Agriculture and

SUBSECTORS

Crop and Forest Yields

Forestry

The U.S. has a robust agriculture sector that produces nearly $330 billion per year in agricultural commodities.[1] The sector ensures a reliable food supply and supports job growth and economic development.[2] In addition, as the U.S. is currently the world's leading exporter of agricultural products, the sector plays a critical role in the global economy.[3]

U.S. forests provide a number of important goods and services, including timber and other forest products, recreational opportunities, cultural resources, and habitat for wildlife. Forests also provide opportunities to reduce future climate change by capturing and storing carbon, and by providing resources for bioenergy production.[4]

HOW ARE AGRICULTURE AND FORESTRY VULNERABLE TO CLIMATE CHANGE?

U.S. agricultural and forest production are sensitive to changes in climate, including changes in temperature and precipitation, more frequent and severe extreme weather events, and increased stress from pests and diseases.[5] At the same time, climate change poses an added risk to many forests due to ecosystem disturbance and tree mortality through wildfire, insect infestations, drought, and disease outbreaks.[6] Climate change has the potential to both positively and negatively affect the location, timing, and productivity of agricultural and forest systems, with economic consequences for and effects on food security and timber production both in the U.S. and globally.[7,8] Adaptation measures, such as changes in crop selection, field and forest management operations, and use of technological innovations, have the potential to delay and reduce some of the negative impacts of climate change, and could create new opportunities that benefit the sector.

WHAT DOES CIRA COVER?

The CIRA analysis estimates climate change impacts on the agriculture and forestry sectors using both biophysical and economic models. The agriculture analyses demonstrate effects on the yield and productivity of major crops, such as corn, soybean, and wheat, but do not include specialty crops, such as tree fruits, or livestock. Further, the analysis does not explicitly model impacts on biofuel production or include technological advances in agricultural management practices. The analyses include yield and productivity impacts, but do not simulate the effects of changes in wildfire, pests, disease, and ozone. Future work to improve the multiple interactions among the CIRA energy, water, and agriculture analyses will aid in better understanding potential impacts to these sectors.

Crop & Forest Yields

KEY FINDINGS

1. Unmitigated climate change is projected to result in substantial decreases in yields for most major agricultural crops.

2. Global GHG mitigation is projected to substantially benefit U.S. crop yields compared to the Reference scenario.

3. Without considering the influence of wildfires, the effect of GHG mitigation on forest productivity is less substantial compared to the response for crops. The direction of the effect depends strongly upon climate model and forest type (hardwood vs. softwood).

Risks of Inaction

Without significant global GHG mitigation, climate change is projected to have a large negative impact on the U.S. agriculture sector. Table 1 presents the projected percent change in national crop yields in 2100 due to unmitigated climate change under the Reference scenario. For all major irrigated crops, with the exception of hay, climate projections from both the IGSM-CAM and MIROC models result in decreased yields, with very substantial declines projected for soybeans, sorghum, and potatoes. For rainfed crops, climate projections using the drier MIROC climate model result in substantial declines for all crops, particularly cotton, sorghum, hay, wheat, and barley. Rainfed yields using the wetter IGSM-CAM climate model are more varied, ranging from a substantial decrease in hay yields to moderate gains in cotton, sorghum, and wheat yields.[9] Projected declines in crop productivity resulting from unmitigated climate change over the longer term are consistent with the findings of the assessment literature.[10]

As shown in Figure 1, the effect of unmitigated climate change on forest productivity in the U.S. varies over time and depends on the climate model used. Using the IGSM-CAM projections, hardwood yields increase by 2100, while the change in softwood yields is very small. Projections using the drier MIROC climate model result in increased hardwood and softwood yields by the end of the century, though the gains are smaller than those projected under the Mitigation scenario.

