

Reviewer 1.

Subject: Review of MS902 for Economics-ejournal

Date: April 9th, 2013

Reviewer comments in black, our responses in red.

1. The contribution of this paper is potentially extremely significant but it is difficult for the reader to ferret this out. I am assuming that the audience is expected to be individuals for whom the subject of this article is not their specific field of study. There are a number of important climate modeling runs initially that provide valuable information. However, as one moves into the scenarios the paper needs more description and interpretation. For example, it is difficult to interpret something like figures 7 & 8 and what they are intended to convey. What meaning is the reader to attach to the differences in the basic characteristics of the different models used?

We add the following in the Impacts of Climate Change (p.3-4):

“All models use the same basic set of physics equations, but each has slightly different ways of representing land surface, cloud, and precipitation processes. Over multi-decadal time periods used in this application, the accumulated differences are large but still well within plausible limits. Since all are consistent with the basic physics of climatic conditions, we interpret these to be different possible realizations of the climate of mid-21st Century. By using all four models to provide input to crop models we create an ensemble of possible yields consistent with this ensemble of possible climates. The range of yields produced by these four climate models can be interpreted as one (maybe not the only one) measure of uncertainty in future yields due to uncertainty (but within the range of physical consistency) in climate model representation of the mid-21st century.”

Figures 7 and 8 are shown to give readers a feeling for the variability of potential climate effects, as depicted through changes in precipitation and temperature, that exists across all US crop growing regions. Because different growing conditions are projected by different models, each using the same basic physical constraints, it is revealing to trace out (see Figures 12-15) how these changes play out in crop yields. For instance, the Canadian model (CNRM) results show significant drying (Figure 7) and much warmer conditions (Figure 8) in southern Kansas and Missouri compared with other models. Tracing the impact of this pronounced climate change onto yields reveals that the regional climate of this geographical region will be unsuitable for maize (Figure 12) and soybean (Figure 14) production if the Canadian model is correct. Other models disagree, however.

2. In Figures 12-15, can something be said about why these resulting yield differences occur? What are the important model artifacts that give these different results? In Figures 14 and 15, what brings about these yield increases (the green areas) and how significant are they? How do the differences above relate to what then goes into the IMPACT model?

A rather usually high level of model agreement is shown in, say, Figure 14 for substantial increase in soybeans yields north of 42° N latitude. Having grown up and still connected to agriculture in southern Minnesota (a major “green” area of Figure 14) I have seen soybean yields double since 1960s (significance) due to higher precipitation and 2-week longer growing season (reasons). Average summer temperatures have increased but mostly due to higher nighttime temperatures because higher precipitation is suppressing increases in maximum daytime temperatures - all in all, a much more favorable condition for soybean production. All models used herein project this recent trend to continue.

Combining this discussion with discussion from the previous comment we provide added narrative (p. 12):

“Regions already marginally too dry and/or too warm for rain-fed maize (on the southern and western boundaries of high producing areas shown in Figure 3) experience significant yield loss

under reduced precipitation (Figure 7) and/or high temperatures (Figure 8) associated with the CNRM and MIROC model results for 2050. For instance, the Canadian model (CNRM) results show significant drying (Figure 7) and much warmer conditions (Figure 8) in southern Kansas and Missouri. Tracing the impact of this pronounced climate change onto yields reveals that the 2050 climate of this region will be unsuitable for maize (Figure 12) and soybean (Figure 14) production if the Canadian model is correct. Other models disagree, however. Production of soybean varieties that are more heat-tolerant than other varieties, by contrast, declines somewhat less with increased temperature but substantially increases north of 42°N latitude where warmer 2050 temperatures, combined with higher levels of precipitation, declines create a longer and more favorable growing season. All models are in general agreement with the need to develop heat-tolerant crop varieties.”

