Rain Followed the Plow: What is the Potential for Land Cover Change to Impact the Precipitative Sources of Earth's Breadbaskets?

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Where are the major food producing regions of the world?

Data and Models:

To identify the major crop producing regions of the world we used crop data from Monfreda et al. (2008), which provided global harvested area for a multitude of crops on a 5'x5' grid.

We used monthly mean evaporative source data from Dirmeyer and Brubaker (2007) to determine the sources of moisture for each breadbasket region. This dataset mapped the locations where precipitation that falls at a given gridpoint last evaporated off the earth's surface on a T62 grid. It was developed by combining observed precipitation data with modeled back trajectories of water vapor for the 1979-2004 time period.

Finally, we used 25-year simulations of the PEGASUS model at 5' resolution to model changes in crop yield and surface fluxes due to land cover change (Deryng et al. 2011; Bagley et al. 2011).

Introduction:

Several recent studies have investigated how crop yields may be influenced by changes in climate due to anthropogenic greenhouse gas forcing. However, there have not been any assessments of the impacts of changing land cover on global crop yields. In this study we examined the potential impacts that land cover change (LCC) may have on the major food producing regions of the world. Specifically, we used a simplified linear model to set bounds on the extent that changes in evapotranspiration due to LCC may influence precipitation and crop yields within earth's breadbaskets and address the following questions:

1.) Where does the moisture for the major food producing regions of the world come from?

2.) What is the potential for the moisture sources of earth's breadbaskets to change due to alterations in land cover?

3.) What bounds can be placed on the impact of land cover change on crop yields?

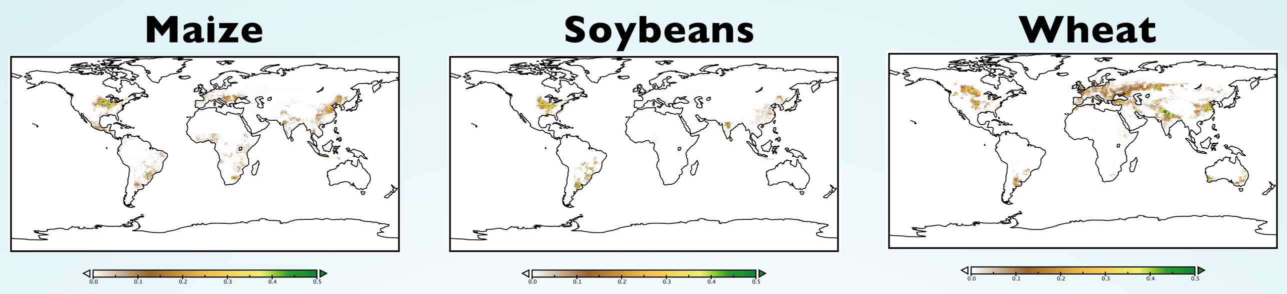


Figure 1: The The observed fractional area (-) of maize (left), soybeans (middle), and wheat (right).

Linear Model:

To calculate changes in precipitation due to LCC we used the following equation:

$$F_i = \frac{P_i'}{\bar{P}_i} = \frac{\sum_{j=1}^{n} \bar{s}_{i,j} \cdot A_j \cdot \frac{E_j'}{\bar{E}_j}}{\sum_{j=1}^{n} \bar{s}_{i,j} \cdot A_j}$$

where P is precipitation, s is evaporative source, A is area, and E is evapotranspiration.