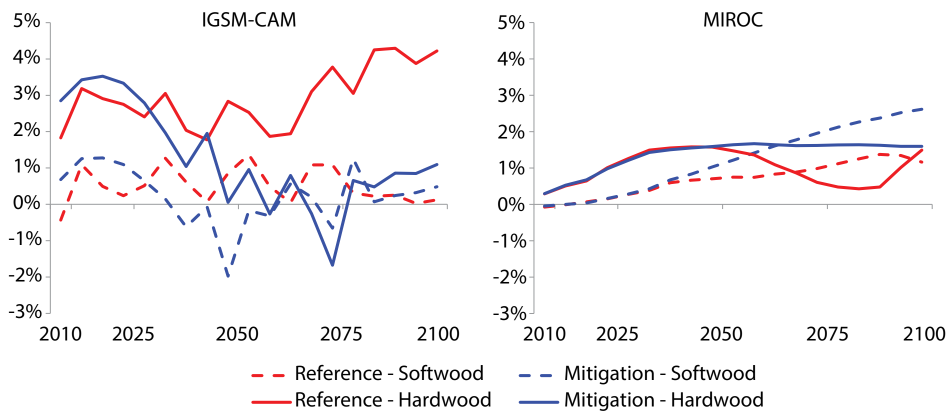
Table 1. Projected Percent Change in U.S. Crop Yields in 2100 without Global GHG Mitigation

Estimates in this table assume no technological improvements in yields over time such that crop productivity in future periods relative to a scenario with no climate change is based purely on differences in climatic conditions. This assumption allows the analysis to isolate and evaluate climate change impacts on crops without confluence with other factors. Results do not include effects from changes in ozone, pests, and disease. Rice and potatoes are simulated under irrigated management only.[11]

CROP	IGSM-CAM		MIROC	
	RAINFED	IRRIGATED	RAINFED	IRRIGATED
Cotton	17%	-11%	-27%	-17%
Corn	6%	-3%	-8%	-10%
Soybean	-5%	-20%	-19%	-23%
Sorghum	18%	-17%	-29%	-22%
Rice	n/a	-3%	n/a	-3%
Hay	-62%	29%	-65%	32%
Potato	n/a	-33%	n/a	-39%
Wheat	18%	-8%	-19%	-13%
Barley	-16%	-22%	-29%	-11%

Figure 1. Projected Change in Potential Forestry Yields with and without Global GHG Mitigation

Percent change in potential hardwood and softwood yields across the U.S. relative to the base period (1980-2009) under the Reference and Mitigation scenarios for the IGSM-CAM and MIROC climate models. Effects of wildfire, pest, and disease on yields are not included.



