3 million ha or 18% of the world's land area according to our preliminary calculations (Table 1). Unmanaged lands are particularly prevalent in Brazil and U.S. where they could provide a substantial land source for expanding croplands and pasture. We refer to lands completely excluded from GTAP due to improbability of ever being cultivated (desert, rock, tundra) as "other".

We recommend including a portion of the unmanaged land category within active GTAP land pools based on accessibility and environmental quality parameters, as this could be a significant source of new agricultural land. Additional thought is needed here to capture the range of potential yields and environmental condition of these lands. Further effort will also be needed to distinguish between those unmanaged lands likely to be converted and those unlikely to be converted due to very poor environmental quality or otherwise not economically viable (e.g., very far from roads, affected by national policy). This is a long-term recommendation because of the effort required to estimate land rents on these lands.

1.5. Inaccessible forests

GTAP's forestry land pool includes forests that are considered economically active and a portion of natural forests, and deems the remaining forests as "inaccessible". The estimates of accessibility are based on the work of Brent Sohngen at The Ohio State University as part of the Global Timber Market and Forestry Data Project. Sohngen delineated accessible and inaccessible lands differently depending on the geographic region. For the US, accessibility is a function of timber demand and price as outlined in Sohngen and Sedjo (1999). For Europe, all forests are deemed accessible and for the tropics and Russia accessibility is based on proximity of forestland to roadways as estimated by FAO national statistics (Table 15 from FAO FRA 2000). More scrutiny is needed to determine if these forests are truly inaccessible. While forests in Canada's wilderness areas may well be out of reach from agricultural expansion, wild areas in the tropics are being gradually cut away as the agricultural frontier expands.

The absence of roads according to the FAO does not mean that the area is inaccessible. For example, transportation infrastructure in the tropics varies from paved roads to emerging dirt roads through the forest, all of which can be used to transport goods. Furthermore, we do not have accurate maps of the world's road network and it is particularly questionable in the tropics where domestic mapping efforts are limited.

We recommend updating the estimates of inaccessible forests to go beyond the FAO analysis in the short-term and developing estimates for each region over the longer term. Our short-term suggestions include consideration of other data sets and information sources including: 1.) The World Conservations Monitoring Center (WCMC) highly protected categories, B. This approach would likely capture most of the currently listed inaccessible forest in the U.S. but would be more restrictive in the tropics allowing more forests to enter GTAP's "forestry" land pool; 2.) Consider national policies such as the Brazilian forest code, which at the household level sets aside a certain portion of land for preservation, and the Indonesian land concession system, which facilitates forest conversion; 3) Use updated, and region-specific road and waterway maps to identify distance to transportation infrastructure, and 4.) Consider environmental quality constraints (e.g., slopes) that could prevent land owners from cultivating land; note that this is different from saying recommending including only lands that are suitable for conversion, rather we are considering lands likely to be converted. One other option would be to develop two forest pools where one is near long-term transportation infrastructure and one is less physically accessible. More research is needed to refine the methods for estimating forest accessibility.

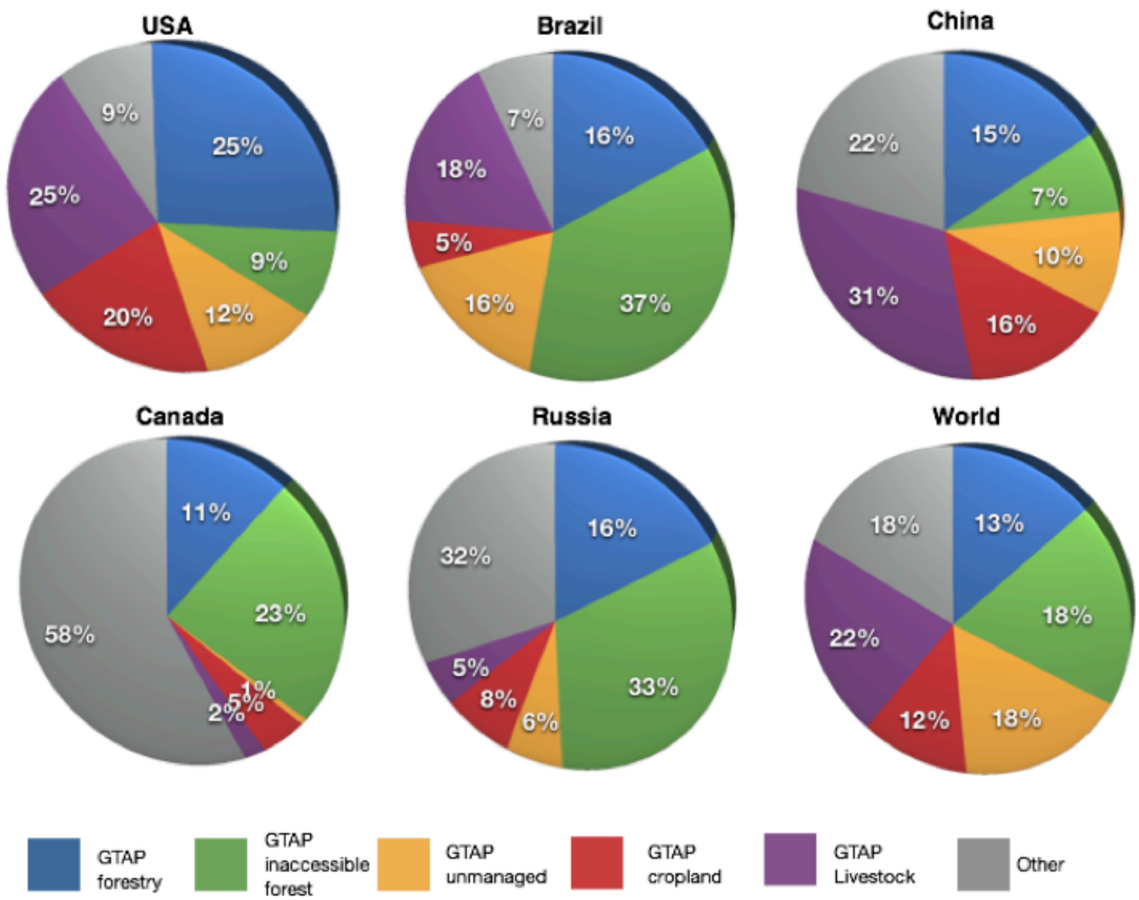
Table 1. Preliminary calculations of the area of land pools included and excluded by GTAP for selected regions

Region	GTAP Forestry	GTAP Unmanaged	GTAP Cropland	GTAP Livestock	Inaccessible forest	Total land excluded from GTAP
USA	224,993,280	111,682,344	184,604,832	231,279,200	78,262,720	189,945,064
Brazil	157,503,248	162,438,768	51,480,484	181,001,040	366,406,752	528,845,520
Canada	99,959,424	6,012,027	43,005,660	20,253,802	210,174,576	216,186,603
Japan	16,251,459	162,995	3,758,013	411,872	8,709,541	8,872,536
CHIHKG	136,793,536	91,760,080	145,998,368	286,299,136	64,539,464	156,299,544
India	17,648,142	27,468,578	171,628,112	11,774,125	50,495,858	77,964,436
Russia	266,811,376	103,699,048	126,363,240	82,133,072	542,158,624	645,857,672
World	1,655,768,723	2,290,108,957	1,530,572,481	2,839,868,293	2,388,452,277	4,678,561,234

All land areas in hectares. Area of cropland, forestry, livestock, and unmanaged land were taken directly from the GTAP 6 database. The area of inaccessible forest was estimated as the difference between the GTAP forestry pool and FAOSTAT estimates of forest for each country. Unmanaged lands include shrubland, grassland and savanna estimated. Total land excluded by GTAP is the sum of inaccessible forests and unmanaged land, but does not include "other land" that is not generally suited for cultivation as show in **Figure 3.**

1.6. Additional land pools

It is also important to note that the accuracy of emissions estimates would be greatly improved by adding new types of land pools so that the estimates of carbon emissions from conversion could be more specific. The coarse land pool categories currently in GTAP each contain a huge range of potential carbon emissions. Carbon stocks vary widely within land cover classes at the region/AEZ level. The biggest differences are found between different types of land cover such as forests (~100 to 400 tC/ha) and grassland (~5 to 50 tC/ha), but they also vary greatly within each class according to biophysical conditions and land use history. See the report from the Emissions Factors Subgroup for more detail on this issue. Increased resolution on all land cover types would be ideal, but here we focus on two critical issues – wetlands and marginal lands. Adding new land pools is a long-term recommendation though, because it requires developing land rent databases.



Area of cropland, forestry, livestock, and unmanaged land taken directly from the GTAP 6 database. The area of inaccessible forest was estimated as the difference between the GTAP forestry pool and FAOSTAT estimates of forest for each country. Unmanaged lands include shrubland, grassland and savanna estimated. The "Other" land pool is excluded from GTAP but not likely to include lands suitable for agriculture (tundra, rock, and desert) and was calculated by taking the total land area minus all other land cover types

Figure 3. Relative proportions of land pools for select regions

1.6.1 Marginal lands

Marginal lands (lands with reduced productivity) are an important consideration because cultivation of these lands may be less likely to displace other land uses and has potential to increase carbon stores with dedicated management and appropriate production scenarios. However utilization of marginal lands faces possible challenges such as low yields, high restoration costs, uncertain land tenure and possible displacement of communities; these factors make it difficult to assign rents to these variable lands.

Over the long term, we recommend incorporating a selective portion of the marginal land pool into GTAP, but recognize that this is challenging due to differences in definitions and a limited ability to map and quantify these areas (at least outside the United States), as well as developing land rents. Definitions or types of marginal land range from idle or abandoned croplands, under-utilized land with large yield gaps, or full-on wastelands. Despite the importance of accurate information on the area and location of marginal lands, no clear consensus exists as to the extent, location or real condition these lands (FAO 2008, Gibbs 2009). There are few if any routine assessments of land degradation or abandonment at the country level to keep track of pre-existing or changing conditions (FAO 2003). Soil type, topography, farming practices, local geo-climatic conditions, and land use history all influence degradation and are highly site-specific and potentially time-specific in terms of rainfall patterns, fire regimes and changes in land management. Global estimates of degraded land range from 400 million to nearly 2 billion ha (Gibbs 2009).

1.6.2 Wetlands

Wetland soils store a much greater amount of carbon than other soil types due to reduced decomposition and should be explicitly considered in GTAP. Peatland soils in Malaysia and Indonesia store a particularly large amount of carbon and nearly half have already been cleared (Hooijer et al 2006). Wetlands are not generally included as a land cover category in global maps making it more challenging to estimate the area in each region / AEZ. However, we recommend using available data in the literature and regional maps to develop "adders" that can be used to add on the area of wetlands in each region / AEZ. Alternatively, wetlands could be included as an ecosystem type (See section).

1.7. Recommendations for Land Pools

Near-term:

- Update the GTAP land cover database using most recent SAGE/M3 agricultural data and satellite-based land cover maps
- Assess and improve methods to estimate the are of inaccessible forest, particularly in the tropics where the current approach is weakest
- Update area of ecosystem types using satellite-based land cover map rather than the WHRC database. Coordinate the update with biomass and soil carbon estimates.
- Increase transparency and precision in defining the GTAP land database to clarify assumptions and data sources

Short-term:

- Estimate the proportion of total cropland that is idle / fallow / abandoned for each region
- Begin defining lands that could potentially qualify as "marginal" lands in economic and environmental quality terms and how they would accessed in GTAP
- Consider methods to account for pasture intensification and price responses in Brazil

Long-term:

- Develop methods to allow GTAP to access some portion of the unmanaged land pool (i.e. grassland, shrubland, savanna)
- Address issues of marginal and underutilized lands within cropland, livestock and unmanaged land categories
- Consider adding a marginal land pool based on results of previous analysis

- Develop estimates of forest accessibility for each region to refine the area of the forestry pool accessed in GTAP

2. Land conversion estimates

The type of land converted for expanding croplands—whether from forests or grasslands—has a huge impact on the estimates of carbon emissions from ILUC.

2.1. CET land supply function – endogenous to GTAP

GTAP estimates the supply of land across cropland, forestry, and grazing land (livestock sector) through a Constant Elasticity of Transformation (CET) supply function (Hertel et al. 2008). The quality of the land use responses estimated by GTAP depend on the quality of the CET input parameters, which are all centered on observations in the U.S. Hertel et al (2008) point to two key considerations: 1) Land use response to market — if the profitability of a given land use increases then the quantity of land supplied for that use will increase, and 2) secular transitions in land use over time, which are independent of changes in profitability of a particular land use.

The own return elasticities are determined with a matrix of land-use transition probabilities for a 5-year period (Lubowski 2002) and own return elasticities of transition probability (Lubowski 2006). These two sets of data are used to simulate land use transitions over a baseline time path where there are no changes to use returns, and then a time path of land use transitions where the transition probabilities in each period changed due to a one percent increase in returns in each use (Hertel et al. 2008). The own return elasticities are then connected to land supply and the CET function. Revenue shares for this calibration are for the US and come from Lee et al (2005, 2008). The Lubowski land use probability data and own return price elasticities are based on plot-level data from the USDA and Natural Resources Inventory.

Consequently, GTAP's land allocation for all regions is based entirely on data for the U.S. Each region may have unique patterns of land allocation and should have individual CET functions. Using data for the U.S. in the developing world is particularly problematic where land ownership, national policies, biophysical potential, culture and other factors strongly influence land use decisions often more than prices. For example, forested lands are frequently the land sources for new oil palm plantations in Indonesia (e.g., Pin Koh and Wilcove 2008) because the government gives free forest concessions to oil palm companies to encourage development. However, previously cleared lands are more likely to be used by family farmers and it is very expensive to mediate community relocation.

Improvements are needed, but most will require substantial outside expertise. Here are possible ideas to improve or replace the CET function:

- Develop CET functions for each region using available satellite data (e.g., Gibbs et al. (2010), PRODES, LAPIG)
- Develop conversion cost parameters for each region that could help account for non-economic factors including land ownership, national policies, and non-

agricultural revenues such as logging (GTAP currently does not account for conversion costs).