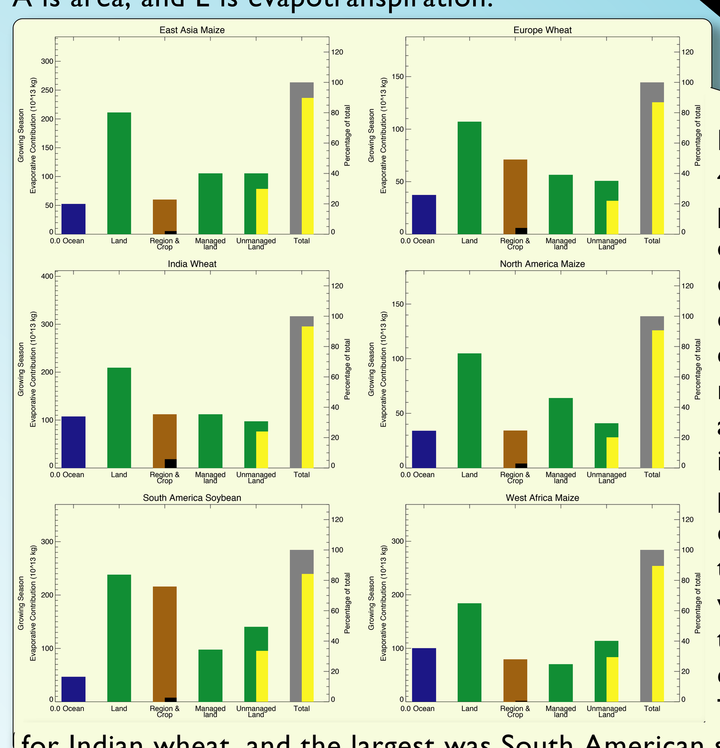


Figure 4 provides quantitative estimates of the evaporative source contribution for relevant areal groupings, and shows the potential impact of LCC on precipitation via changes in evaporative source. We found that the impact of removing vegetation from unmanaged land typically reduced