Climate Change Webinar Transcription 2/17/16

Climate Change, Water Scarcity, and Adaptation in the U.S Fieldcrop Sector, my name is Nancy McNiff and I will be your host. This webinar is being recorded and will be posted on the ERS website next week. At any time during the webinar you may enter a question into the chat feature at the bottom left corner of your screen and our speaker will answer you at the end of the presentation. Our speaker today is Elizabeth Marshall. Elizabeth is an economist in the Conservation and Environment Branch at the Economic Research Service US Department of Agriculture. Liz specializes in developing and applying a national agricultural production model called R-E-A-P to issues ranging from the environmental and economic impacts of Bioenergy crop production to agricultural adaptation strategies around climate change. I think we're ready to start so Liz you can now start your presentation.

Thank you Nancy, and thank you to all the participants for joining the webinar today. In this session I'm going to present a broad overview and a quick overview of results from a research report that we recently released here at ERS entitled Climate Change, Water Scarcity and Adaptation in the US Fieldcrop Sector. I only have time to skim the surface of our methods and our results though so I encourage anyone interested in more in depth information to check out the report itself. The report and its technical appendices are all available online at ERS's website and I'll put the UR, URL up at the end of the webinar.

The objective of our research was to explore in-depth the potential impacts of climate change on crop yields, agricultural production, fieldcrop prices and farmer returns as well as how those impacts might vary regionally and over time. There are two distinct sets of dynamics that determine the impacts of climate change. On one hand it's clear that changing growing conditions will have an impact on crop growth at the field level so the first important set of dynamics are the biophysical foundations of changing patterns of temperature and precipitation and the impacts of those changes at the field level on crop growth including impacts on yields and crop water use. The second dynamic however acknowledges that our system of AG production is not static and in fact is constantly evolving. So farmers will adapt to changing growing conditions and market conditions under climate change by altering what the grow and how the grow it. So a comprehensive examination of the potential impacts of climate change has to account for both the initial biophysical impacts on crops and the farmers adaptational response to those changes. In this analysis the aspects of potential climate change impacts that we were particularly interested in exploring in more detail included how effective will adaptation be at allowing farmers to buffer and mitigate the impacts of climate change and will there be constraints to adaptation that prevent them from being fully flexible in their adaptation response.

There are many ways in which farmers can adapt and, and are likely to adapt to changing climate conditions and we weren't able to account for all of them in our research. The adaptation strategies that we looked at are primarily changes in crop plant allocation such as switching between crops or rotations in response to changing growing conditions or changing production methods such as tillage and irrigation use. In this analysis we focus in particular on changes in the extent and the intensity of irrigation as an adaptation strategy and in exploring irrigation as an adaptation response we're particularly interested in whether changes in irrigation availability under climate change would arise and whether those changes would limit farmer’s flexibility to use irrigation as an adaptation response. So in answering that question we first look at how and where climate change and the changing patterns of precipitation are likely to effect the availability of surface water for irrigation and then we explore the impacts of those shortages on farmer decision making in their cropland allocation decisions. For those of you who have to duck out earlier I'll do a quick recap of our results before launching into a little more detail about how the study was conducted and some more detailed results. We preface the review of results by saying that we looked at impacts for the years 2020, 2040, 2060 and 2080. So looking broadly at the field and market impacts of climate change we found that yields and total production of most major field crops declines under climate change whether they're irrigated or not. When averaged over all the climate projections that we looked at projected production losses for 2080 reached 16 percent for corn and 14 percent for soybeans. These are averages so declines for some climate projections were much larger and under others were much smaller. But while field, most field crops faired pretty poorly under our climate change projections there were exceptions. We found that wheat, hay and by the end of the century barley actually increased their field level yields and were subsequently associated with increased production under climate change. And turning to economic indicators we calculated an index of prices based on value of production and found that, that index when averaged over climate futures increased over all the years that we looked at by, between five and 10 percent.