- Replace the CET function with an Exogenous Land Conversion Database that is based on satellite observations and literature review; similar to Ecosystem Types but would trump rather than augment CET function. Database could account for economic and non-economic factors as well as more detailed land pools including peatlands, marginal lands and degraded forests.
- Use Exogenous Land Conversion Database to provide modifiers or adders for specific regions where we know the CET function is not providing accurate results.
- Link GTAP to exogenous, dynamic land-use model that accounts for economic and non-economic factors

2.2. Ecosystem Types – Exogenous to GTAP

The CET function estimates land transitions between the pasture, forestry and cropland category but does not tell us what type of forest is converted to cropland or grazing land (e.g., montane forest vs moist deciduous). Instead, GTAP uses an exogenous "ecosystems types" database to provide this more detailed information important for estimating emissions factors. GTAP currently uses the Woods Hole Research Center (WHRC) database to estimate the ecosystem types and associated carbon stocks. The WHRC database estimates the area covered by different ecosystem types by subtracting estimates of cropland expansion and deforestation from area estimates of potential land cover (i.e. without human impact). The estimates of land cover change are based on FAO national statistics for cropland and forestry (Searchinger et al 2008). Coarse assumptions were used to make the best of available data. For example, forest was designated as the land source if forest cover decreased while cropland increased. The FAO database provides valuable information at the global scale and through time, but has been plagued with inconsistent data between countries and years, and provides only net changes in area at a coarse spatial scale. **We recommend developing an updated database of ecosystem types based on satellite-derived land cover maps** such as the GLC2000 to estimate the area of different ecosystems. Important classes such as peatlands could also be added using higher-resolution information for critical regions. See the Emissions Factors Subgroup report for more information on estimating carbon stocks by ecosystem types.

Another key issue is estimating which ecosystem types are more likely to be cleared. It appears that GTAP currently assumes ecosystems are cleared relative to their availability (i.e. in proportion to their area). However, some ecosystem types may be more likely to be cleared than others**. We recommend developing estimates of the conversion probability for the different ecosystem types**. For example, most agricultural expansion in the Amazon occurs in the "arc of deforestation" where forests are more likely to be somewhat degraded from fires, smallholder clearings and logging than in the heart of the Amazon. Spatial databases and literature review could be used to identify those ecosystems more likely to be cleared for expanding agriculture as well as those ecosystems unlikely to be cleared (see Section 1.5 Inaccessible forests).

2.3. Data option to improve estimates of land allocation and ecosystem types

The land sources for new croplands around the world remain surprisingly uncertain. Most studies have focused on static snapshots of the locations of land cover or net changes in the area of forests or crops. However, we need estimates of land transitions between forests, grazing land and croplands (and hopefully additional classes) not just the net changes. Here we review the major databases related to land conversion based on agricultural census, coarse-resolution satellite imagery, higher-resolution satellite imagery and regional studies that could be used to update or refine components of the GTAP modeling framework.

2.3.1 National-level Agricultural census data

The WHRC database was used by Searchinger et al. (2008) to estimate the types of land sources for expanding croplands as estimated by FAPRI / FASOM (and by GTAP for ecosystem types). As mentioned above the WHRC database is based on FAO national census data for croplands and forestry and involved coarse assumptions. For example, if the area of forest declined during a year when cropland increases it was assumed that forest was the land source for new cropland. The national-level spatial resolution and use of net changes over such a large area are limitations of this approach.

2.3.2 Coarse-resolution satellite data (MODIS)

The EPA estimate used FAPRI/FASOM to estimate the amount of new land needed but unlike GTAP, they do no not model the land sources but rather rely on exogenous estimates from Winrock International (Harris et al 2009). The Winrock database used land cover maps created from MODIS imagery. Harris et al (2009) applied the differencing method, also known as post-classification change detection, which involves simple comparison of two or more already processed land cover maps. Specifically, they subtracted MODIS land cover maps (500m resolution) from 2001 and 2007 to identify the land use transition during that time (2001-2004 at 1km spatial resolution were used in the first version).

As noted by Harris et al. (2009) there are significant limitations to using global land cover products to estimate land transitions. One issue is that the land cover classification uncertainty greatly exceeds the rate of land cover change, which means that differencing maps can lead to spurious transitions. Mark Friedl and colleagues have conducted analyses showing that about 10% of all pixels change from year to year in the product (pers comm.). Some of these are actual change, but many arise from classification uncertainty. Classification issues tend to be more problematic in the tropics due to persistent cloud cover, aerosols from fires and heterogeneous landscapes. It is evident from Table 4C in Harris et al. (2009) that the pixels are jumping around quit a bit, moving from one class to another due to misclassifications rather than actual land use change. It is likely that the errors are highest in classes that are more similar such as grassland, shrubland, agriculture and mixed classes (Table 2). Combining shrubland and grassland together and cropland and mixed (aka agricultural mosaic) together may improve results, making them a more reliable data source for GTAP.

Another issue involves using the differencing method to estimate land change transitions. True change detection involves processing images for both time periods simultaneously to provide estimates of change. Here we examine the land cover changes estimated for Brazil by differencing MODIS land cover maps (Table 4C, Harris et al. 2009) as compared to Landsat change detection by the FAO (Gibbs et al. 2010; see Section 4.1). To create Table 2 we estimated the portion of each land cover category that changed into another land cover category between 2000 and 2007 (total area in 2001 - area remaining in 2007) / total area in 2001). Table 2 shows the unrealistically high percentage of change for most land cover classes. For example, 94%, or nearly all of the shrub land cover type was estimated to change to another land cover category over a 7-year period. Similarly, over half of the cropland pixels changed into other land cover types between 2000 and 2007.

The relatively coarse, 500-1000m spatial-resolution of MODIS imagery also means that many of the pixels are a mix of different land cover types, which contributes to classification errors and inflation of change estimates. These issues are particularly problematic at the agricultural frontiers in the tropics where much of the region is a shifting mosaic of different land cover classes.

Table 2. . Comparison of land cover changes between 2001 and 2007

Land Cover Type	% change MODIS / Winrock	% change FAO / Gibbs
Forest	9%	5%
Mixed	59%	na
Savannah	16%	na
Shrub	94%	9%
Grassland	80%	na
Cropland	54%	4%

Portion of each land cover class that changed to another land cover class between 2001 and 2007 according to analysis of MODIS land cover maps (Harris et al 2008) and between 1990-2000 according to an analysis of Landsat imagery classified by the FAO (Gibbs et al. 2010). The high rates of change in the shrub, grassland, mixed and cropland categories underscore limitations of using this data for ILUC analyses. Percent changes in land cover categories were computed as (total area 2001-area remaining 2007)/total area 2001).

2.3.3 Higher resolution satellite data (Landsat)

Gibbs et al. (2010) analyzed a detailed library of classified Landsat imagery from the FAO to systematically describe the agricultural expansion pathways across the tropical forest belt. This remotely-sensed database is distinct from the FAO country statistics. The FAO conducted a statistical survey of tropical land cover, consisting of 117 sampling units across the tropics: 47 in Africa, 30 in Asia and 40 in Latin America (FAO 2000). Each sampling unit was comprised of three separate Landsat satellite images acquired approximately in 1980, 1990, and 2000 and statistically standardized to those years. The survey includes all tropical forest types, in wet, moist and dry conditions, and covers 63%

of the total tropics and 87% of tropical forests. Non-forest tropical areas (e.g., deserts) were excluded.

Unlike most satellite-based studies that only identify locations of land conversions, the interdependent visual change detection method used by the FAO tracks each land parcel as it transitions from one land cover class to another. This method involves manual interpretation of both images (historical and recent) at the same time, which reduces errors associated with change detection and offers major advantages over single period analysis or compilation of different sources of imagery.

Gibbs et al. (2010) quantified and mapped the relative proportions of land sources for expanding agricultural lands between 1980-1990 and 1990-2000. They organized the tropical belt into seven broad regions with similar land use trends, and note that the agricultural expansion pathways vary between regions. The results could be used to inform the CET function or an exogenous database. Benefits include detailed change detection that provides more accurate results than MODIS differencing method or national-level census data, covers the entire tropical forest belt and has high spatial resolution. However, croplands and pastures are aggregated together, which means this data provides very limited information for ILUC in South America. In addition, data is not available for this decade and some trends in expansion pathways have changed (e.g., dramatic reduction in deforestation rates with soy and cattle moratoriums and policy changes in Brazil).

Other regional studies exist that could supplement or verify results. For example, Morton et al. (2006) tracked the origins for expanding soybean fields in Brazil, using a combination of remote sensing and field verification in the state of Mato Grosso along the Amazon basin's agricultural frontier. Similarly, Brown et al. (2005) examined soy expansion in a portion of Rondônia, Brazil. The LAPIG/UFG database led by the Remote Sensing Laboratory of Federal University of Goias measures native vegetation conversion due to annual crops and pasture expansion in the Cerrados. Brink and Eva (2008) used a sample of Landsat imagery to quantify land cover dynamics across sub-Saharan Africa between 1975 and 2000.

2.4. Recommendations for Land Conversion Estimates

Near-term:

- Update area of ecosystem types using satellite-based land cover map, coordinated with biomass and soil carbon estimates (if ecosystem types are needed – depends on methods used for estimating carbon emissions)

Short-term:

- Identify rough-cut conversion probabilities for ecosystem types using available data so that we can estimate the carbon stocks from land most likely to be cleared
- Consider developing regional look-up-tables or modifiers that can help adjust CET function results and account for critical non-economic factors in specific regions (e.g., forest concessions in Indonesia)

Long-term:

- Investigate methods to improve CET function / land allocation that will account for regional differences and move beyond applying data for the U.S. to all regions
- Refine conversion probabilities for ecosystem types by identifying those areas most likely to be cleared in each region to help improve estimates of carbon emissions

3. How much land is needed?

The most important questions about the area of land required for new biofuels involve assumptions about yield:

1. How do assumptions about current and projected yields of biofuels crops influence the estimate of direct land use changes due to biofuels demand?
2. How do assumptions about current and projected yields for all crops (including feedstocks for biofuels) influence the estimate of indirect land use change due to biofuels demand?
3. What is the yield of newly converted lands for use in agriculture?

With regard to the first question, two different types of yield influence how much direct land impact a biofuel has:

1. The yield per unit area of land of a crop used as a feedstock for biofuel production
2. The yield of fuel per unit mass of crop used as a feedstock for biofuel production

The direct land impact is inversely related to both of these yields:

$$A_{biofuel} = Q_{biofuel} \times \frac{1}{Y_{crop\ per\ ha}} \times \frac{1}{Y_{biofuel\ per\ crop}}$$

where $A_{biofuel}$ is the direct area requirements for a given biofuel, $Q_{biofuel}$ is the demand for a given biofuel; $Y_{crop\ per\ ha}$ is the yield of a biofuel feedstock per unit area (ha) of land; and $Y_{biofuel\ per\ crop}$ is the yield of biofuel per unit of crop feedstock.

The second question involves a broader understanding of the future of agriculture in both developed and developing nations. The degree to which overall agricultural yields will influence greenhouse gas emissions from land use change due to biofuels depends very much on the relative *rates* of change in yields and the *rates* of change in demand for agricultural products and biofuels. As is argued later in this report, the current approach used by GTAP makes some implicit assumptions about these relative rates that are not necessarily going to be true. They represent, therefore, only a limited view of the potential future impacts of new demand for biofuels.

The third question involves data that is inherently hard to get for the obvious reason that we cannot know the yield of specific crops on land not currently producing those crops.

So, the best we will ever be able to do is make educated guesses about how this land would perform when converted to specific production systems. Another variable influencing our understanding of the relative yield performance of new lands brought into agriculture is their specific land use histories. Some of these lands are truly "pristine", while others are abandoned agricultural lands that have fallen into disuse either because of reduced need or because the land has been degraded to the point of no longer being productive.

3.1. Direct land use effects of biofuel crop yields

For existing crops—corn and soybeans in the US—the effect of future improvements in crop yields could range from relatively small to very large, depending on whose projection is to be believed. The claims in public meetings by Monsanto of yield improvements that could double for corn offer signs of hope for avoiding a major increase in land clearing, but more transparent documentation of such potential is needed if regulators are to establish policy options that promote further demand for land by incentivizing biofuels.

For corn ethanol, direct land use effects of yields in the US are likely to show only modest impacts on land use change. As Figure 4 shows, yields of corn have followed a linear trend of improvement for the past few decades in the US. This trend is secular in nature; it has followed a persistent pattern of improvement over many decades that suggests little connection with market price for corn. Since 1990 that growth in yield has been about 2 bushels per acre compared with yields that grew from 120 to 160 bushels per acre. Thus, in 2009, a linearly projected improvement in yield will only lead to 1.25% change in direct land use impact.

For soybeans, the yield improvement impacts on land use change are likely smaller than for corn. As Figure 5 shows, yield over the entire time series for soybeans in the US has grown linearly. This improvement is also seemingly unrelated to soybean prices. Improvements in yield since 1990 have been around 0.4 bushels per acre, compared with an improvement in yield from around 35 to 40 bushels per acre. Thus, in 2009, a linearly projected improvement in yield would result in less than 1% change in the estimate of direct land use change.

3.2. Applying an adaptive policy approach to yield

One approach would be to evaluate yield performance annually to see if assumptions in the models used to estimate land use change still hold. However, as Figure 6 shows, using each year's change would be highly problematic. The variability in annual yield change can be huge, influenced more by weather conditions than by long-term technological improvements in yield or management practices. Thus, it makes more sense to evaluate yield trends using only actual yield trends measured over decades rather than annually.

The historical trends support the notion that adjusting for a linear improvement in yields for calculation of direct land use effects of US biofuels production should be further considered. In the near term, we recommend using exogenous yield trends to reflect what we know has been happening, rather than forcing an economic model to capture an artificial and immeasurable (though perhaps logical) market relationship for yield.[1] We offer two notes of caution with this recommendation:

1. There will be a limit to the future yield of growth. Thus, it will be critical to continue to observe yield trends over time to establish any changes in long-term trends.
2. The effects of exogenous yield improvement on direct land use change for continued in US corn and soybean are very small—on the order of 1 to 2%. So, while methodologically, it may make sense to capture this yield improvement trend, in reality, it will make little difference on the total direct land use impact of corn ethanol and soy biodiesel.