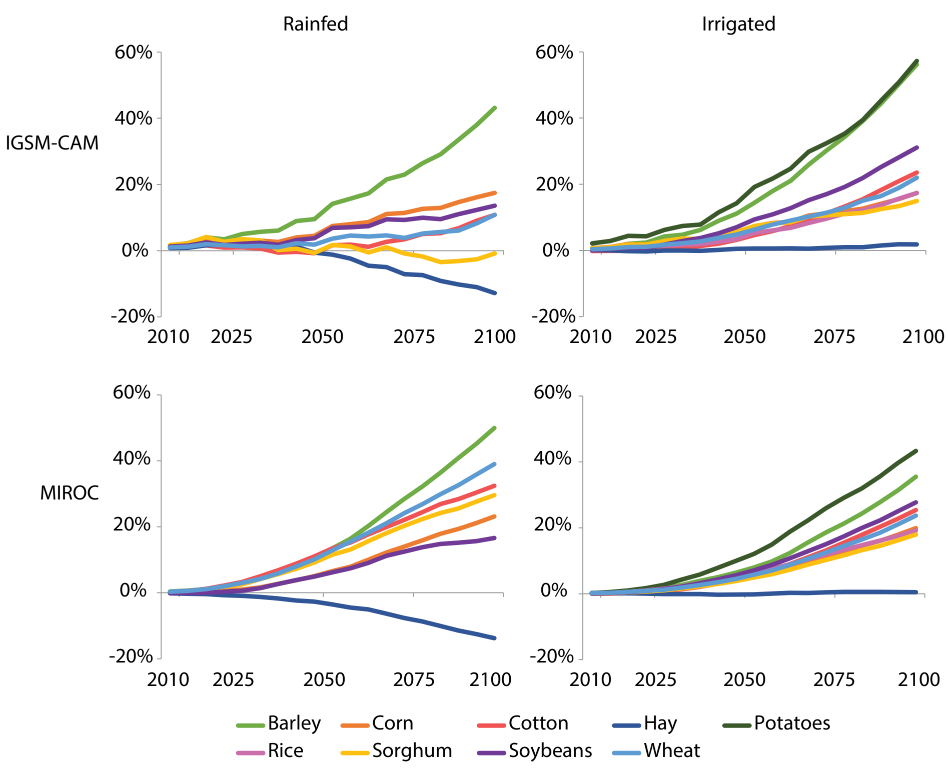
Reducing Impacts through GHG Mitigation

Global GHG mitigation is estimated to substantially benefit U.S. crop yields. Figure 2 presents the projected change in national crop yields for key crops under the Mitigation scenario compared to the Reference. The figure shows changes in rainfed and irrigated yields using projections from the IGSM-CAM climate model and the relatively drier MIROC model. In general, the benefits to crop yields of global GHG mitigation increase over the course of the century, with the exception of rainfed hay (for both climate models) and rainfed sorghum (for IGSM-CAM). Global GHG mitigation is projected to have a particularly positive effect on the future yields of irrigated soybeans, irrigated potatoes, and irrigated and rainfed barley.

The projected effect of GHG mitigation on forest productivity is less substantial compared to the response for crops. Figure 1 shows the estimated percent change in average national forest productivity (contiguous U.S.) under the Reference and Mitigation scenarios relative to the base period. Although forest productivity generally increases with climate change under both scenarios, projections using the relatively wetter IGSM-CAM climate model result in larger gains under the Reference scenario, particularly for hardwoods. Higher forest productivity under the IGSM-CAM Reference in the future is likely driven by the enhanced positive effects of CO_2 fertilization under the high-emission Reference, along with the response to increases in precipitation in many areas of the contiguous U.S. that are forested. The MIROC climate projections, on the other hand, result in slightly rising yields of both hardwoods and softwoods through 2100 under the Mitigation case. It is important to note that these yield estimates do not include the effects of wildfire, pests, or disease, which would likely decrease simulated productivity based on the findings of the assessment literature,[12] especially under the Reference scenario (See Wildfire section of this report).[13]

Figure 2. Projected Impacts of Global GHG Mitigation on Crop Yields

Percent change in crop yields from the EPIC model in the contiguous U.S. under the Mitigation scenario compared to the Reference for the IGSM-CAM and MIROC climate models.[14] Rice and potatoes are simulated under irrigated management only.



APPROACH

The analysis uses the Environmental Policy Integrated Climate (EPIC) model[15,16] to simulate the effects of climate change on crop yields in the contiguous U.S. The analysis examines agricultural crop productivity for multiple crops, including corn, soybean, wheat, alfalfa hay, sorghum, cotton, rice, barley, and potatoes. Yield potential is simulated for each crop for both rainfed and irrigated production with the exception of rice and potatoes, which are assumed to be irrigated.[17] Because production regions may change over time in response to climate change, EPIC simulates potential cultivation and production in areas within 100 km (62 miles) of historical production regions.

EPIC is driven by changes in future climate from both the IGSM-CAM[18] and MIROC climate models under the Reference and Mitigation scenarios. The results presented in this section include the effect of CO_2 fertilization on crop yields; Beach et al. provide a sensitivity analysis of the effect of CO_2 fertilization on the crop yield results from EPIC.

Changes in forest growth rates are simulated using the MC1 dynamic vegetation model, consistent with the approach described in Mills et al. (2014)[19] and the Wildfire and Carbon Storage sections of this report.[20] MC1 is also driven by the IGSM-CAM and MIROC models, and assumes full CO_2 fertilization effects.

The effects of changes in wildfires, pests, disease, and ozone are not captured in this analysis.[21] Inclusion of these effects on crop and forest yields would likely result in increased benefits of GHG mitigation compared to those presented in this section.

For more information on the CIRA approach and results for agriculture and forestry crop yields analysis, please refer to Beach et al.[22]

Market Impacts

KEY FINDINGS

1. Based on the projected changes in yields, global GHG mitigation is estimated to result in lower crop prices over the course of the 21st century compared to the Reference.