precipitation over crops (yellow bars) between 7-17%. The smallest impact was found to be for Indian wheat, and the largest was South American soybeans and European wheat.

What is the potential for land cover change to impact breadbasket moisture sources?

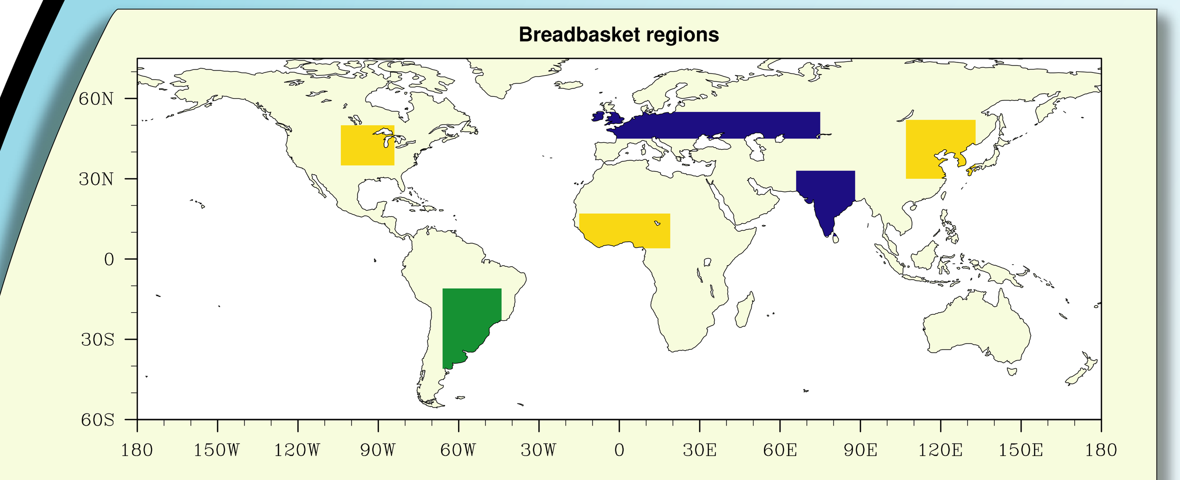
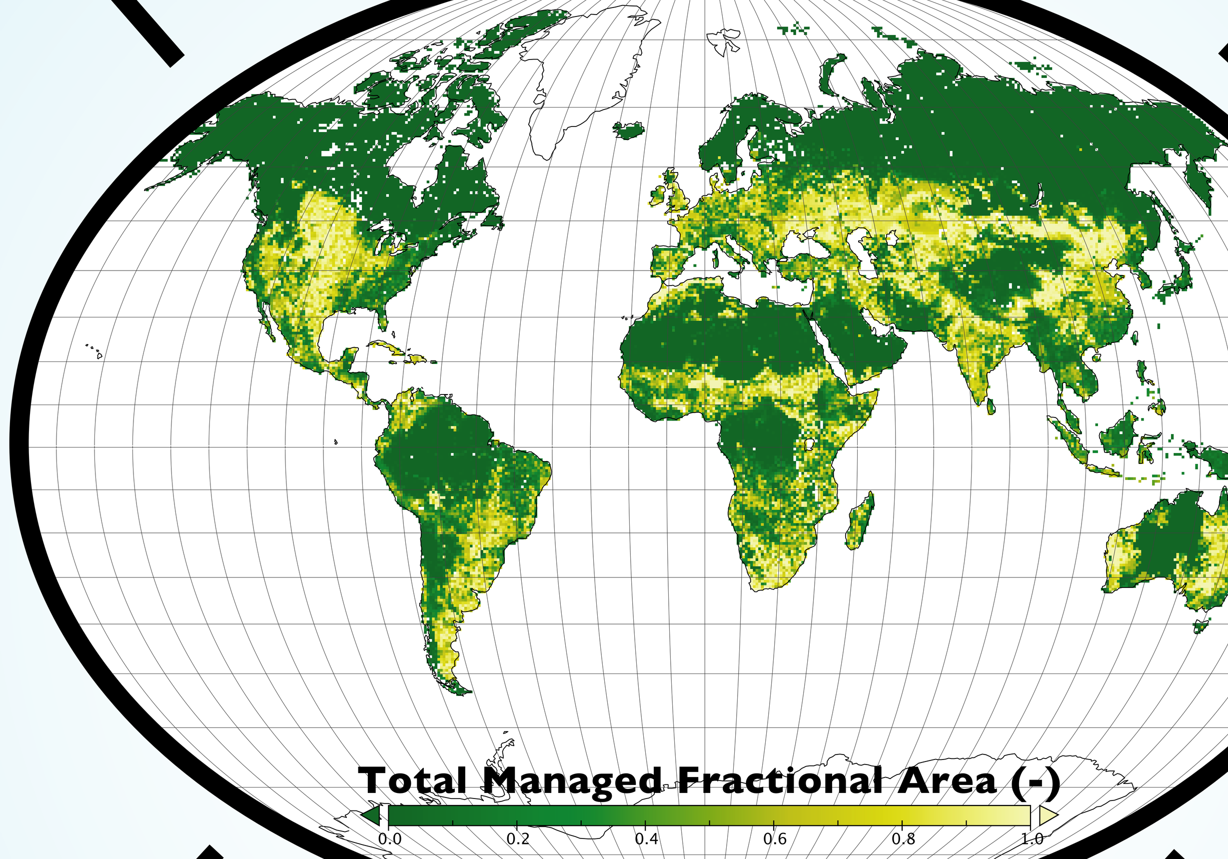