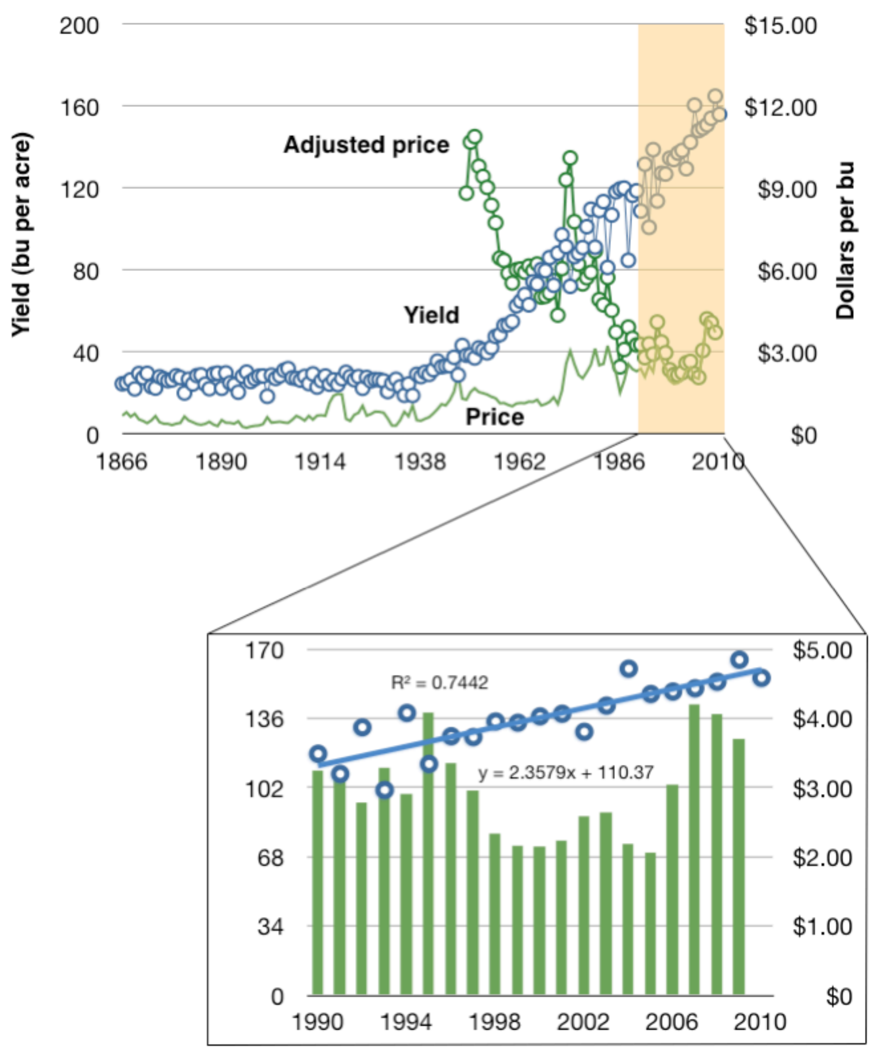


Figure 4. US Corn price and yield trends

[1] Yield elasticities are being reviewed by another subgroup of the Expert Working Group, but we offer this recommendation because it is an important aspect of understanding total land demand issues.

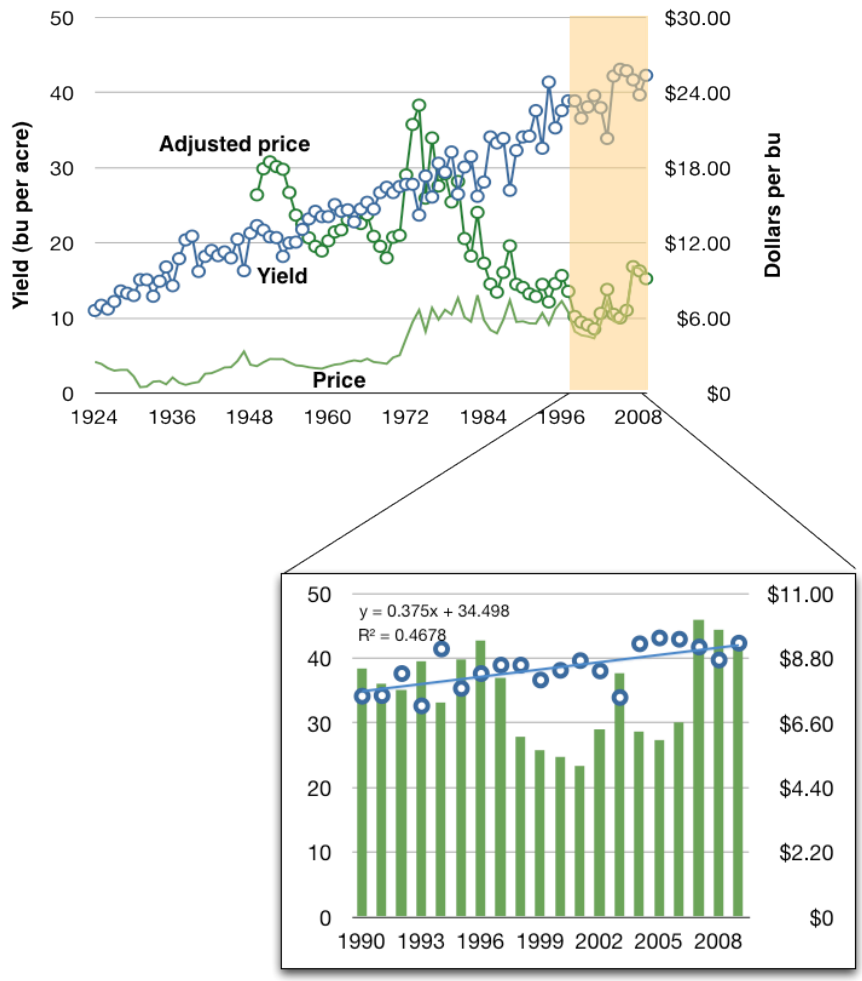
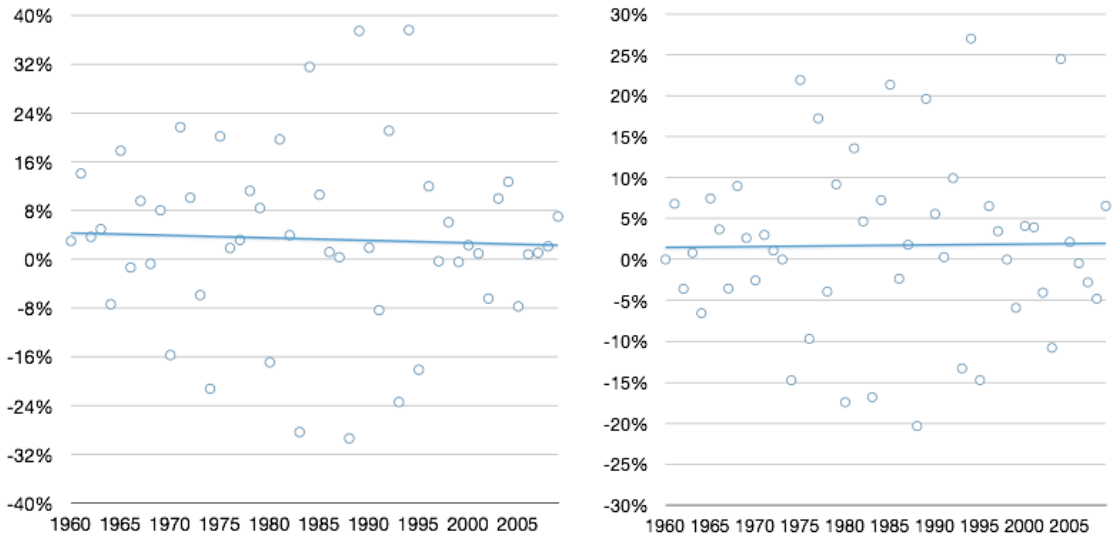


Figure 5. US Soybean price and yied trends

3.3. Indirect effects of background yields in agriculture

The current GTAP analysis implicitly limits itself to an assumption that land is constrained under all circumstances—that is, it makes the assumption that improvements in global agricultural productivity will not be able to keep up with growing demand. In this section, we address this question from two perspectives. First, we argue the theoretical merits of a more open and flexible methodology that allows for all possibilities rather than constricting the range of outcomes on the basis of an a priori assumption of land scarcity. Second, we consider that such flexibility could be more than just a theoretical concern by examining a future scenario in which global productivity improvements are assumed to continue at historical rates.



Source: USDA National Agricultural Statistics Service (www.nass.usda.gov)

Figure 6. Year to year variability in US corn and soybean yields

3.3.1 Rethinking the methodology for accounting for future productivity improvements

Whether or not demand for biofuels is causing new land to be cleared may be influenced by whether or not the global agricultural system is in a net land scarcity or net land surplus regime. Land requirements are in a net scarcity regime when the rate of growth in demand for food products outpaces the rate of growth in improved productivity of agricultural land (both cropland and pastureland). In the converse, if productivity is improving faster than the rate of demand, it follows that the net amount of land required to meet new demand could actually shrink. Note that a reduction in net land demand for agriculture does not per force lead to avoided land clearing. Many other factors come into play in making land use decisions. The point we make here is that any methodology for estimating indirect land use effects should account for the possibility of a net reduction in total agricultural land requirements, and not implicitly assume a future based on net growth in land demand.

It may seem obvious that what regime we find ourselves in (net growth in demand versus net reduction in demand) matters. But this is not so evident in the public and published debate about the effects of biofuels on land use. In the first round of analyses developed and debated by experts for CARB and for the USEPA, the ceteris paribus framework was used to establish that biofuels will always exert a land clearing penalty relative to a baseline in which no biofuels are introduced.

Here is how the argument goes: A logical way to simplify and clarify the effects of biofuels is to conduct a thought experiment in which land use is assessed with and without the introduction of biofuels. The effect of biofuels on land use is calculated as the difference between the two scenarios. It simplifies the question because it ostensibly removes all background changes that influence land use since the same effects that occur in both cases disappear once the analysis is based on the difference between the two.

Thus, in the debate about the mitigating effects of ongoing improvements in agricultural yields, analysts quantified the view that biofuels do not deserve to "take credit" for changes that would have happened regardless of the role of biofuels in agriculture.

This approach is correct if the focus is strictly on calculating the amount of land impacted by biofuels. But it does not capture how the land is influenced by biofuels. Figure 7 illustrates the problem.

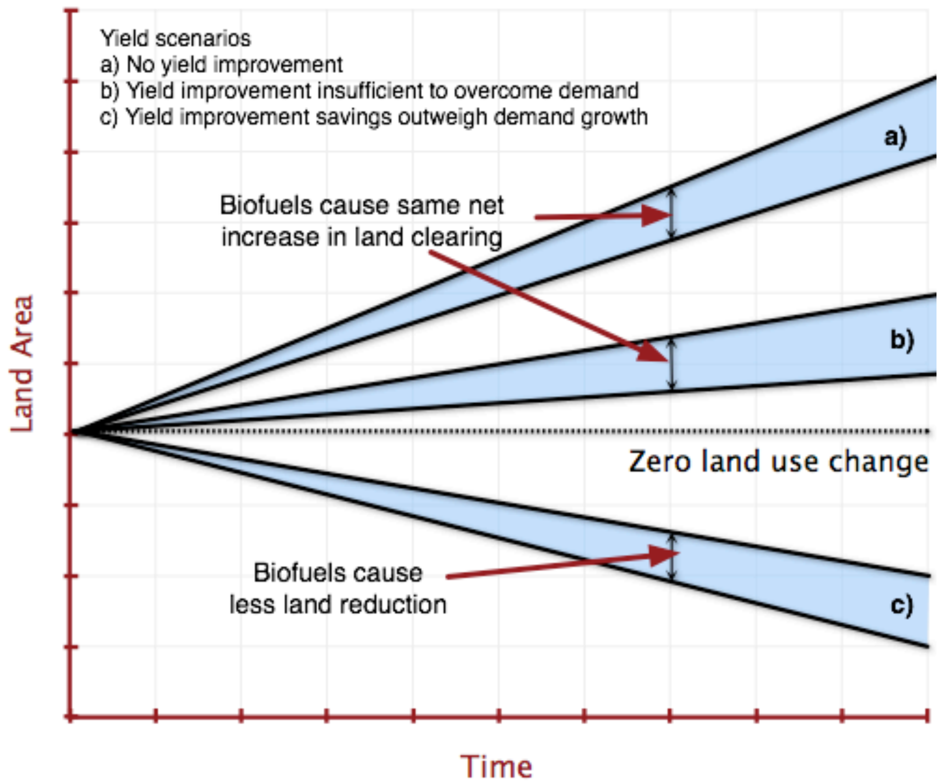


Figure 7. The effect of biofuels on land use under different land supply regimes

Case a) is a hypothetical sketch of growing land use without any improvements in yield, assuming linear growth in food production and no change in land intensity of the dietary mix. The lower bound in case a) is the baseline without biofuels; the upper bound in a) reflects the increase in area due to a steady (presumably policy driven) increase in demand for biofuels over time. In case b) we introduce a linear increase in overall agricultural yields that occurs independent of the effects of biofuels. But the rate of increase in overall agricultural yields is smaller than the rate of increase in demand for food. The result is that, while the absolute level of new land added to agricultural stocks is lower, the net effect of introducing biofuels is essentially the same (or at least still positive).

Now consider case c), in which background yields increase at a rate that outpaces the rate of food demand for land. The result is that land decreases with and without biofuels. The upper and lower bounds of land demand are now reversed. That is, the scenario with biofuels leads to less reduction in the amount of land needed for agriculture, relative to the baseline. The net effect is that biofuels still imposes a higher level of land demand.

But how this higher demand is met matters a lot. In cases a) and b), the net land burden of biofuels is met by clearing new land. In case c) the net burden of biofuels translates into an opportunity cost for land that could have been used to sequester carbon. The carbon cost of land clearing is much higher than the carbon cost of a lost opportunity for carbon sequestration.[2] Case c) also assumes that biofuels land demand is less than the land savings due to yield improvement. If policies are developed that allow biofuels demand to exceed savings from yield improvement, then we are back to a land scarcity regime.