We also calculated a measure farm returns as the difference between revenue and variable cost of production and we found that when averaged over all potential climate futures this measure of farm returns for the full field crop sector declined over all of our analysis years. Aggregate numbers often hide interesting differences however and our research is no exception. There's substantial variability in price and farm return impacts across the crop sectors and in the case of returns across production regions so we'll look at those differential impacts in more detail later. I mentioned that an important part of this research was to explore specifically the irrigation response to climate change. So in order to look at whether farmer flexibility to adapt would be constrained by irrigation shortages under climate change we first needed to map out where such shortages might occur. To accomplish that we built on a water shortage analysis that was completed by the US Forest Service for the 2010 Research Planning Act Assessment. We used their water shortage numbers to develop a surface water irrigation shortage map for each climate projection in each analysis year. This slide shows an example of one of those map series for one particular climate projection. While there is again variability across the climate projections we found that in general surface water supply shortages occurred across portions of the Pacific Mountain and Plain states and that they became increasing severe after mid-century.

So once we developed irrigation shortage maps under climate change we then explored to what extent those shortages might limit the potential for farmers to adapt to climate change by expanding or intensifying their irrigation. We found that irrigation shortages are an important constraint to adaptation and that they do limit national production under climate change to a certain extent under all time periods. However, we also observed an interesting dynamic in the later years of our analysis. In some regions even under much warmer production conditions farmers chose to reduce the amount of irrigated production acreage even when they were not faced with any constraints on the availability of irrigation water. In those cases the contraction of acreage appeared to be purely an economic decision where irrigated production became relatively less profitable than dry land production under changed climate conditions. We'll look at the reasons for that in a little more detail but I'll preface that discussion here by saying that the, the impacts of temperature stress on crop growth may influence farmer irrigation decisions in counter intuitive ways. Okay, so that was a really brief overview of our results and now we're going to dive a little bit more into the nitty gritty of the study methodology and the results.

This slide presents an overview of the entire modeling system that feeds into our impact analysis. Our climate impact analysis considers the potential impacts associated with nine climate projections. There's a lot of uncertainty about what's likely to happen with greenhouse gas emissions over the next century and what the implications of those emissions are for climate and local weather patterns so those nine climate projections represent a range of potential climate futures. Construction of that range begins in the upper left corner here with three potential greenhouse gas emissions pass representing a low, a middle and a relatively high pass of emissions over the next century. Then to capture some of the variability that exists across climate models each of those paths, those emissions paths then run through different, three different climate models giving a total of nine possible climate paths for, for regional climate outcomes over the next century. Those regional climate outcomes represent changes in monthly temperatures, precipitation, as well as annual atmospheric carbon dioxide levels projected as a result of climate change. As mentioned earlier the US Forest Service used those climate projections in a water routing model to calculate regional water supply and demand and to use those supply and demand comparisons to calculate subsequent shortages that might arise under climate change across all sectors. We took those aggregate water shortage estimates and used them to derive surface water irrigation shortage estimates for the fieldcrop sector in the United States. We also took the estimates of regional changes in temperature, precipitation and atmospheric carbon dioxide and used those as inputs into the epic crop growth model. The epic model allows us to estimate how crops respond in terms of yields and water use to the changing growing conditions that's associated with each of these future climate projections. The final step was use the regional crop data or the regional crop impact information and the regional irrigation shortage information as inputs into REAP which is the Regional Environment and AG Programming model.

REAP is an economic model that focuses on land use allocation within the US fieldcrop sector. In order to isolate the impacts of climate change on production we first estimated for each of our years of interest, 2020, 2040, 2060 and 2080 a reference scenario. The reference scenario is a pattern of yields, production and prices that has been designated, that has been designed, excuse me, to represent a reasonal, a reasonable snapshot of what agriculture might look like in that year in the absence of climate change. The climate in the absence of climate change is called our reference climate and it actually represents and average of conditions over the period 2001 to 2008. We then change or shock our reference system by introducing a set of new yields, new water demands and costs associated with the changing growing conditions under each of the different climate scenarios which we calculated using this regional crop growth model epic. The model takes these changed inputs and recalculates and reallocates crop land into a pattern of crop acreage and crop production methods that optimizes the economic surplus from production given the new conditions. Those changes in production patterns, prices, returns and all of the other outputs from REAP are changes we attribute to climate change, they are differences from the reference.