Figure 2: The maize (yellow), soybean (green), and wheat (blue) growing regions used in this study.



Simulations: In order to test the impact of varying LCC scenarios on precipitation and crop yield we ran a series of 25-year simulations for each region:

1.) Control simulation with potential vegetation.

2.) Bare-soil scenario with all vegetation removed. This represented the maximum potential impact for the purposes of this study, and is shown in yellow bars in Figure 4 and green points in Figure 5.

3.) 5% increments of LCC assuming gridpoints with 0% managed area remain so, locations > 3000km away do not impacit evaporative source in a region, and those points with large % of managed and are closest to local maxes in crop fractional area are converted first (Figure 5).

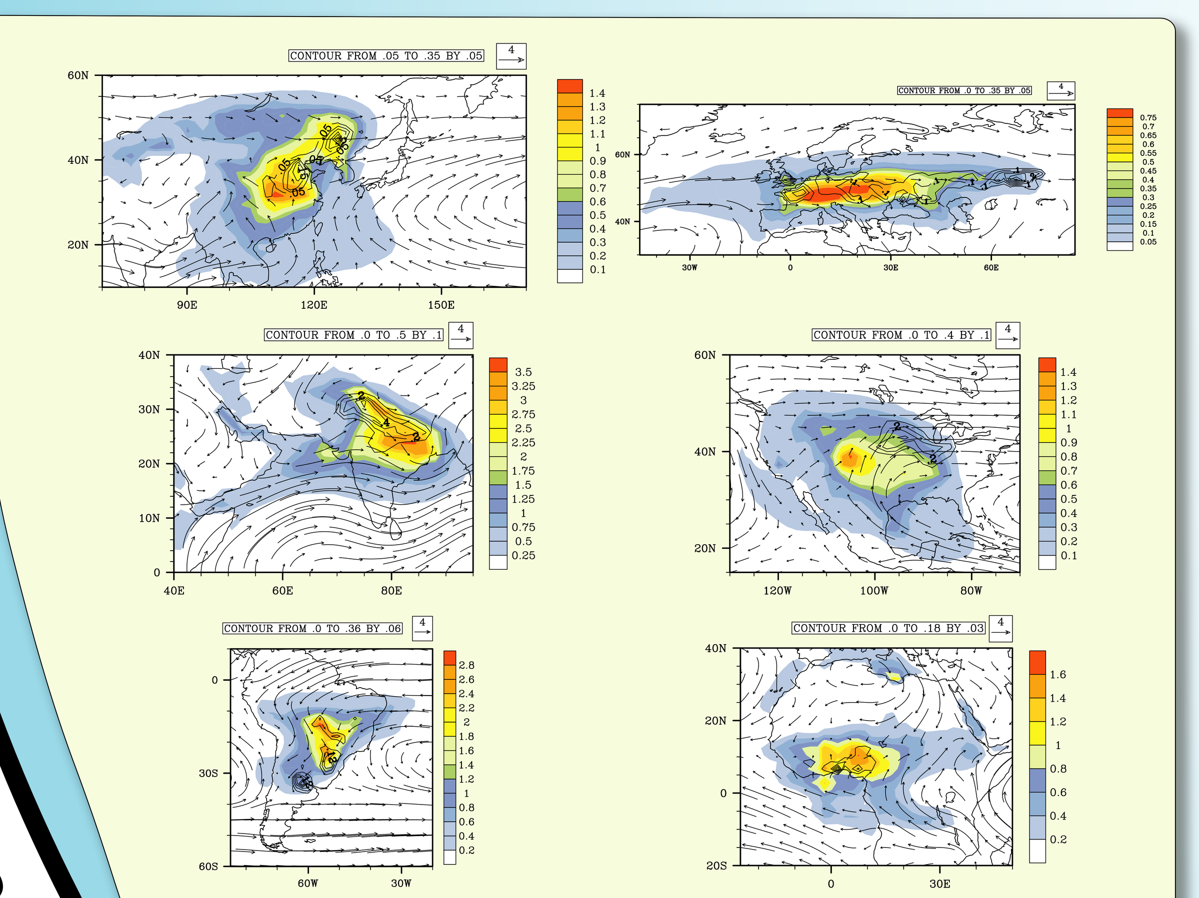


Figure 3: Evaporative source (mmH2O*m-2) of crop growing sections of each region during its growing season as defined by planting/harvesting dates (shaded). Also shown are the observed crop fractional area (-) (contours), and NCEP Reanalysis-II 850mb climatological winds (m/s) (arrows).

Using the crop data from Figure 1 we selected six regions as breadbaskets to be the focus of this study. These regions are shown in Figure 2. The regions chosen were maize in the Midwest United States (US), soybeans in Southeast South America (SA), maize in West Africa (WA), wheat in the European-Asian wheat belt (EUR), wheat in India (IND), and maize in East Asia (EA). The specific breadbasket regions shown in Figure 2 were chosen taking several factors into account. First we selected regions that represented major crop producing regions. Second, regions were selected to be geographically distinct and represent unique ecosystems. Finally, we selected regions that represented a diverse range of climatological and meteorological conditions.

With the evaporative source dataset described above we calculated the total evaporative source of precipitation that falls over the fraction of each region that contained the specified crop. This was done for the growing season of each of the breadbasket regions. This is shown in Figure 3.

In general, we found that that the evaporative source patterns were strongly related to low level climatological winds, which were driven by local meteorology. The SA and EUR regions were noted as being strong candidates for impacts from LCC, as a large fraction of their evaporative source was terrestrial in origin.

Conclusions:

- Alterations to biosyical regulation of surface energy balance and moisture flux due to LCC has the potential to influence precipitation and crop yield in breadbasket regions.
- The evaporative source of breadbasket regions depended on both local meteorological conditions and regional vegetative cover.
- Precipitation in all regions was found to be susceptible to changes in evaporative source due to LCC.
- Reductions in precipitation ranged 5-16%. Reductions in yields ranged from 0-23%.
- Regions with mean soil moisture fraction > .65 had minimal changes in crop yield due to LCC.
- Greatest impacts found for South American soybeans and European wheat.