To appease critics who claimed that biofuels demand would induce further yield reduction, analysts for CARB ran the GTAP model to calculate the land clearing effect of biofuels with background yields held constant, and then did a post-analysis correction for future yield changes in agriculture (see Figure 8). But this approach still restricts the validity of the model to cases in which land supply is scarce. It is actually worse, because it gives the appearance of addressing the background yield effect, when all it does is reduce the impact of the a priori assumption of land scarcity.[3]

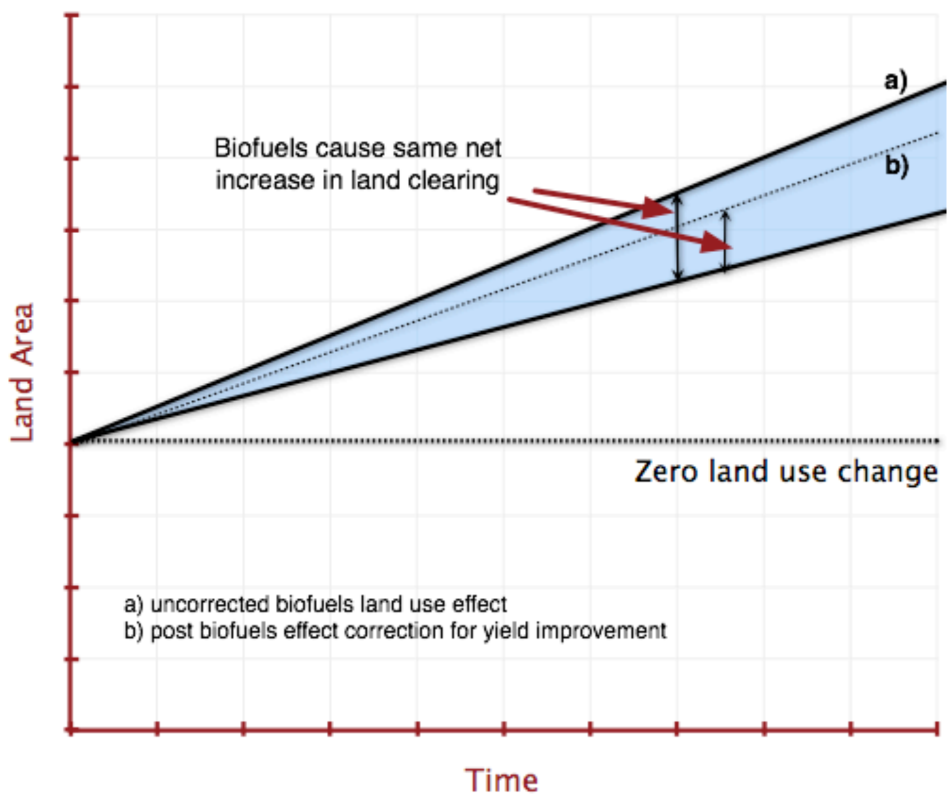


Figure 8. Post modeling correction for background yield effects

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[2] The subgroup of this expert working group on time effects of carbon emissions also estimates much smaller carbon effects for the missed opportunity to sequester carbon versus released carbon from clearing. Both the magnitude and the timing of land clearing make it worse than the opportunity cost.

[3] The yield effect also led to an arcane debate about the elasticity of yield in response to market price, resulting in further confusion in the public discussion.

3.3.2 Historical shortfall in yield improvement versus demand for corn and soybean

Figure 9 shows the global yield and demand trends for corn grain (maize). The global rate of yield improvement in maize is less than the US rate of improvement shown previously in Figure 4. The chart on the left shows the absolute numbers of yield (Mg per ha) and total demand (millions of Mg). Because of the differences in scale and metric, the comparison of the relative slopes of each parameter is what matters. The chart on the right makes this comparison clearer. Here, the yield and demand trends have been normalized to 1961 levels. The outpacing of demand over yield is more obvious, especially in the early years and again during the past decade when world demand jumped dramatically. These results are consistent with the notion that there is an acute demand for increasing land devoted to corn production. In such a situation, demand for corn ethanol can only lead to the net addition of more land for corn production.

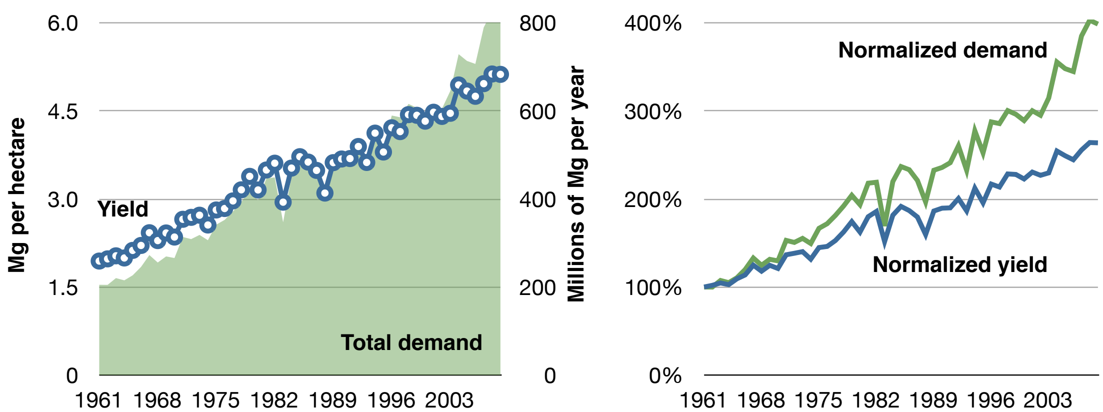


Figure 9. Global yield and demand trends for maize. Source: FAOSTAT (www.faostat.org)

For soybeans, the acute demand pressures are more dramatic (see Figure 10). Since 1961, global soybean demand growth has continually outpaced yield improvement. But this has particularly been true for the past decade or so. Demand has been growing exponentially while yield has grown linearly.

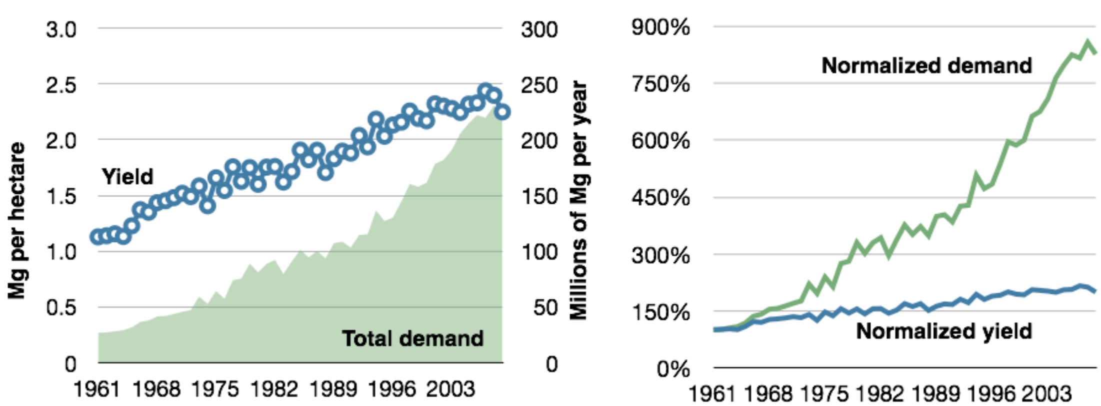


Figure 10. Global yield and demand trends for soybeans. Source: FAOSTAT (www.faostat.org)

From this analysis, we can conclude that land for corn and soybean production are likely to be in the land scarcity regime in the near term. Biofuels demand will cause an additional increase in land for these two crops and a subsequent land clearing effect.

3.3.3 Historical pasture intensification and livestock demand trends

Data on the yield of animals grown on pasture and range land is problematic (in comparison to crop yield data) because no one actually measures this yield directly. FAO and USDA statistics provide estimates of live animal stocks per year. The number of live animals reported per year is larger than the number of animals slaughtered per year—which is more reflective of actual meat yields. In addition, grazed animals are used for dairy and other products as well as for meat. In most cases, animals are also fed grain and forage crops to supplement calories obtained by grazing on pasture and range land. With respect to the latter point, intensification of livestock production in developed countries is due to supplementing pasture production with highly concentrated commercial feedlot operations known as CAFOs (Confined Animal Feedlot Operations). On the plus side, such operations reduce the land footprint of animal production by making more efficient use of grain to increase animal weight more rapidly. On the negative side, they also often have greater air and water quality impacts. The complexity of animal production systems thus makes it more difficult to assign simple yield estimates to pasture and range land, which at best represent only a part of the animal production process in modern agriculture.

On the demand side, consumption of animal products (both meat and dairy) continues to grow. Indeed, some experts suggest that increasing wealth in developing countries may lead to a dramatic rise in demand—a phenomenon that has been referred to as the "livestock revolution" (Delgado, et al 1999). The combination of higher demand and the significantly lower yield of animals per unit of land (compared to crops) represent a significant potential stress on global land supply.

Historical demand for meat is indeed on the rise, but this does not correspond to expansion of pastureland (see Figure 11). Despite the steady growth in meat production, pastureland has seen dramatic declines since the 1990s.

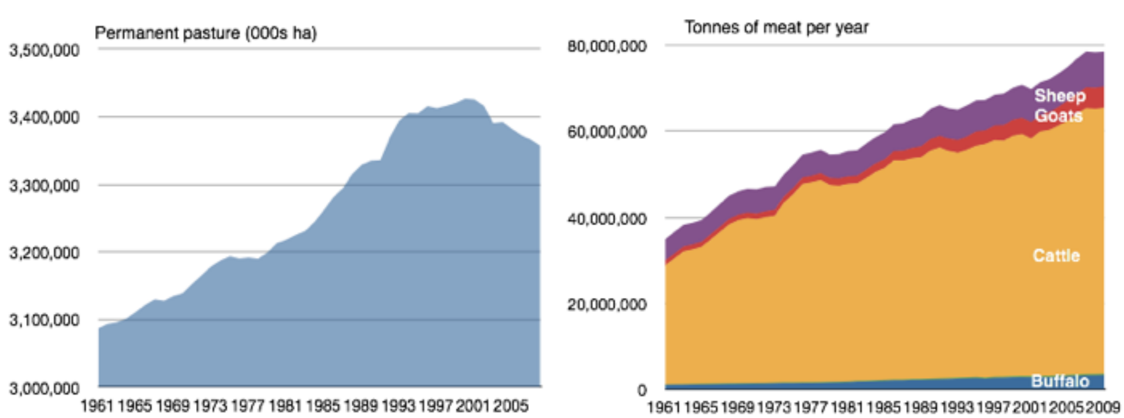


Figure 11. Pastureland and meat demand trends. Source: FAOSTAT (www.faostat.org)

One explanation for the apparent disconnect in land demand versus actual meat demand is increased efficiency in animal production systems. This is due to both more efficient use of pastureland and the adoption of more efficient grain and hay based animal feedlot systems. Evidence for both effects can be seen in the historical global data from FAO (see Figure 12).

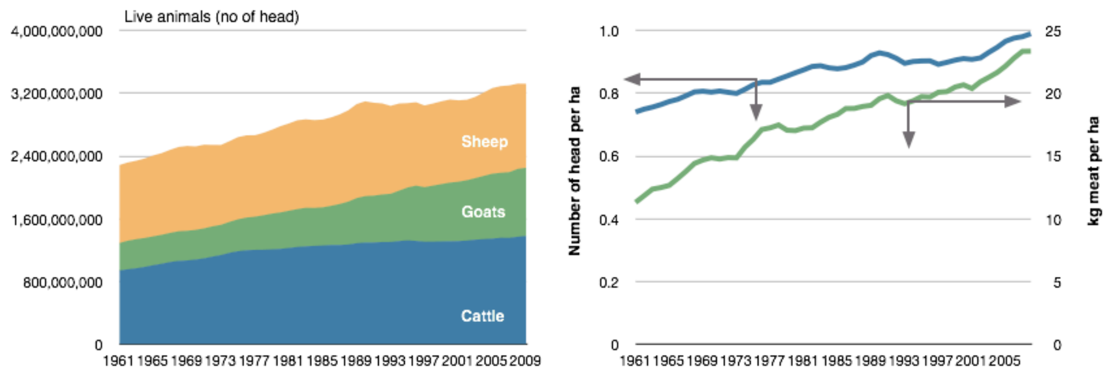


Figure 12. Live animal stocks and meat production yields

The chart on the left shows that total stocks of cattle, sheep and goats continues to grow. The chart on the right shows trends in live animal stocks per hectare of pasture and meat production per hectare. The size of the animal stock per hectare has risen by almost one third since 1961. Actual yield of meat per hectare has almost doubled over that same time period. The last 20 years have seen a dramatic rise in meat yield. The more rapid increase in meat yield compared to live animals maintained per hectare of pasture suggests that improved efficiency of animal production (in feedlots) may be the larger contributor to reduced pastureland demand, though it is likely that intensification of pastureland use is occurring as well.

Intensification of animal production is not necessarily restricted to developed countries. Andre Nassar (Director-General, Institute for International Trade Negotiations, Brazil) has submitted data to our subgroup demonstrating the occurrence of pasture intensification in certain regions of Brazil, where concerns about the effects of pasture expansion on tropical forest clearing are particularly acute (see Figure 13). Overall in Brazil, a 25% increase in herd size from 1997 to 2008 has led to a slight decline in total pasture area. But there is significant regional variability. Rapid growth in animal stocks in the Northern Amazon region, for example, has led to expansion (extensification) of pastureland.

Given the large land footprint of animal production (measured in kg per ha versus tonnes per ha for crops), we need to better understand future trends for pasture intensification and overall animal production efficiency, and the role they may play in reducing pressure on global land use. We also need to understand the environmental implications of increased reliance on confined feedlot systems (CAFOs).