3. Beginning on page 18 with the IMPACT model, interpreting what is going on becomes more difficult with the increase in the number of combinations and permutations. IMPACT adds on a supply/demand/trade/price model and the results from these runs are difficult interpret. Since we have now combined climate, plant growth, economic factors, etc. the complexity is such that the reader looks at the results with little understanding of what is driving the results or what they mean. What are the major drivers, and for which scenarios? With many possible combinations and permutations the results become much less meaningful. The reader has difficulty tracing back things that may have been obvious to the writer. (Maybe if one took one of the whiskers and deconstructed/partitioned it by the different climate models or other main drivers, that might help give an understanding of what was behind it.)

Narrative is added on p. 20 to trace specific lines of impacts of the optimistic and pessimistic assumptions:

“IMPACT is a dynamic model, and changing any input in the model can create different countervailing reactions. In the case of maize, a pessimistic world would see an increase in global population and lower global GDP; increases in population of lower income consumers would stimulate the demand for staples like maize. In an optimistic world we would see increases in income, which would lead to improving diets and a larger demand for high value products like meat. Higher demand for meat would stimulate the livestock feed demand for maize. Therefore, one might get similar results for a single commodity market, but derived from very different variables.”

A brief discussion of Figures 18-23 is added to draw attention to the impact of assumptions of economic and demographic factors (p 20):

“An overview of Figures 18-23 shows that economic and demographic factors (optimistic vs pessimistic) have quite limited impacts, except on exports, on all grains except rice. The range of climate effects is revealed in the box and whisker plots. In most cases the range of possible climates introduces more uncertainty in predictions than do economic/demographic factors. The graphs show that, compared to a pessimistic future, an optimistic economic/demographic future predicts higher exports for cotton, soybean and “other grains” but lower exports for maize, rice, and wheat. Furthermore, an optimistic future creates lower prices for all commodities except soybeans.”

See also our response to item 6 below.

4. There are some additional problems with clarity. For example, on the middle of page 19 there is a note that talks about “s most optimistic future yields for corn and soybeans falling far short of the late 20th century. The reader then goes back to the referenced figures 10 and 11 and looks at the IMPACT Max lines which appear to rise well above the late 20th century seven year moving average.

We thank the reviewer for pointing out this need for precision in our statement.

We wrote: “Note that, even for the IMPACT model’s most optimistic socio-demographic and climate-favorable future, maize and soybean yields (Figures 10 and 11, respectively) fall far short of the late 20th century.”

We change this to (p. 21):

“Note that, even for the most optimistic socio-demographic and climate-favorable future predicted by the IMPACT model, maize and soybean yields (Figures 10 and 11) fall far short of the extrapolated trend from the 20th Century that has been and will continue to be a target for meeting global demand for these commodities. These results are consistent with a recent summary (Walthall et al, 2012) that predicted that continued climate change in the U. S. will have overall detrimental effects on most crops by mid-century and beyond. Although some recent declines in maize yields in many countries have been attributed to warmer temperatures associated with climate change (Lobell et al., 2011; 2013), reduction in daily maximum temperatures in the U. S. Midwest (Talle, 2011) likely have contributed to yield gains for maize and soybeans (Lobell and Asner, 2003).”

5. In looking at the IMPACT whisker graphics for the various crops (figures 18-23) is it possible to say more about what drives them? Why in some instances are the pessimistic, baseline and optimistic outcomes the same? How much is it prices, how much climate, how much population growth? There is no discernible set of results here relating specifically to economics.

The results aren’t the same, though there are instances where they are very similar. We add the following narrative on p 20:

“IMPACT is a dynamic model, so changing any input can create different countervailing reactions. In the case of maize, a pessimistic world would see an increase in global population, and lower global GDP. Increases in population of lower income consumers would stimulate the food demand for staples like maize. In the optimistic world we would see increases in income, which would lead to improving diets and a larger demand for high value products like meat. Higher demand for meat would stimulate the livestock feed demand for maize. Therefore, one might get similar results for a single commodity market, but have very different reasons for reaching that result.” [see changes made in this paragraph above]

And further on p. 20 (as mentioned in item 3 above) we add: [see changes above]

“An overview of Figures 18-23 shows that economic and demographic factors (optimistic vs. pessimistic) have quite limited impact, except on exports for all grains except rice. The range of climate effects is revealed in the box and whisker plots. In most cases the range of plausible climates introduces more uncertainty in future results than economic/demographic factors. The graphs show that, compared to a pessimistic future, an optimistic economic/demographic future has higher exports for cotton, soybean and “other grains” but lower for maize, rice, and wheat. Furthermore, the optimistic future creates lower prices for all commodities except soybeans.”

