Is Converted Land Less Productive than Current Land?

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

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

Some evidence of the extent of well suited land still available can be obtained from the work of Fisher et al (2002).[1] Utilizing their agro-ecological zoning, combined with land cover information, these authors estimated that close to 19% of the global land with rain-fed cultivation potential (Very Suitable, Suitable, and Moderately Suitable in their classification) was under forest ecosystems at that time. This would amount to an area of 464 million hectares out of a total of 2,430 million hectares. Considering only Very Suitable land, about 237 million hectares are occupied by forest ecosystems. While expansion over forest ecosystems should be discouraged, it seems the analysis conducted for CARB penalizes biodiesel twice; first by the alleged forest displacements, and second by yield reductions when the evidence indicates that there is still quality land available.

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

In this line, Table 2 presents regional information extracted from Table 5.13 in Fisher et al. (2002). While the land used in crop cultivation refers to the 1994-1996 period, the table indicates that globally, only half of the land classified as moderately suitable for rain-fed cultivation potential or better was being used for that purpose.

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

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

The extent to which agricultural expansion for biofuel production must all be accommodated by a combination of forestland and pastureland conversion could also be questioned. A recent peer reviewed study (Campbell et al 2008)[2] concluded that between 385 and 472 million hectares of abandoned agricultural land (cropland and pasture) could be brought back into production. It is important to notice that this figure excludes abandoned agricultural land that had transitioned to other ecosystems such as forest. The authors highlight that their estimates are between 66% and 110% of the figures reported in previous assessments. This indicates the numbers are consistent with the range provided in other studies.

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

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

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

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

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

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

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

precisely because of this differential yield growth. Higher yields make it more likely that farmers will choose to plant a crop.

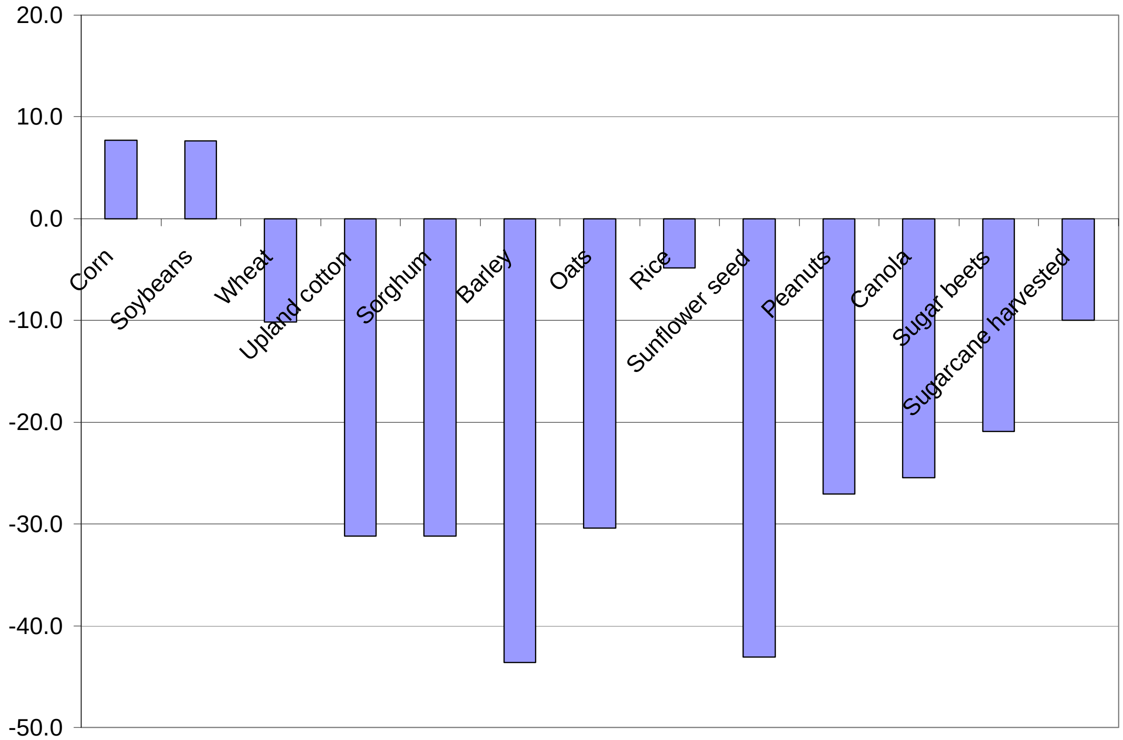

Figure 1. Percentage Change in Acres: 2009 vs 1998

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

How crop mix changes in the United States is the key to understanding how crop yields will change in response to new land being cultivated. A test of the CARB assumption would require a careful accounting for the dramatic changes in crop mix that the United

States has experienced in the last 10 years. Such a test is beyond the scope of this analysis.