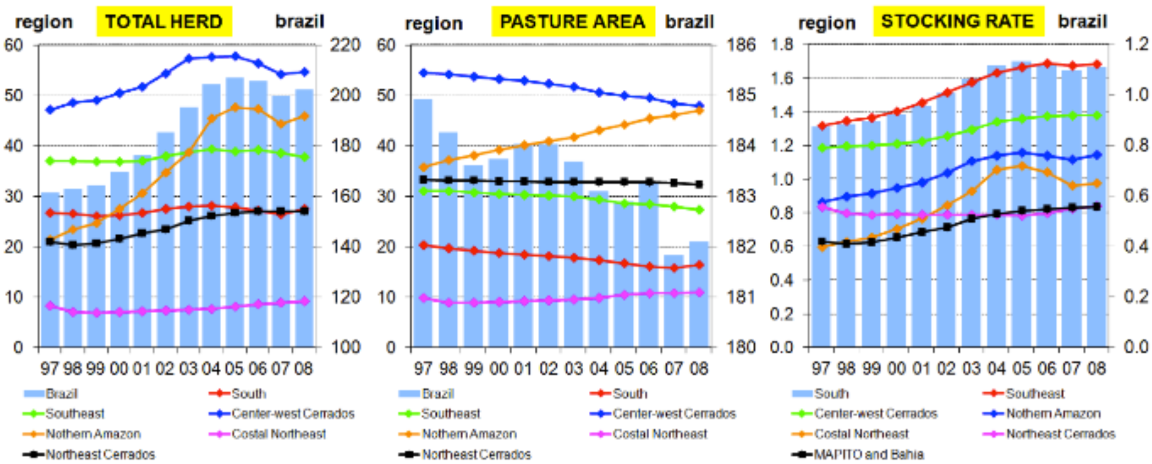


Figure 13. Animal production trends in Brazil. Source: Nassar, A.M. (2010)

3.3.4 A simple, holistic perspective on total global demand for agricultural land

Of course, a more complete analysis of agricultural land demand for all commodities is needed to determine if (and for how long) total agricultural land needs to increase just to meet food demand. Sheehan (2009) presents a preliminary analysis of total agricultural land that takes into account:

- Yield improvements for grains and oilseeds
- Per capita demand for grains and oilseeds
- Per capita demand for pasture land
- Population growth

The analysis is based on a system dynamics model built using the Stella™ system dynamics-modeling tool (ISEE, Lebanon, NH, USA). The model views global land as a set of four aggregate stocks (see Figure 14):

- Unused (natural) land
- Agricultural land
- Abandoned and degraded land, and
- land diverted to energy crop production.

It is a simple thought experiment designed to explore the effects of new biofuels demand on global land stocks It offers no insight into regional distribution of land, but instead focuses on high level trends of food demand and land productivity to understand—beyond the local institutional and social causes—when demand for agricultural land for food or fuel exceeds capacity of the land supply and leads to land clearing.

Population. The model relies on a set of UN population growth scenarios, for which the median scenario shows a slowing down in the rate of population growth by the middle of the century (see the median growth scenario shown in Figure 15). Users of the model can select one of the four population scenarios shown in Figure 15.

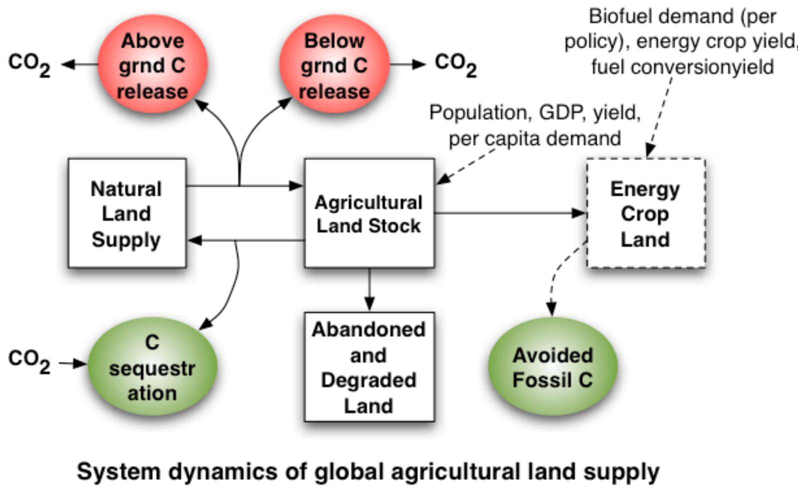


Figure 14. Schematic of Stella™ system dynamics model of global land use

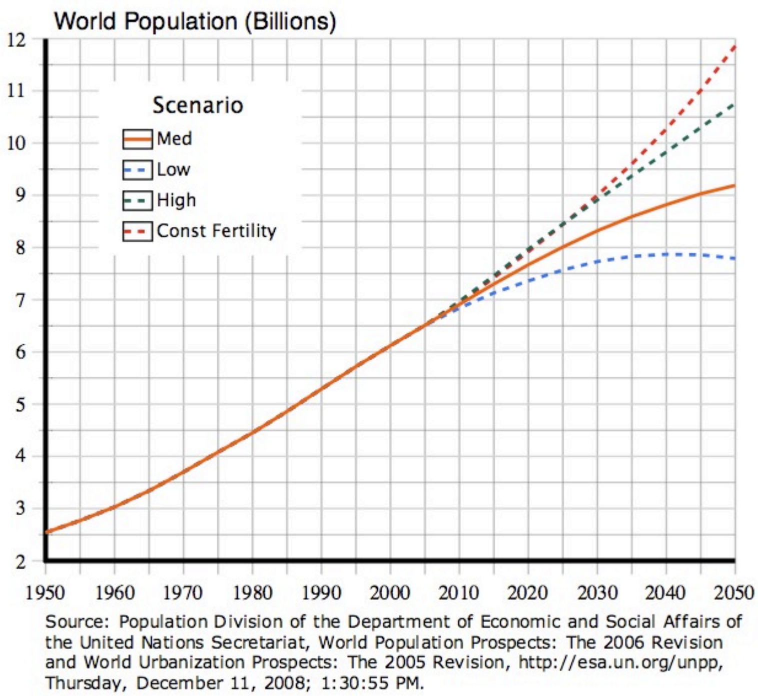
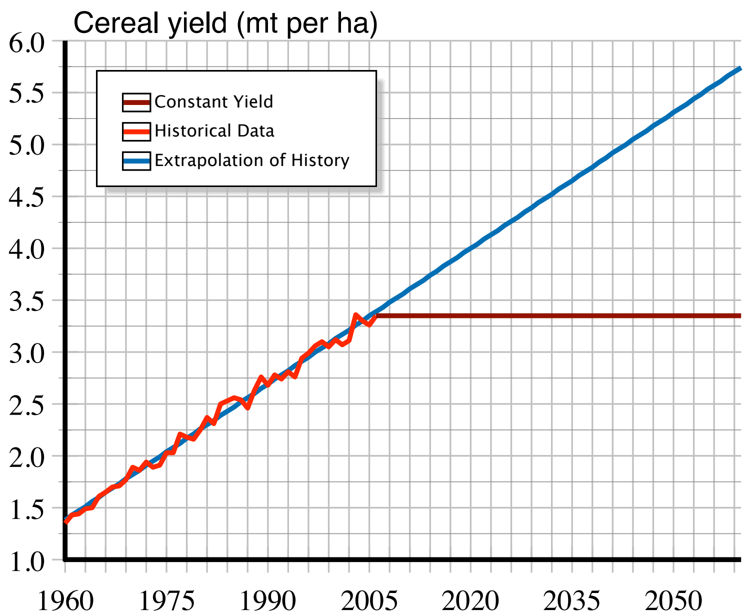


Figure 15. UN global population growth projections used in global land system dynamics model

Projecting global yields of cereals and oilseeds. The model has the option to utilize FAO historical data on global yields as a basis for projecting future yield changes. Average yield for all grains globally has been linear over time since 1961. This is similar to the trend shown previously for maize, which—along with wheat and rice—accounts for the bulk of the total global production of grain (see Figure 16). For the purposes of projecting the future, we consider two options: an optimistic and a conservative case. The latter assumes continuation of linear annual yield improvement.



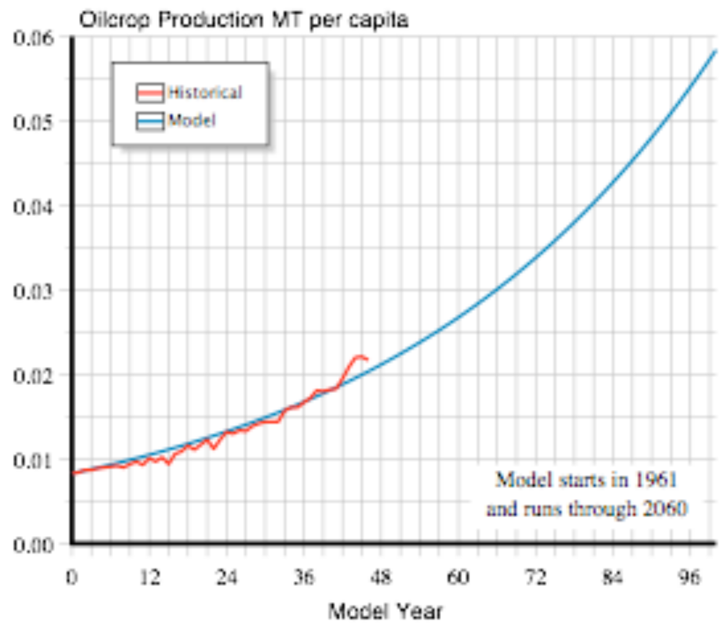
Historical data from FAOSTAT (www.faostat,org) is fit to a linear regression for the purposes of extrapolation.

Figure 16. Future yields of cereals based on a projection of historical global trends.

Global oilseed yields look very different than the yields for US soybean (see Figure 17). Yields have been increasing exponentially. This reflects expansion of oil palm as well as yield improvements in row crop production of soy and rapeseed. As with grains, we consider an optimistic scenario in which yield in the future follows historical trends and a conservative scenario in which yields remain flat.

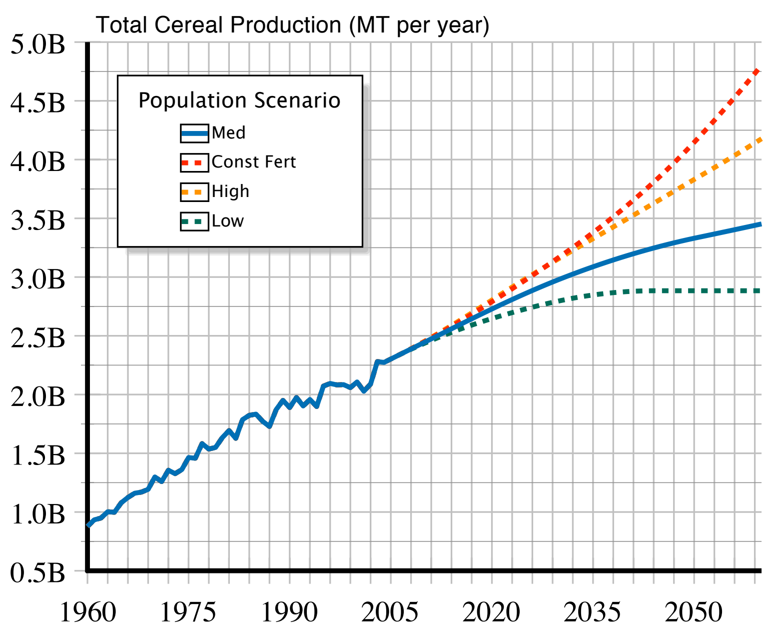
Demand for grains and oilseeds FAO crop production time series data is combined with population time series to come up with historical trends for cereal production per capita. Figure 18 shows the total demand for cereals based on a combination of population growth and projected per capita demand (analysis of per capita demand not shown). Historical data for total cereals show a slowing down in the rate of demand in the long run, reflecting the slower growth rate for population. Oilseeds, by contrast, would see significantly higher rates of growth than grains when historical trends are projected forward.

Demand for pasture. Global data on pastureland and grazing productivity is poor at best (see discussion in section 3.3.3). To get a rough handle on demand for pasture, we combine data on population and total land in pasture to predict per capita pasture demand. Per capita demand actually declines over the period of 1961 to the present. (see Figure 20). Combining this with population growth shows a slowing and even a decline in pastureland (see Figure 21).



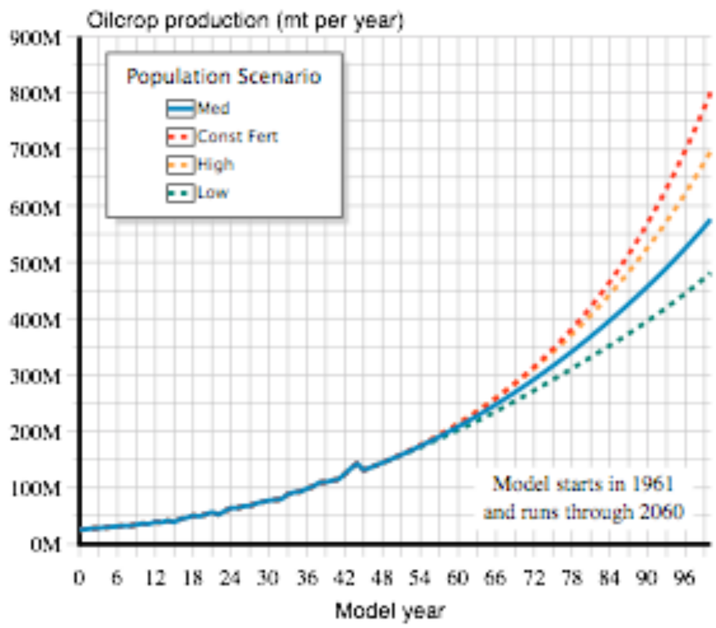
Historical data from FAOSTAT (www.faostat,org) is fit to a an exponential regression equation for the purposes of extrapolation.