6. The reader also needs information about the 3 graphics on pages 26 & 27. Are these to separate out the climate change impacts from all the other factors included in IMPACT? If so, what does the graphic tell us?

These three graphs and accompanying narrative are eliminated from the manuscript.

7. This article leaves the reader with the “so what” question. The work may have high internal validity, but it is not presented in a way that makes the results interpretable or very usable.

We summarize here the key changes we have made to address this overarching concern. We point out that our summary here also includes changes made in response to online comments we received (see below), which further respond to the “so-what” question.

- a) The introduction has been expanded (last three paragraphs) to outline the motivation and methods we used.
- b) In the Impacts of Climate Change section we describe how by use of four global climate models we show a range of yield outcomes, thereby revealing how significantly climate change contributes (as compared to, say, prices or economics/demographics) to changes in food security. We also add interpretation of the climate outcomes (item e below)
- c) The example of item 2 above shows a clear link from the climate change scenario to the future yield scenario.
- d) More explanation of the IMPACT model is given to provide insight into the interaction of various drivers.
- e) The conclusions link more closely to the high points covered in the body of the report,

We hope these many additions and clarifications will allow the non-specialist to gain a deeper understanding of the interaction of many biophysical, climate and economic factors on future agricultural productivity in the U.S. We thank the reviewer for very constructive comments that led to improvements in the manuscript.

Eugenia Serova, Food and Agriculture Organization of the United Nations - Reader report
March 05, 2013 - 11:05

The paper is dedicated to a very acute topic of impact of the climate changes on agricultural production; the topic is considered by example of the USA, one of the biggest agricultural producers in the world. The authors use four global climate models in order to simulate the change in US climate and assess the impacts on production of four key crops in the first half of 21 century. The paper is very well illustrated by simulation maps; visualization of the model results is very high. The paper is based on a quite good reference list. The conclusions are seemed to be relevant and reliable.

At the same time, we would recommend to notably improve the structure of the paper. The own approach for modelling should be clearly described at the beginning of the paper and evidently distinguished from the results of the other models' simulations. The majority of maps are not supplied with sufficient explanations. For the works dealing with model simulation the assumptions are very important, but the authors of referred paper do not provide any discussion regarding their assumptions. Also it is not clear what type of input data was used for modelling. All of this reduces a value of findings for the readers.

Also we would like to stress that the authors assess an impact of climate change on food security in the USA. Not clear how the results in production of the key crops discussed in the paper can affect food security of the country which is a major net exporter of these crops (not to say that cotton production is least important for food security). On the other side, farmers' income issue is completely not addressed. In spite of small climate based changes in overall US production of the crops under consideration, the regional changes in production are predicted in presented scenarios and these changes can have critical effects on farm income distribution.

There are several minor comments which we inserted into the original text of the paper (see attached file). Only two of them worth to mentioned here. Abstract of the paper does not present the actual content of the paper. Equally Conclusions are not based on the findings of the paper, contain the quotations from other authors and are quite poor for the paper presenting such profound and expanded study.

Here is a summary of the specific comments and additional comments in the manuscript

Specific comments

1. "The own approach for modelling should be clearly described at the beginning of the paper and evidently distinguished from the results of the other models' simulations."