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

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

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

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

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

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

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

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

which can be rearranged as

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

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

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

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

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

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

or

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

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

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

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

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

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

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

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

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

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

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

Data

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

Table 1. Regional Soybean Yields and Area in Brazil

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

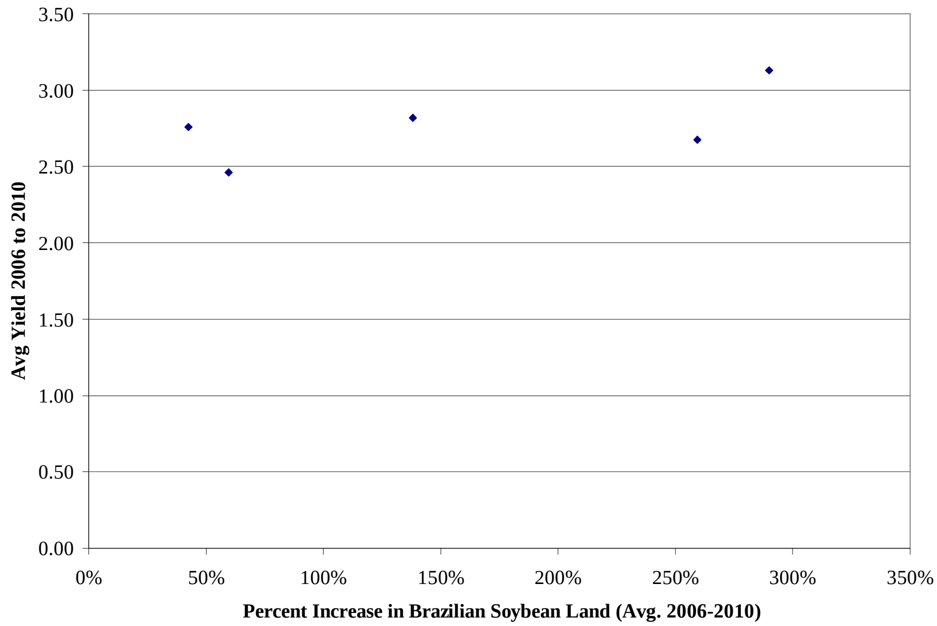

Figure 1. Relationship Between Recent Soybean Yields and Soybean Land Growth

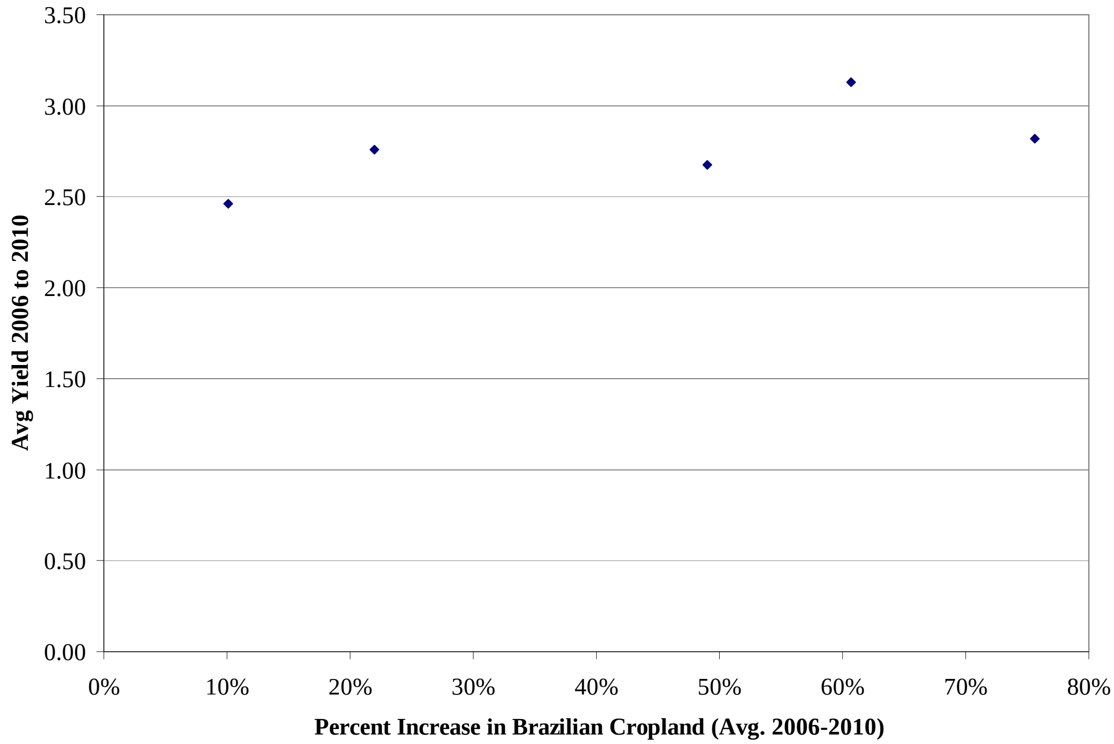

Figure 2. Relationship Between Recent Soybean Yields and Cropland Growth

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

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

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

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

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

Table 2. Regression Results

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

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

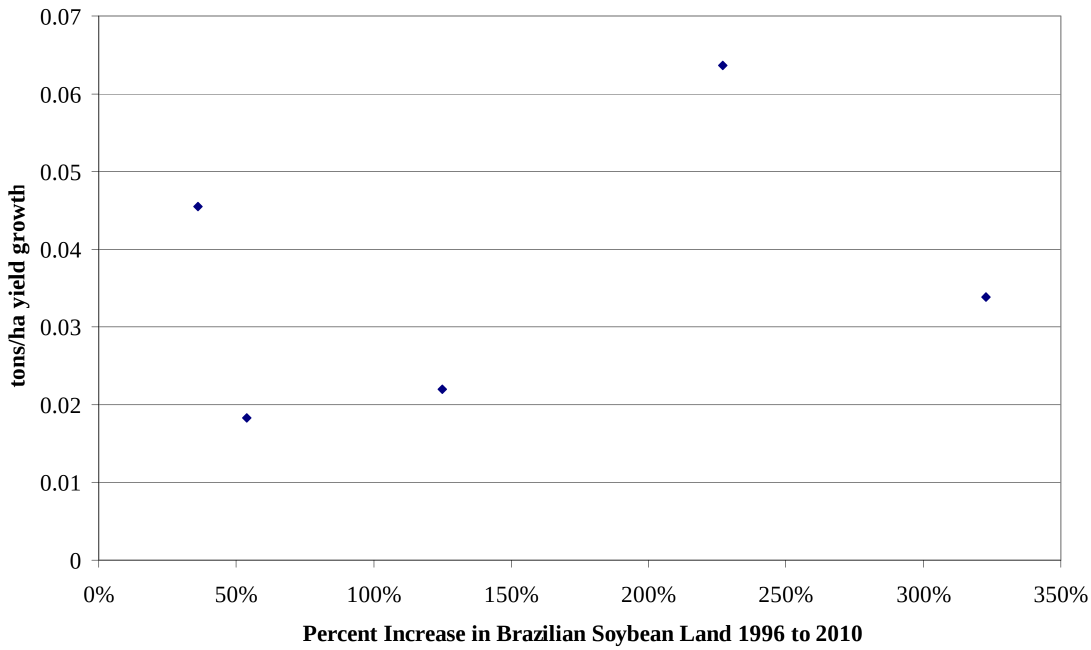

Figure 3. Relationship Between Soybean Yield Growth and Soybean Land Growth

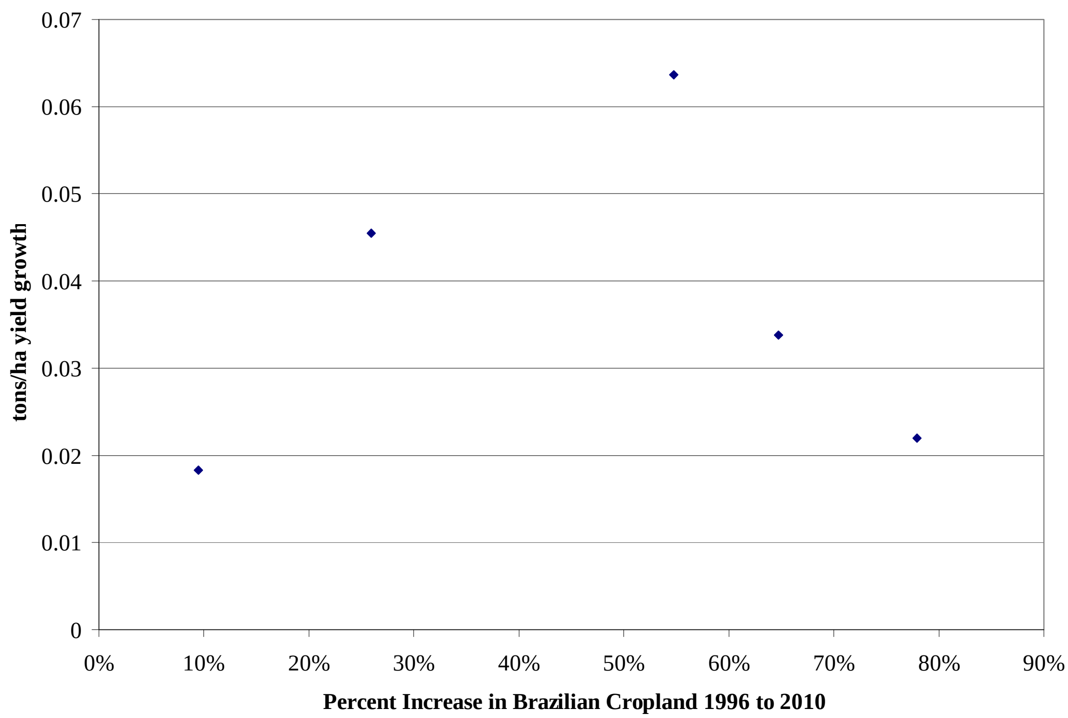

Figure 4. Relationship Between Soybean Yield Growth and Cropland Growth

Concluding Remarks

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

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

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

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