Figure 17. Future yields for oilseeds based on a projection of historical global trends



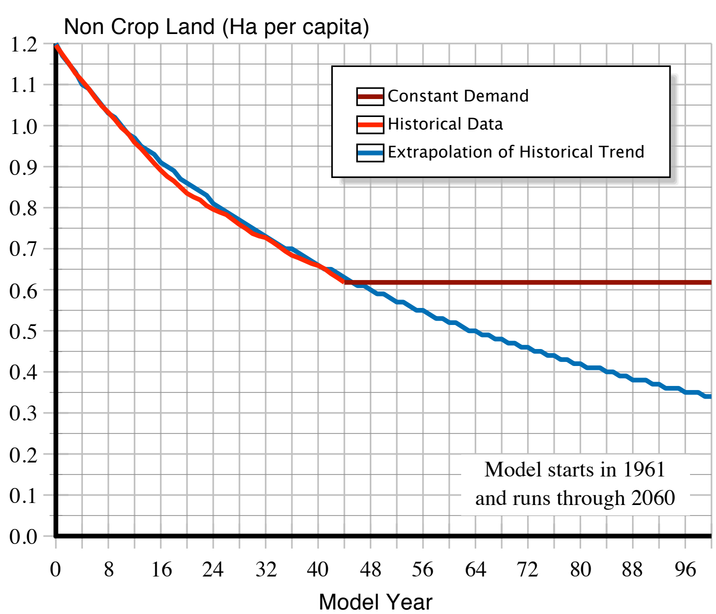
Extrapolated per capita cereal grain demand trends are combined with population trends to estimate future demand for cereal grains (Sources: FAOSTAT and UN Population Division website)

Figure 18. Projected demand for global grains



Extrapolated per capita oilseed demand trends are combined with population trends to estimate future demand for cereal grains (Sources: FAOSTAT and UN Population Division website)

Figure 19. Projected demand for global oilseeds



Extrapolated per capita pastureland demand trends (Sources: FAOSTAT and UN Population Division website)

Figure 20. Projected per capita global pastureland demand

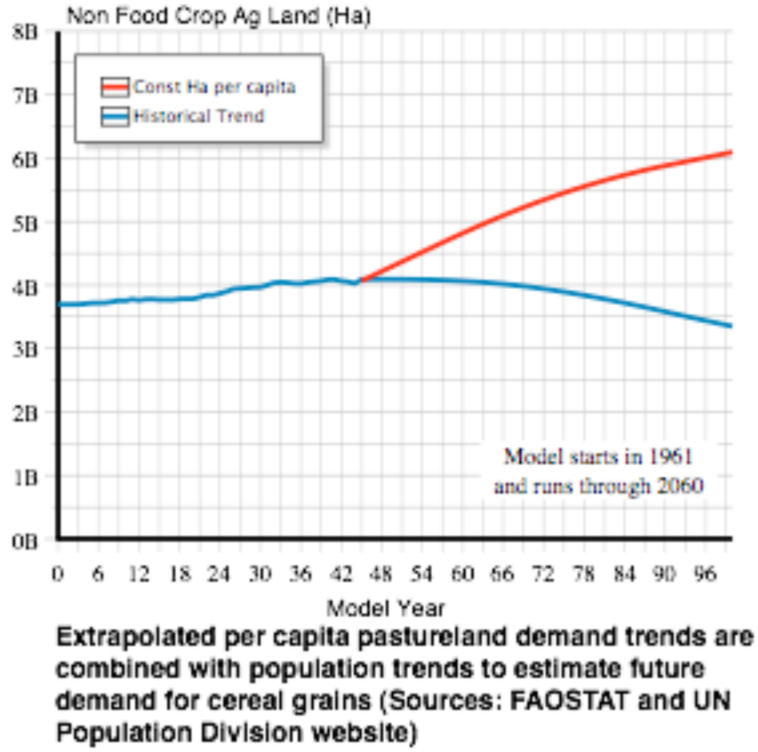


Figure 21. Projected global pastureland demand

Possible futures for global agricultural land demand. Figure 22 and Figure 23 present the optimistic and conservative scenarios for yield under the median population growth scenario. Pastureland demand exerts the most influence on whether a future scenario for land demand is in surplus or scarcity regime. It represents far and away the largest contributor to total land demand. The assumption that the pasture required per capita can continue to decline at the dramatic rate that it has shown in the past is also critical. There may be two explanations for this dramatic decline. First, the high pasture per capita numbers in the early years may simply reflect highly underutilized pastureland. Second, animal production technology has intensified a great deal, with the introduction of animal feed lots.

The future likely lies somewhere between the two extremes for global land demand portrayed in Figure 22 and Figure 23. Factors that will influence the growth of future land demand include:

1. Growth in per capita demand for animal products that will put pressure on the already- large requirements for pasture and grazing. The demand projections in the analysis presented here are based on long-term historical data, which may dilute the effect of recent GDP per capita-driven growth in demand for meat and dairy products in the developing world. As the income disparity between developed and developing countries continues to shrink (especially in countries like China and India), we can expect a shift in diet more reflective of wealthier nations.

2. A slowing down of yield improvements in the developed countries—where yields could approach something close to theoretical limits in the next fifty years—may reduce average global crop yield growth below the linear improvement rates seen historically.
3. Continued stagnation or decline in overall yield improvements for agriculture in the least developed nations concentrated largely in Sub Saharan Africa and South Asia.

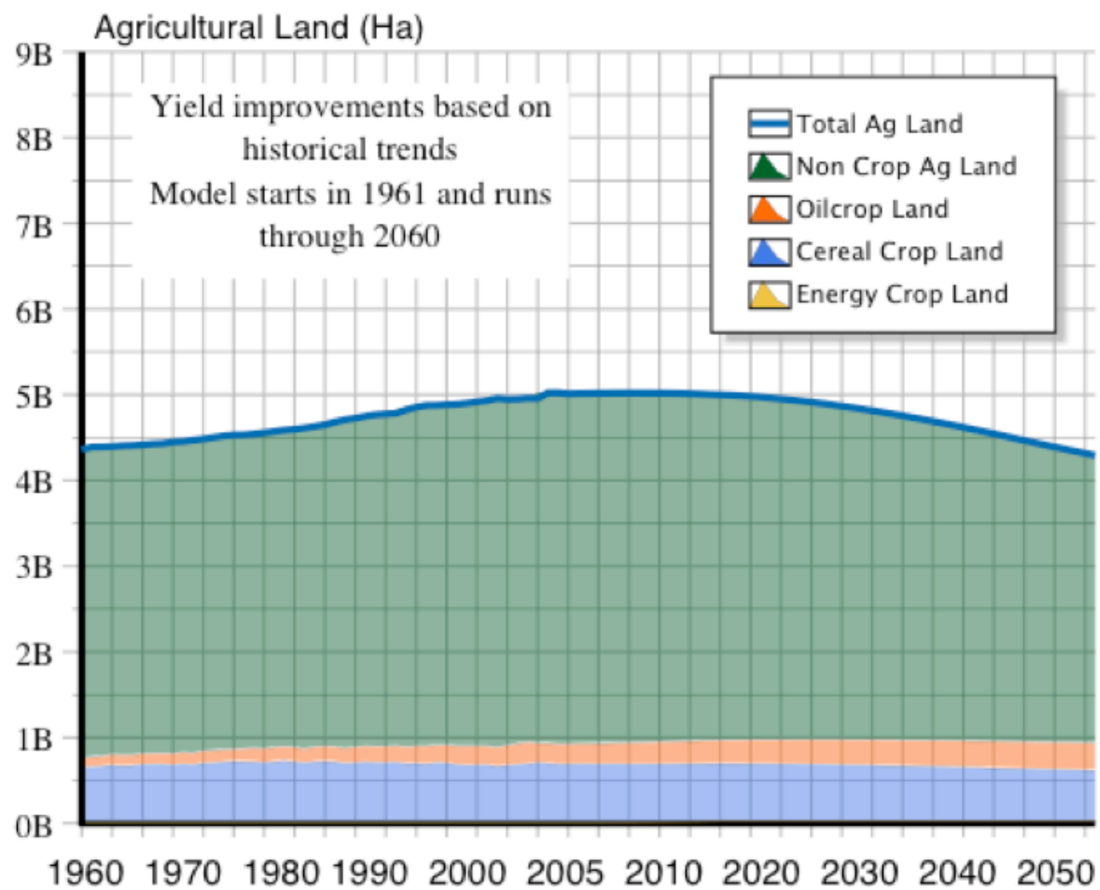


Figure 22. Optimistic yield case for future global agricultural land demand

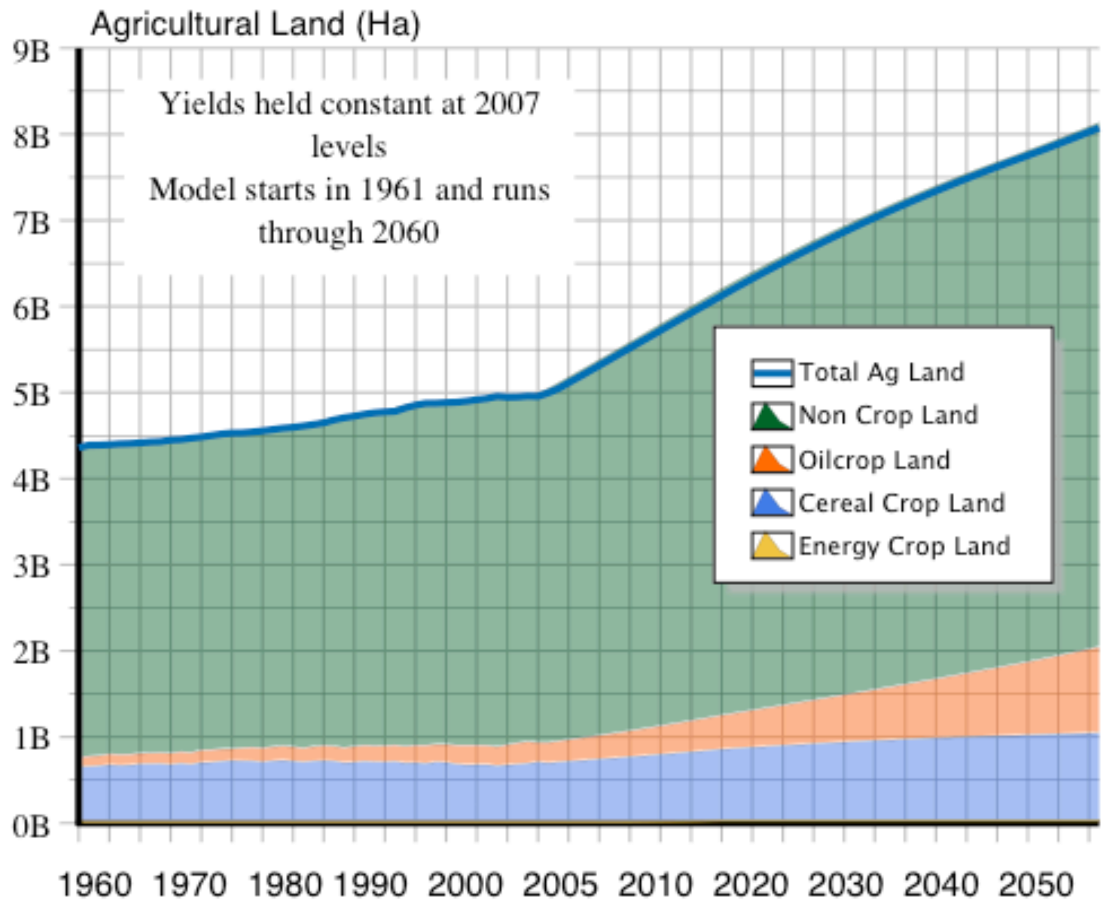


Figure 23. Conservative yield case for future global agricultural land demand

Factors that may reduce the demand for new agricultural land include:

1. Spread of pasture and livestock intensification around the globe (a technological shift in livestock production predicted by some experts to have the same impact on food security that was seen as a result of Borlaug's "Green Revolution" in Mexico and Asia).
2. An effort to improve agricultural yields in Sub Saharan Africa.
3. A shift from land-intensive meat consumption to more land efficient poultry consumption in the developed world.

3.4. Recommendations on assessing indirect effects of background yield

Near-term:

- Correct the methodology used by GTAP modelers to permit an accounting for background yield changes. This can be done by exogenously including a time dependent yield trend in the analysis for corn, soybean and other major grain and oilseed crops

- Study recent trends in pasture intensification and livestock production efficiency to better understand their role in future land use change.

Short-term:

- Adopt a modeling framework that allows for the dynamic nature of land use change. A dynamic model can fully incorporate time dependent changes such as technology driven yield improvements and food demand (influenced by the dynamics of economic and demographic change). This could be done using a dynamic version of GTAP.

Long-term:

- Develop new and more flexible system dynamics models that can capture time and rate dependent effects.

3.5. Yields on new land entering global agricultural land stocks

3.5.1 Current approach to estimating new land yields

The GTAP modeling done for CARB made an assumption about the relative yield capability of new land brought into agriculture as a result of biofuels demand. Based on the idea that market forces would dictate the use of the most productive land first, modelers assumed that any new land would come in at a yield proportionally lower than the yield of existing land in a given agroecological zone (AEZ). This proportion was defined as Eta:

$$Eta = \frac{Y_{delta}}{Y_0}$$

where Y_{delta} is the yield on a new increment of land brought into agricultural production and Y_0 is the yield on existing agricultural land (see Figure 24).

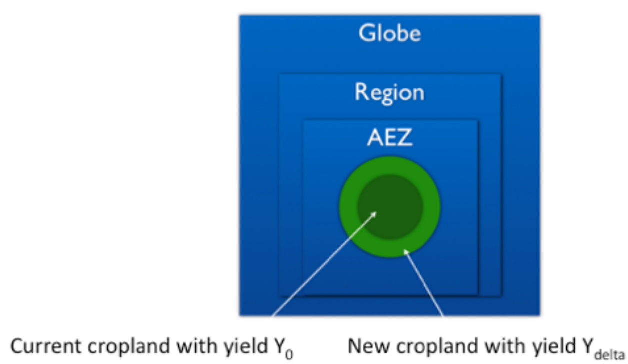


Figure 24. Definition of yield penalty for new agricultural land

Yield on existing land is estimated in GTAP for each of the 18 AEZs (see the section entitled Spatial resolution for a description of how GTAP characterizes land productivity by AEZ). The ratio Eta in the GTAP model has been assumed to be constant, with a value of roughly 0.67. In other words, the analysts assume that all new land will only be two-thirds as productive as existing land within a given AEZ.