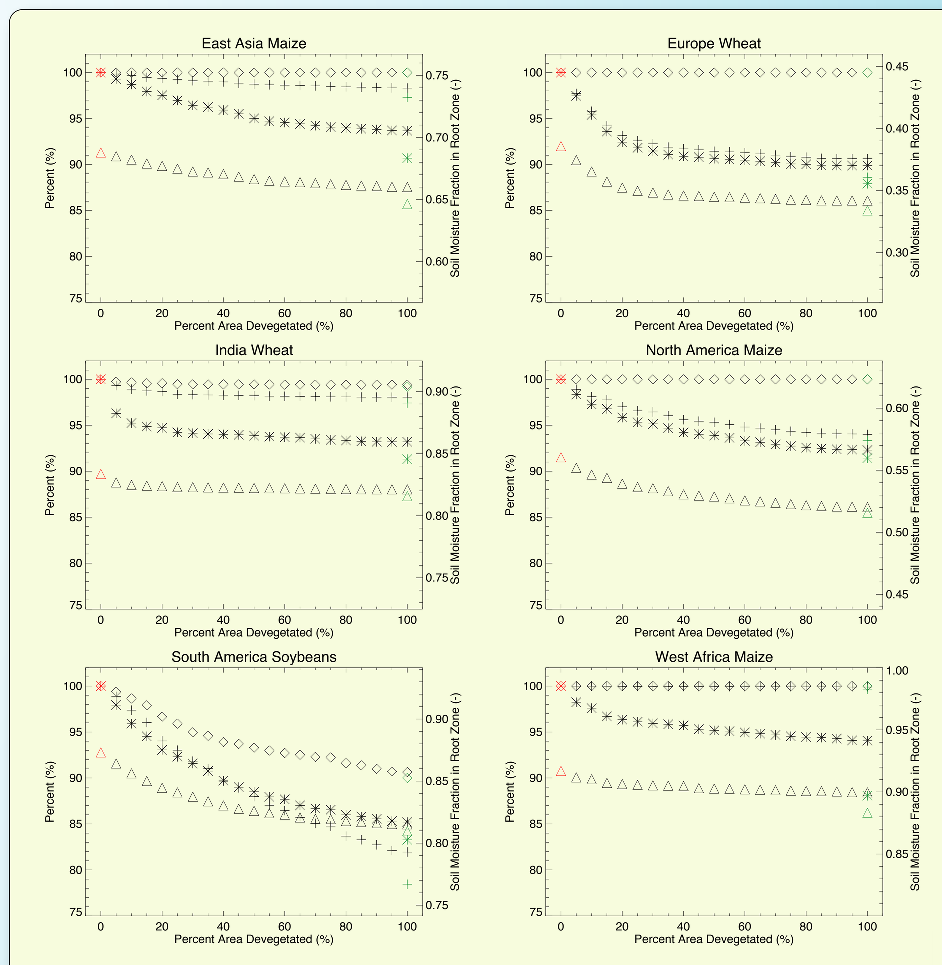


Figure 5: The change in mean precipitation (asterisks), total crop area (diamonds), mean soil moisture fraction in the root zone (triangles), and total crop yield (crosses) for increasing LCC. The mean precipitation, total crop area, and mean soil moisture are represented as a the percentage of their climatological control run values, and the mean soil moisture fraction in the root zone is shown as its raw value. Also shown for each of the above quantities are the results form the climatological control run (red points), and the bare soil scenario (green points).

When humans modify a landscape it is well understood that the surface energy balance changes and water vapor flows from the landscape are altered as the partitioning of water to evapotranspiration, runoff, and soil-vegetation storage are perturbed. As the flux of water from the land to the atmosphere is changed on climatological timescales, a remote region whose evaporative source footprint encompasses the area of LCC will have its precip perturbed (Figure 4).

Figure 5 shows the impact of incremental vegetation removal on crop yield, as well as the total vegetation removal scenario from the previous section. We found that for total vegetation removal the impact on crop yield was greatest for South American soybeans where a 15% decrease in precipitation caused a crop yield reduction of ~22%, and the least for West African maize where a 5% decrease in precipitation had a negligible impact on crop yield. There were also critical differences in the rate at which crop yield responded to land conversion. For example for European wheat 80% of the total potential change in crop yield occurred with just 30% of the available vegetation removed, while for South American soybeans only ~39% of the total potential change in crop yield occurred with 30% of available vegetation removed. This suggests that moisture that contributes to European wheat growth is particularly sensitive to changes in terrestrial LCC in the region.

However, it should be noted that this model doesn't account for changes in circulation or stability associated with LCC.

Where does the moisture for the major food producing regions of the world come from?

What bounds can be placed on the impact of land cover change on crop yield?

References:

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