This comment is unclear whether it refers to (a) the broader IAM modeling approach used in the paper, or specifically to (b) the "own-crop" terminology used for interpreting results of Figures 24-26. We provide responses for both interpretations.
 - (a) Yield reductions below expectations for well-managed crops in any given year are largely due to less-than-favorable weather conditions during the growing season. Global climate change caused by increasing accumulations of heat-trapping gases is expected to create climate conditions outside the range of observations over the last hundred years. We use results of widely accepted global climate models to project changes in climate over the next 40 years to assess their impacts on yields, both directly through crop-climate interactions and indirectly through prices, income, and international trade. ((we insert this as the fourth paragraph of introduction))
 - (b) We have eliminated Figures 24-26 and their accompanying narrative.
2. "maps are not supplied with sufficient explanations."

see below
3. "authors of referred paper do not provide any discussion regarding their assumptions"

We clarify our underlying assumptions:

We take population scenarios from different population variants of the UN Populations Prospective 2010 Revision (introduction).

GDP scenarios are based on work done in the Millenium Economic Assessment by the World Bank (p. 9)

We combine these drivers to create socioeconomic scenarios that range from optimistic (high GDP, low population) to pessimistic (low GDP, high population) (p. 9).

We use several different GCMs, which were chosen to show some of the variability of climate projections coming out of the different GCMs. Different GCMs were chosen to reflect extreme and less extreme climate effects (p. 3)

The climate futures, and socioeconomic futures were combined into 15 scenarios, which were meant to create a fairly broad range of plausible futures, which serves as a useful data set to calculate the many and unknown effects of climate change in the future (Figures 18-23).

4. “Not clear how the results in production of the key crops discussed in the paper can affect food security”
We add the following:

“We focus on five crops that are widely traded through international markets and also consumed directly as human food or indirectly through cooking oil or feed for animals that produce meat, milk, or eggs. We do not address contributions to food security from locally grown fruits and vegetables and lower-volume components of international commodity markets.” ((last paragraph of Introduction))

5. “farmers’ income issue is completely not addressed.”

We add the following:

“In our modeling framework, producers of these commodity crops protect their income by responding to price signals through changes crops planted and other management strategies.”

6. “Abstract of the paper does not present the actual content of the paper.”

Abstract has been revised to link specifically to findings in the paper.

7. “Conclusions are not based on the findings of the paper, contain the quotations from other authors and are quite poor for the paper p[resenting such profound and expanded study”

The conclusions are rewritten to eliminate citations of related work (which are now cited in the body of the paper and discussed in the context of our results.

Additional comments in manuscript:

8. Evidence for “Higher temperature and humidity eventually reduce yields of agricultural crops and tend to encourage weed and pest proliferation.”

We added the following references in 3rd paragraph in section on Impacts of Climate Change:

Lobell, D.B. and S.M. Gourdji, 2012: The influence of climate change on global crop productivity. *Plant Physiology*, **160**, 1686-1697.

Lobell, D. B., G. L. Hammer, G. McLean, C. Messina, M. J. Roberts, and W. Schlenker, 2013: The critical role of extreme heat for maize production in the United States. *Nature Climate Change*. DOI: 10.1038/NCLIMATE1832.

Oerke, E.C. 2006: Crop losses to pests. *Journal of Agricultural Sciences*, **144**, 31-43.

9. Need comments on: Figures 2--6 are the estimated yield and growing areas for five key US crops: cotton, maize, rice, soybeans, and wheat. These figures are based on the SPAM data set (You et al. 2009), a plausible allocation of national and sub--national data on crop area and yields. Note that the production (MT) for a particular location is the product of the yield (MT/ha) times the area harvested (ha).

We insert the following (p 5):

“These figures represent the results of the Spatial Production Allocation Model (SPAM) data set (You et al, 2009), which takes data from international, national, and subnational sources as well as land quality and crop suitability maps and attempts to reconcile them using an entropy method to estimate where the crops are likely grown within a country. This spatial allocation of crop production is used as an input to the IMPACT model, to allow us to correctly assign production from FAO’s national statistics to the Food Production Units (FPUs – intersection of national boundary and watershed) within IMPACT. The correct allocation of crops to subnational levels is also essential with respect to climate change, as climatic change has an obvious local effect on agriculture, and better spatial disaggregation will improve the capacity to model climate change’s effects on agriculture.”