3.5.2 Using ecosystem process models to estimate new land yields

Modelers at Purdue recently conducted a new set of analyses using GTAP in which they revised and improved assumptions and capabilities of the model for estimating land use change. A report from Purdue is available describing the work, which was done in conjunction with Argonne National Laboratory (Tyner et al 2010). In lieu of simply assuming that the yields for new land will be uniformly lower, they used the Terrestrial Ecosystem Model (TEM) to estimate relative yields (Eta) on new lands (see Figure 25). The model was run for each of the AEZs so that productivity could be estimated for specific climate conditions around the globe.

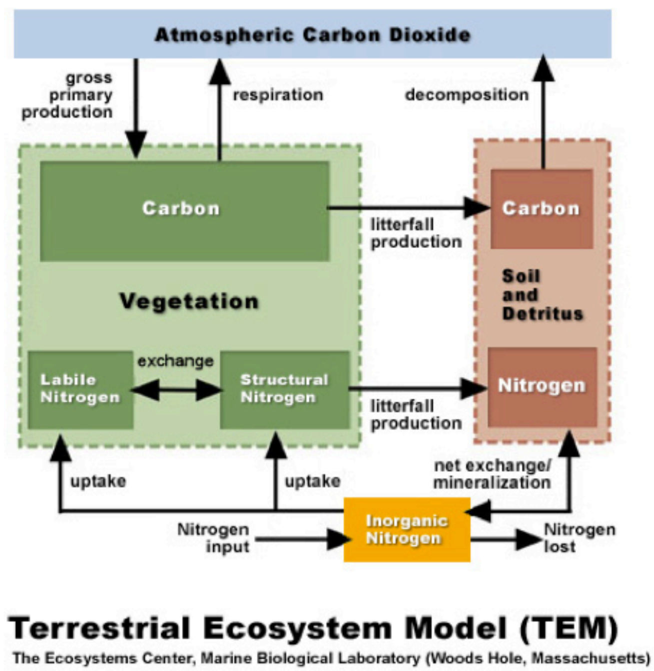


Figure 25. Structure of the natural ecosystem model used to assess new land yield

This model is not normally used to evaluate managed agricultural systems. Instead, what it can do is estimate productivity of native ecosystems. TEM is a process-based model developed by The Ecosystem Center at the Marine Biology Laboratory in Woods Hole, MA. It estimates carbon and nitrogen flows between the land and the environment. Of interest to our analysis is its calculation of the land's net primary productivity (NPP) measured as Mg of carbon per hectare per year:

$$NPP = C_{photosynthesis} - C_{respiration} - C_{decomposition}$$

This is the net uptake of carbon into biomass. Cphotosynthesis is equivalent to gross primary production as shown in Figure 18, while NPP is a proxy for biomass yield on the land (both above and below ground).

Key drivers in the model include:

- Average monthly climate (precipitation, temperature, cloud)
- Soil texture
- Elevation
- Vegetation—generic C4 crop
- Water availability

To connect this natural ecosystem productivity to managed productivity, the modelers make the following leap of faith:

$$\frac{Y_{delta}}{Y_0} \cong \frac{NPP_{delta}}{NPP_0}$$

Climate data is known for each of the 18 AEZs, and data is available on soil texture and elevation for each grid cell in an AEZ. The ratio of NPPs for converted and available lands is at best an approximation of the potential relative performance of available lands brought into agriculture. While far from perfect, it is better than the previous arbitrary assumption of 0.67. Later, we propose alternative approaches to estimating yield performance on new land.

NPP is calculated for all of the land in an AEZ (less exclusion of grid cells defined as inaccessible). Then the results for all of the grid cells in areas available but not in crop production are ordered from highest to lowest NPP value, resulting in an NPP versus land area curve as shown in Figure 26. The ratio of areas A and B in this figure represents the value of Eta for all new land in the AEZ.

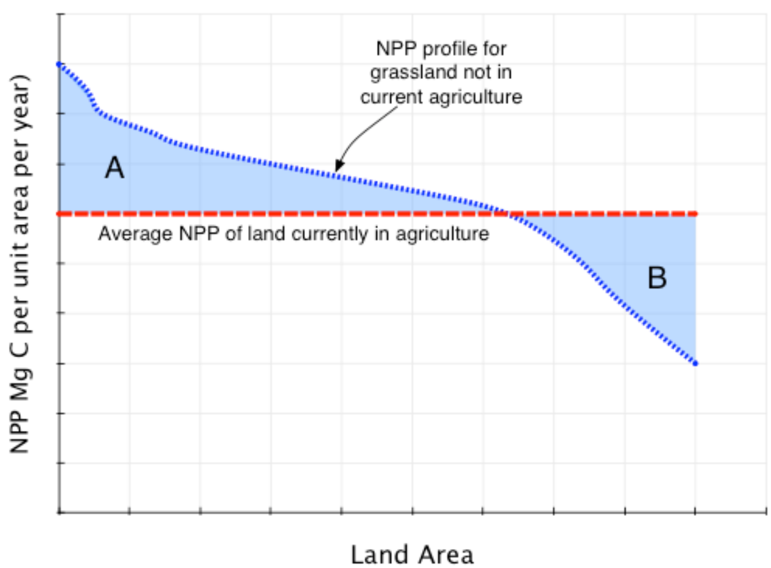


Figure 26. Calculation of NPP ratios for new land entering agriculture in an AEZ

3.5.3 Values of Eta for new cropland

Figure 27 shows the average, minimum and maxium values for NPP estimated for each of the 18 AEZs. In general the trends for NPP make sense. Within each major ecozone type (tropical, temperate and boreal), productivity increases as moisture and the length of the growing season increase. The degree of spread in the NPPs for an AEZ is a reflection more of how well defined an AEZ is, rather than some measure of error in the measurements.[4]

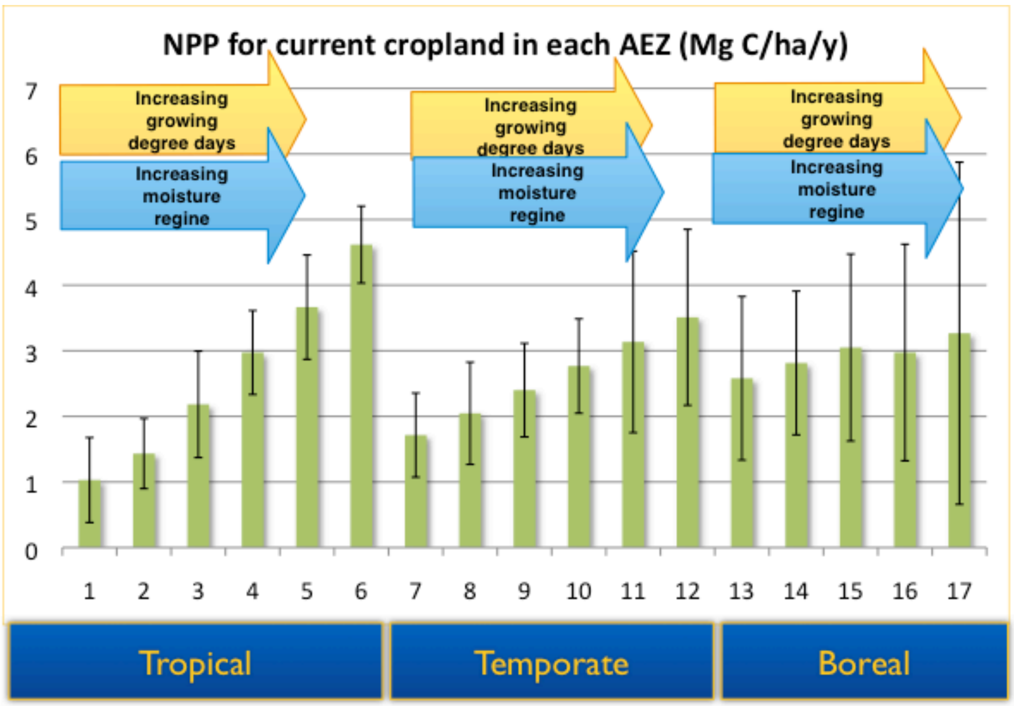


Figure 27. NPP (Net primary productivity) for current cropland for all AEZs

Figure 28 shows selected values for Eta as estimated by TEM. The results suggest that the current assumption of a fixed value of 0.67 for Eta in all AEZs is inappropriate, and that the arbitrarily selected value was probably too low. The raw values for Eta are often greater than unity. This seems contrary to conventional economic wisdom, which would suggest that land already in production should be the most productive. To mitigate this apparent contradiction, the modelers normalize all of the data so that the no AEZ can have a value greater than unity in each region (shown in green as adjusted values).

[4] These results underscore the remarks made in the earlier section on spatial resolution in the GTAP model, which is problematic because each AEZ covers such a large range of ecosystem types and climate conditions.

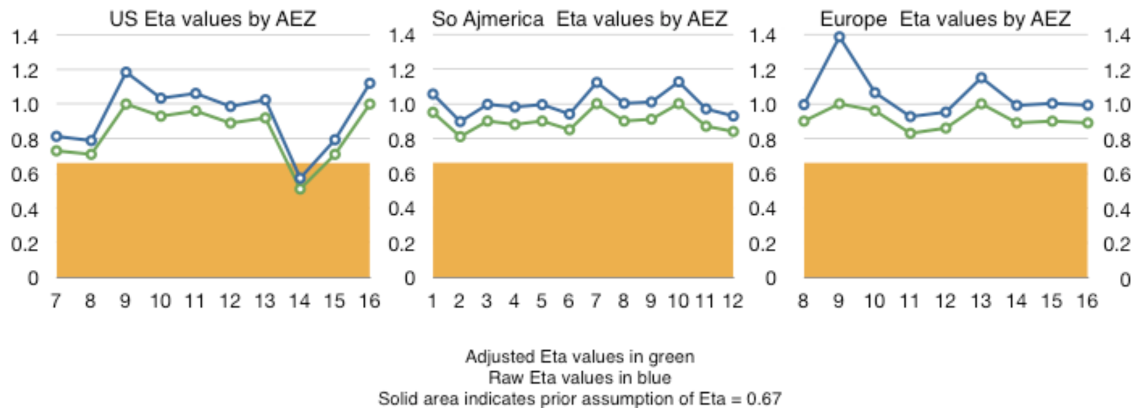


Figure 28. Selected values for Eta in different regions and AEZs

3.5.4 Alternative approaches to evaluating yields on new cropland

As a first pass, the ecosystem model based approach represents an improvement over the assumption of a fixed penalty yield applied across all new land in all AEZs. So, as a step toward improving CARB's estimates of land use effects biofuels, this new analysis should be adopted. In the near to long term, CARB should consider alternative approaches. One of the most serious limitations of this approach is that local management practices will have significant effect on actual crop yield once land is put in production. The ecosystem model does not take this into account at all.

Jon Foley's group at the University of Minnesota has created a global data set for agriculture that statistically predicts yield based on both climate and management practices. Using this data might enable analysts to combine available information (or at least assumptions about) management practices with climate to predict yields. Using an approach similar to the AEZ framework adopted by the GTAP modelers, Foley has broken the world into roughly 100 equal sized climate bins defined by indicators of moisture and length of growing season (growing degree days). These represent a substantial improvement in resolution over the 18 AEZs currently used in GTAP. These bins have been defined for each of over 170 individual crops. Figure 29 shows the binning for global wheat production.

The bounds of each bin along the y-axis (precipitation) and x-axis (growing degree days) are set in order to balance the number of pixels (area grid cells) across all one hundred bins. In the figure above, there is a color scale that has a maximum shown in yellow reflecting the number of grid cells at that point with exactly the same climate coordinates.

A combination of satellite data and census data is used to come up with estimates of yields within each bin. From this, it is possible to construct a profile from highest to lowest yield across each bin. An example is shown in Figure 30. The difference from lowest to highest yield is the yield gap associated with that climate bin.

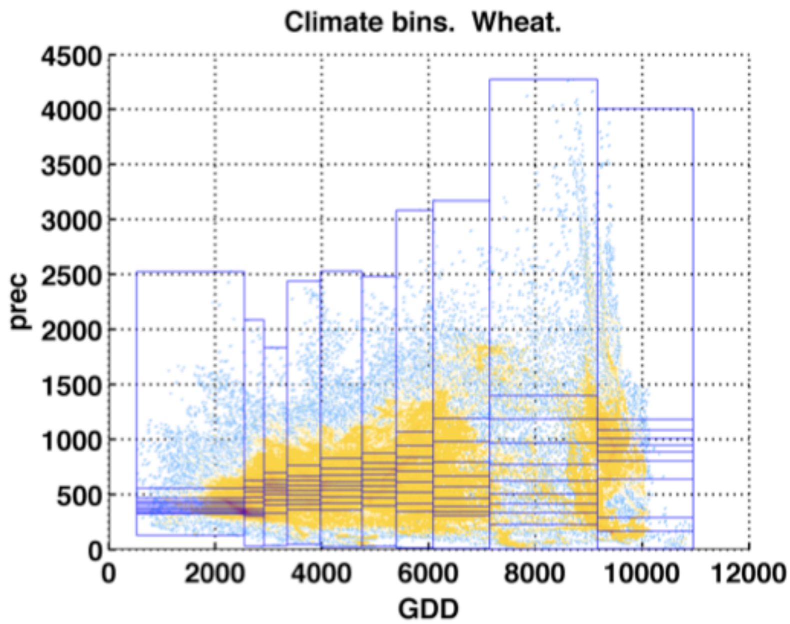


Figure 29. Climate bins defined for global wheat production

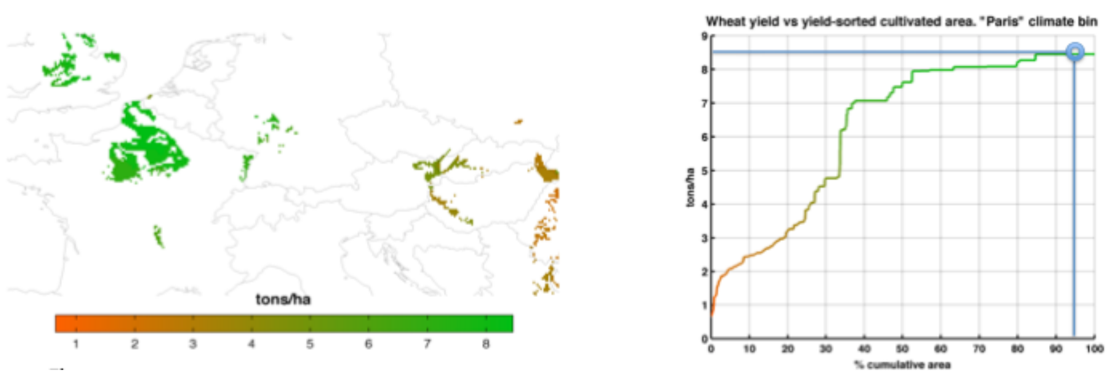


Figure 30. Example climate bin with yield data ordered from highest to lowest yield

Such results can be used to assess the potential for increasing agricultural production simply by closing that yield gap. Statistical analysis and data collection is now under way to explain the causes of the yield gap, including management practices. Figure 31 shows an example of statistical analysis of the effect of nitrogen fertilizer addition rates on yield within a given climate bin. Darker circles indicate greater numbers of data points aligned on the same coordinates of the yield/Nitrogen application rate graph.