2. Changes in crop and forest productivity alter related market dynamics, land allocation, crop mix, and production practices, which in turn affect GHG emissions and carbon sequestration from the agriculture and forestry sectors. Global GHG mitigation has a large effect on emissions fluxes in managed forests: however, the magnitude and direction of the effect are sensitive to climate model projection.

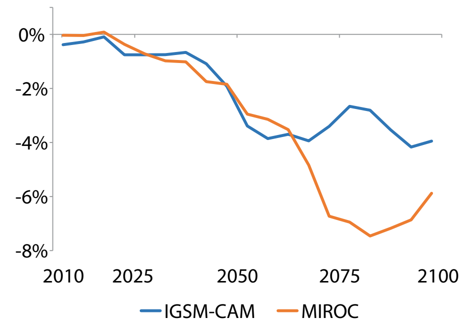
3. Under both climate model projections, global GHG mitigation increases total economic welfare in the agriculture and forestry sectors by $43-$59 billion (discounted at 3%) through 2100 compared to the Reference. The magnitude of estimated economic welfare impacts in the agricultural sector is much larger than in the forestry sector.

Changes in Crop Price

As described in the Crop and Forest Yields section of this report, global GHG mitigation is projected to result in generally higher crop yields in the U.S. relative to the Reference. As a result, mitigation is projected to result in less pressure on land resources and declining commodity prices. As shown in Figure 1, climate projections from both the IGSM-CAM and MIROC climate models show steep declines in a broad index of crop prices starting around 2040. Projections using the drier MIROC climate model result in greater declines in crop prices by the end of the century than those using the wetter IGSM-CAM model. Adverse effects of climate change on crop and food prices, which are largely avoided in the Mitigation scenario, are consistent with the findings of the assessment literature.[23]

Figure 1. Projected Change in National Crop Price Index Due to Global GHG Mitigation

Percent change in crop price index under the Mitigation scenario relative to the Reference for the IGSM-CAM and MIROC climate models.



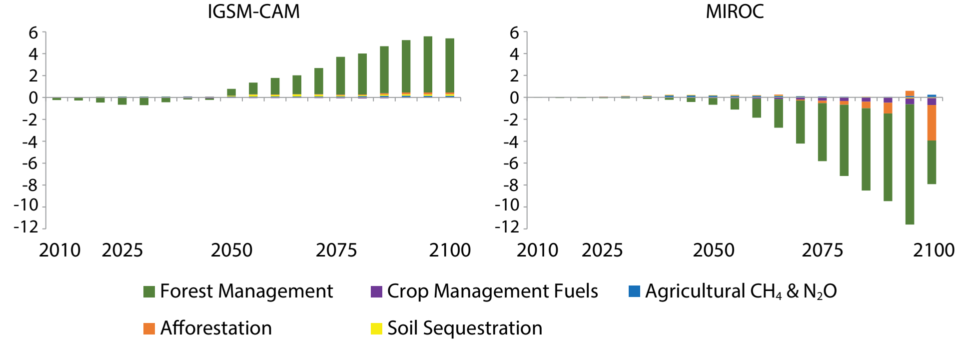
Changes in Emissions

Changes in land allocation, crop mix, and production practices in turn affect GHG emissions from agriculture and forestry practices. Figure 2 shows the estimated changes in cumulative GHG emissions under the Mitigation scenario compared to the Reference using projections from the IGSM-CAM and MIROC climate models. Under the IGSM-CAM projections, GHG mitigation is estimated to increase net GHG emissions from these sectors in the second half of the century. The increase is due in large part to the generally lower forest productivity that is projected to occur under the Mitigation scenario compared to the Reference, as the latter has higher productivity driven by the generally warmer and wetter future climate, as well as the enhanced positive effects of CO_2 fertilization (see the Crop and Forest Yields section). Thus, global GHG mitigation results in less forest carbon sequestration over time. Higher levels of carbon storage in forests under the generally warmer and wetter future of the IGSM-CAM Reference scenario are consistent with the findings presented in the Carbon Storage section of this report.