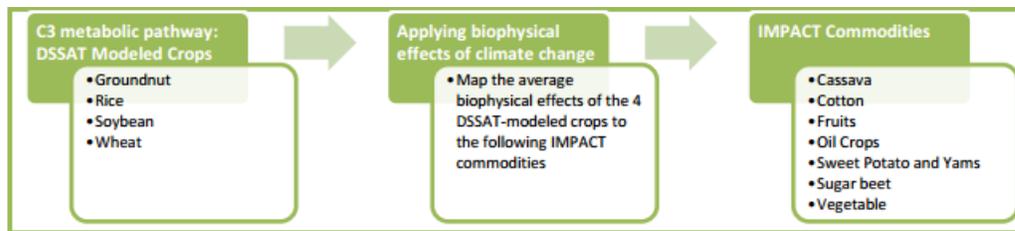
10. The scenarios of these figure should be better explained:

The output for key crops is mapped in Figures 12--15. The comparison is between the crop yields for 2050 with climate change compared to the yields with 2000 climate. We add narrative on p. 12:

“Downscaling climate change as modeled by GCMs to local scale is essential to trying to model the effects of climate change on agriculture. Using the spatial allocation of crops from SPAM, we then downscale climate effects to the pixel level and then use DSSAT model crop production at the pixel under the downscaled climate effects in 2050 from four GCMs. These results are then compared to the crop yields that were modeled for the 2000 climate. The output for key crops is mapped in Figures 12-15. Each figure overlays these results on a map to show the changes in crop yield between 2050 and 2000 as a consequence of the different GCMs. Each GCM projects different changes in local temperature and precipitation, and these figures illustrate how these differences can create even greater variability of its effect on agriculture.”

11. Cotton was not modeled in DSSAT due to para 1 in this section. How was this figure simulated: Figure 9

DSSAT currently models a limited number of crops, for crops like cotton that are not currently being modeled in DSSAT we apply the average climate effects of the commodities that are modeled by DSSAT and apply this average climate effect to the cotton yields.



We add narrative on p. 12:

“For crops like cotton that are not currently being modeled in DSSAT we apply the average climate effects of the commodities that are modeled by DSSAT and apply this average climate effect to the cotton yields.”

12. Not clear what this picture depicts: Figure 16

We add narrative on p. 19:

“Figure 16 is a schematic of the interaction of different drivers within the IMPACT model. IMPACT is an iterative model that dynamically solves for the world prices that ensure global supply equals global demand. The schematic shows the interaction of different drivers, both endogenous and exogenous. The orange arrows describe where exogenous inputs define the behavior of the dynamic actors (elasticities) and how they change over time (growth rates). The black arrows show the interplay of dynamic actors in determining equilibrium. To model results for multiple years, the model must be shocked exogenously (growth rates) to force it out of equilibrium, and cause the dynamic drivers within the model (supply, demand, prices) to adjust to create a new equilibrium.”

13. Too anecdotal, optional section: Opportunities and Constraint of Adaptation to Climate Change

References are added and context broadened. Narrative added (p. 27):

“Burke et al. (2011) conclude that, by mid- to late 21st Century US maize yields and farm profits would decline under a range of climate scenarios, which would constrain adaptation options. Furthermore, Malcolm et al. (2012) point out that both public and private investments will be needed to adapt agricultural production and infrastructure to climate change. If producers cannot cover increasing adaptation costs, or if extremes of climate change (not well modeled by current global climate models) constrain crop production, US food security may be challenged before mid-century.”

14. This model of CC mitigation does not look sustainable: the prices may not provide enough investment for that purposes:

The reviewer is correct. This is supported by references as per the response to the previous comment and by our statement on p. 27:

“The resilience of future food security in the US in the face of climate change assumes that producers will continue to have financial resources to respond as they have in the past 40 years and that fundamental biophysical processes are not constrained by extremes of climate change in the next 40 years.”

See also response to previous comment.

15. What is a USA food security in this context? Sufficient production of wheat? :

We did not pursue the implications for food security beyond 2050, but surely the challenges will become increasingly severe.

We thank Dr. Serova for very constructive comments that led to improvements in the manuscript.