A comparison of actual and modeled yield maps in Figure 32 illustrates how well the combination of climate and management data can be used to reproduce actual data for yield of corn globally.

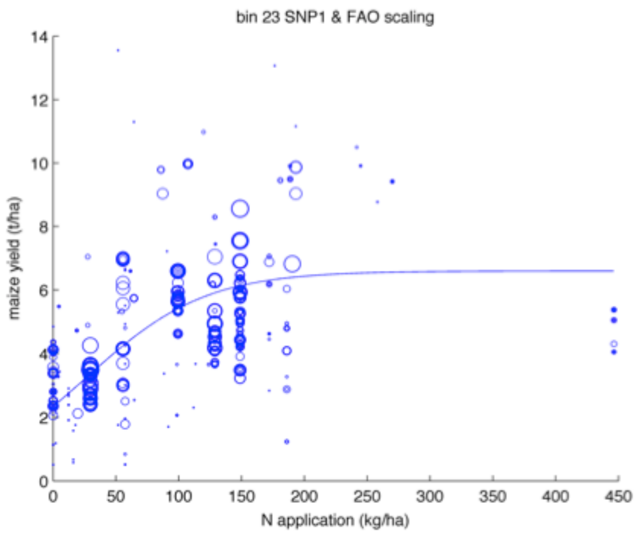


Figure 31. Logistic function fit to yield data and nitrogen addition data in a climate bin

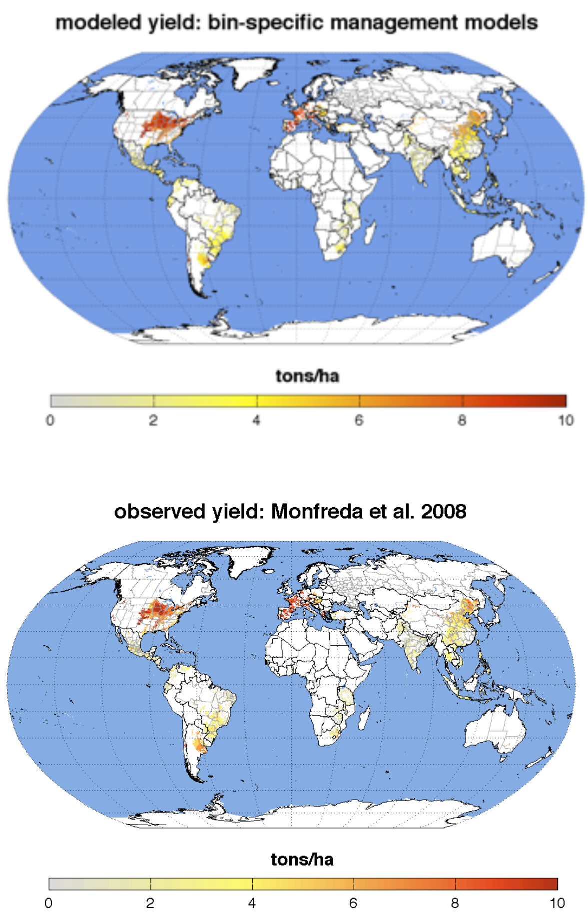


Figure 32. Modeled versus observed data for maize yields

4. Environmental Quality Issues

The selection of candidate land bases or pools needs to take into consideration how their long-term environmental quality will be affected as types of crops, rotations, field management practices, and yields are projected onto them. Environmental issues directly related to air, soil, and water quality vary widely due to local geo-climatic effects (soil topography, precipitation and temperature regime, etc.) and it is important as well to consider how the land was impacted due to previous use and managements, etc. Each of these will directly affect a lands propensity for soil erosion, maintaining soil tilth and contributing to local and regional water quality and runoff, etc. and in turn, will have a direct effect on land base selection. If certain aspects of environmental quality are low, then that land may not be converted or may provide low yields rendering it unusable for certain crops or bioenergy feedstock production. Therefore, it is important to account for these issues as we consider adding land pools such as unmanaged and marginal lands discussed earlier in the report, as well as for estimating yields for current and newly converted lands.

Material presented in the following portions of this section have a direct bearing on several of the previous sections in this report such as unmanaged and marginal lands and possible utilization of fallow or CRP acreages. The global agriculture sector land base is comprised of many different land classifications/types/pools, many of which are not included in GTAP. Cropland, range and pastureland, scrubland, and marginal acreages possess significant spatial and geo-climatic potential for possible alternate liquid fuel production. An assessment of these lands could/should include how the agronomics/environmental quality of the lands are affected due to moving different cropping systems (e.g., corn, herbaceous energy crops, or high-yielding oilseeds) onto lands not commonly utilized for bioenergy feedstock production. Databases such as the National Land Cover Database and other similar resources could be used to first evaluate select agriculturally-based cropping rotations or bioenergy feedstock production scenarios for providing sustained field-level environmental quality and then linked to other modeling databases such as GTAP to help guide appropriate land use decisions. This data could potentially be used in conjunction with other energy and economic modeling efforts guided toward estimating shifts in land use and production levels.

"Marginal" acreages exist that may very well have the ability to produce a number of other crops (e.g., canola, Camelina, flax, and safflower and herbaceous energy crops and sweet or photoperiod sorghum) which could potentially be used as bioenergy feedstocks while possibly providing environmental quality improvement over their current condition. Managed feedstock production has been shown to enhance environmental quality versus some conventional agriculture schemes through decreased soil erosion, moisture retention, and landscape diversity. These If these types of lands are to be considered in GTAP or other economic/trade models, the agronomic effect associated with incorporating different cropping systems/scenarios onto these lands definitely needs to be taken into consideration.

4.1. Environmental Quality Assessment of Land Bases and Potential Conversions

The global agricultural sector definitely has a potential role to play in helping meet the world's energy and economic security goals while maintaining or enhancing air, soil, and water (environmental) quality. Bioenergy/biofuel resource production almost exclusively requires a land base and how these lands are utilized and managed for bioenergy production is extremely critical in assessing the energy, environmental, and economic sustainability of bio-based renewable fuels as well as natural resources used for their production.

Cropland, range and pastureland, scrubland, and marginal acreages possess significant spatial and geographic potential for alternate liquid fuel production. Accurate assessment of the agricultural biomass resource base is critical to optimizing energy returns, providing environmental enhancement, and economic feasibility all of which help define "sustainability" with respect to alternate fuel development and production. An assessment of these lands must also include how the agronomics/environmental quality of the lands are affected due to moving different cropping systems (e.g., corn, herbaceous energy crops, or high-yielding oilseeds) onto lands not commonly utilized for bioenergy feedstock production.

4.1.1 Land Base Assessment – Utilization and Environmental Quality (United States)

The National Land Cover Database[5] has spatial information on select land uses such as cropland, forest, grassland/herbaceous, etc. Table 3 presents 15 separate land base categories as provided by the National Land Cover Database which include major land classifications/types of cropland, pasture, grasslands/herbaceous, forest, etc. Within at least some of these 15 categories separate SSURGO-based data[6] exists on a) land capability class, b) field topography (i.e., field slope, etc.), and c) soil texture characteristics provided mainly by data within the SSURGO database.

Table 3. Major land classifications (National Land Cover Database 2001)

Water	Barren land	Grassland/Herbaceous
Developed, open space	Deciduous forest	Pasture/Hay
Developed, low intensity	Evergreen forest	Cultivated crops
Developed, medium intensity	Mixed forest	Woody wetlands
Developed, high intensity	Shrub/Scrub	Emergent herbaceous Wetland

Lands potentially available for "new" production (commodity crops, dedicated energy crops, etc.) could use these databases as a starting point for evaluating impacts associated with sustained production concerning expected environmental quality and ecosystem services. The sub-categories of grassland/rangeland, pasture, cultivated cropland, and scrub/shrub in combination with detailed soils data regarding slope, available water capacity, etc. can provide a "first cut" as to what environmental quality improvements could 1) potentially be expected, and 2) what lands are "out-of-bounds" in the sense that

5 http://www.mrlc.gov/

6 http://soils.usda.gov/survey/geography/ssurgo/description.html

production of certain crops, rotations, field management practices, etc. are deemed to be unsustainable given the geo-climatic parameters of a particular geographic location. This data could potentially be used in conjunction with other energy and economic modeling efforts guided toward estimating shifts in land use and production levels.

4.2. Marginal lands and possible improvement with production changes

In addition to conventional agricultural commodity crop production (corn, wheat, soybeans, grain sorghum, etc.) on typical "cropping" areas, other geo-climatic areas referred to as "marginal" acreages exist that may very well have the ability to produce a number of other crops (e.g., canola, Camelina, flax, and safflower and herbaceous energy crops and energy sorghums (sweet or photoperiod) which could potentially be used as bioenergy feedstocks and at the same time provide environmental quality improvement over their current condition. These lands are broadly defined as those not as productive as current cultivated lands and also include sub-par cropland/cultivated, pasture, forest, and scrub/shrub, and range and in some cases can be combinations of these. Others probably exist, but are defined differently.

Currently, no real accepted definition of 'marginal land' exists via USDA, FAO, or other agriculturally-based organizations or credible entities, but in general it may be something of the order of: "Land, such as upland, or desert border, which is difficult to cultivate, and which yields little profit or return and may have been the first land to have been abandoned." Another definition may be: "Lands which can not adequately sustain required levels of production to at least maintain necessary soil health."

Several researchers and teams (Dale, Kline, et al. Wiegmann, Henneberg, and Fritschem, Lubowski et al) have proposed varying definitions of what constitutes one or more aspects associated with land deemed in a very large scope to be marginal. Many appear to be within a range of acceptable definition and in general marginal acreages involve probable past cultivation or some type of economic activity, but currently none of any real consequence and more than likely involve continued deterioration. In all of these cases degraded, idle, abandoned, waste, are words used to describe marginal acreages and fairly widespread agreement exist that marginal refers to a reduction in productivity of the land or soil and economics.

These type of lands have not been evaluated on a large-scale and with much detail and their possible utilization must be evaluated carefully at the very least from an agronomic standpoint as they have been classified due to one or more geo-climatic parameters such as higher field slopes, low water availability or precipitation, salinity, etc. and the choice of crops, rotation (if applicable), field management practices, etc. would have a direct effect on sustained soil and water quality. Databases such as the NLCD and other similar data resources could be used to first evaluate select rotations for providing sustained field-level environmental quality and then make appropriate environmental quality decisions. In addition, means to possibly evaluate select land bases on a spatial scale with environmental quality parameters for marginal lands/acreages include:

- Acreages in current Conservation Reserve Program (CRP) as select topological parameters are known for program enrollment

- National Resource Conservation Service (NRCS) – erosion index (EI) which is still used in the CRP program as one criteria
- Land capability classification[7] (LCC I-VIII)
- Rates/levels of commodity crop production (e.g., USDA Census of Ag 2002 and 2007)
- Select soil physical properties (e.g., bulk density, field slope, available water capacity, sand/silt/clay, etc.) available from the SSURGO and STATSGO databases

Soil and water quality improvements may be able to be made on these lands with respect to cropping selection and field management change(s) as a function of targeting this land base with the intent of not only cropping system diversity, but landscape diversity for enhancing local and regional environmental quality. Herbaceous energy crops such as big bluestem, switchgrass, and/or mixed grasses are candidate RFS-2 feedstocks that may be able to potentially meet RFS-2 goals. Managed feedstock production has been shown to enhance environmental quality versus some conventional agriculture schemes through decreased soil erosion, moisture retention, and landscape diversity. Advantages of these crops include possible environmental quality and enhanced economic return improvement on 'marginal' (e.g., lower land capability class) acreages not commonly used for commodity crop production, low field preparation/maintenance and chemical inputs over the production lifetime resulting in less fossil fuel inputs, and reduced water requirements. If these types of lands are to be considered in GTAP or other economic/trade models, the agronomic effect associated with incorporating different cropping systems/scenarios onto these lands definitely needs to be taken into consideration.

4.3. Recommendations for evaluating environmental quality issues

Near-term:

- Begin defining in economic and environmental quality terms what could potentially qualify as "marginal" lands that could potentially be used in GTAP and how they would accessed

Short-term:

- Investigate what needs to be included and what can realistically be done to really improve the "detail" of the model especially with respect to US production.
- Investigate what it would take for GTAP to incorporate environmental quality parameters and land cover types from SSURGO and the NLCD into the internal workings of GTAP.
- Get a much better definition of what does and what does not constitute 'marginal' acreage with respect to geo-climatic parameters as well as land-based agronomics.

Long-term:

[7] http://www.mn.nrcs.usda.gov/technical/nri/findings/cropland_lcc.htm

- Determine how soybeans (and other crops) are accounted for in cropping rotations and moved into other land pools in GTAP and does their movement onto other lands make agronomic sense?

5. References

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