Under the MIROC climate projections, on the other hand, forest productivity is enhanced under the Mitigation scenario relative to the Reference, and forests take up and store more carbon. In addition, although emissions from livestock agriculture rise, GHG emissions related to crop production generally decline as less area is devoted to crops due to higher yields.

Figure 2. Projected Changes in Accumulated GHG Emissions in the Agriculture and Forestry Sectors Due to Global GHG Mitigation

Projected change in cumulative GHG emissions by type under the Mitigation scenario relative to the Reference for the IGSM-CAM and MIROC climate models (billion metric tons of CO_2 equivalent).



Changes in Consumer and Producer Surplus

The changes in crop prices and the level of production and consumption of agriculture and forestry products have important implications for the economic welfare of consumers and commodity producers. The analysis measures these effects through changes in consumer and producer surplus,[24] as summarized in Table 1. Using both climate model projections, global GHG mitigation increases total economic welfare (well-being) in the agriculture and forestry sectors by $43 to $59 billion (discounted at 3%) through 2100 compared to the Reference. Estimated consumer surplus is higher under the drier MIROC conditions than it is under the IGSM-CAM, primarily due to the larger crop yields under the Mitigation scenario compared to the Reference (see the Crop and Forest Yields section).

The effect of global GHG mitigation on producer surplus varies depending on the climate model used. The IGSM-CAM climate projections result in an increase in producer surplus, though not as substantial as the projected increase in consumer surplus. The drier MIROC projections result in a slight decrease in producer surplus due to the substantial increase in crop yields and resulting decrease in prices.

Table 1. Projected Effect of Global GHG Mitigation on Consumer and Producer Surplus in the Agriculture and Forestry Sectors

Change in cumulative consumer and producer surplus from 2015-2100 under the Mitigation scenario compared to the Reference (million 2014$, discounted at 3%). Results are rounded to two significant digits and therefore may not sum. In addition, the agriculture and forestry results do not sum to totals due to rounding, and because the table reflects independently calculated average values for agriculture, forestry, and combined totals.

	CONSUMER SURPLUS	PRODUCER SURPLUS	TOTAL
IGSM-CAM			
Agriculture	$29,000	$13,000	$43,000
Forestry	$67	$350	$420
TOTAL	$29,000	$14,000	$43,000
MIROC			
Agriculture	$62,000	-$3,300	$59,000
Forestry	-$160	$920	$750
TOTAL	$62,000	-$2,400	$59,000

APPROACH

The CIRA analysis uses the Forest and Agricultural Sector Optimization Model with Greenhouse Gases (FASOM-GHG)[25,26] to estimate changes in market outcomes associated with projected impacts of climate change on U.S. crop and forest yields. As described in the previous section, projected yields across regions and crop/forest types are generated by the EPIC and MC1 models. FASOM-GHG is driven by changes in potential yield from EPIC and MC1 for each of the five initializations of the IGSM-CAM climate model for both the Reference and Mitigation scenarios,[27] as well as the drier MIROC climate model.

FASOM-GHG simulates landowner decisions regarding crop mix and production practices, and projects the allocation of land over time to competing activities in both the forest and agricultural sectors and the associated impacts on commodity markets.[28] Given the changes in potential yields projected by EPIC and MC1, FASOM-GHG uses an optimization approach to maximize consumer and producer surplus over time.[29, 30] The model is constrained such that total production is equal to total consumption, total U.S. land use remains constant (with the potential movement of land from forest to agriculture and vice versa), and non-climate drivers in the agriculture and forestry sectors are consistent between the scenarios to isolate the effect of climate change. In addition, the analysis assumes no price incentives for avoiding GHG emissions or carbon sequestration in the agriculture and forestry sectors (i.e., the sectors do not participate in the global GHG mitigation policy). Finally, although the EPIC simulations assume that crops can be irrigated to a level that eliminates water stress, the FASOM-GHG simulations include shifts in water availability for irrigation based on data obtained from the water supply/demand framework described in the Water Quality section of this report.[31]

For more information on the CIRA approach and results for the FASOM-GHG agriculture and forestry market impacts analysis, please refer to Beach et al.[32]