In order to explore potential limits due to irrigation shortages we can also introduce a new set of constraints into the model's decision making that forces it to consider irrigation shortages in determining how to allocate production as part of its re-optimization procedure. Before I move on I want to give credit where credit is due and emphasize that all of the analysis shown in the green boxes were completed outside of ERS. These are the analysis completed by the IPCC, by several climate modeling teams around the world and by the Forest Service. Okay, this figure illustrates how we differentiate the production regions within our crop production modeling system and our economic modeling. The smaller lines shown here delineate 267 model regions which represent an overlay of the USDA farm production regions, NRCS land resources regions and, and watershed boundaries. We model crop production within each of these regions on soils and under weather conditions that have been customized to be appropriate for those regions and the crops that we model are shown in the box on the right. A lot of detailed information comes out of this modeling system so for presentation purposes we generally aggregate those results up to the level of the farm production regions which are shown here as the uniformly colored blocks. I just want to point out though that those results, results that are aggregated up to the farm production region can mask a lot of variability that's occurring across these smaller REAP sub-regions. And before we go on into more results I'll give you a quick overview of the climate projections that we're using.

These graphs illustrate for all of our climate projections a cropland weighted average of the changes in growing conditions that are observed nationally. The top graph shows national average change in growing season maximum temperature and the bottom graph shows national average change in growing season precipitation. As shown in the legend on the right each of the markers represents the conditions associated with a particular climate scenario or climate projection and there are nine of them. The green line then represents average conditions for change across all of the climate scenarios. Looking at the top graph, the temperature graph we see an increase in average growing season maximum temperatures with broadening divergents across climate futures over time which reflects growing uncertainty in what temperature impacts are likely to be as you move further out into the century. The precipitation graph shown below is less consistent in terms of directional change but we generally observe declines in growing season precipitation relative to the reference climate conditions across all years. And I just before moving on I want to remind you these numbers are acreage weighted national averages and so there's also quite a bit if regional variation that exists across the projections for projected precipitation change. There're also growing season averages so they don't explicitly illustrate that we sometimes see a seasonal shift toward winter and early spring precipitation. So the growing season declines that are shown here are sometimes accompanied by increases in winter precipitation and those shifts can be particularly important in influencing the growth potential for crops that remain on fields over winter which in our analysis generally hay and winter wheat.

Okay, as mentioned earlier the first dynamic driving climate change impacts is the biophysical impact of changing climate conditions on crop growth including yields and water use and we're going to explore that dynamic in a little, a little bit more in this slide. In our analysis climate change influences, influences crop growth through three pathways. The first pathway is through changes in temperature stress. Crops have ideal temperature ranges for growth and as growing conditions begin to exceed those ranges crops can experience temperature related declines in growth rates. The result of declining growth rates is reduced biomass and often reduced yields. If growth rates decline enough you may actually see declines in water use as well as smaller plants may need less water for growth even under warmer growing conditions. For that reason temperature stress, the temperature stress pathway is not entirely independent of the second pathway through which crop growth can be affected by climate change which is through changes in moisture stress. One generally assumes that as temperatures increase crop water use will increase as plants lose more water due to warm temperatures and if you're talking about plants of a fixed size that's generally true. However, if plant growth is limited by high temperatures you may find as we pointed out above that crop water use declines as crop biomass declines and moisture stress may become relatively less important at limiting crop growth than temperature stresses. One imputation of this as suggested by our modeling is that when growing temperatures get high enough some crops may begin to suffer from decreased water use efficiency so the yield benefit associated with irrigation declines. This fact has significance for farmer decision making and adaptation behavior and we'll look at that later. And at a very fundamental level moisture stress may also respond in a straight forward way to changes in precipitation with increased precipitation leading to decreased moisture stress particularly for crops grown under dry land conditions. The final pathway through which climate change impacts crops growth in this analysis is through increased atmospheric carbon dioxide. This phenomenon is often referred to as carbon dioxide fertilization because increased atmospheric carbon dioxide has been observed to increase crop growth rates. This boost in growth can happen for two reasons, roughly speaking the first is that in a more carbon dioxide rich atmosphere plants spend less time breathing so they lose less water that's a very rough colloquial way of saying it. The second reason is that enriched atmospheric carbon dioxide can increase the efficiency with which some crops photosynthesize radiation energy. This later photosynthetic effect operates differentially across crops and in our analysis is weakest in corn and sorghum.

Okay, to give you a glimpse at the, the differential biophysical yield impacts of climate change on crops in this analysis let’s look at two crops that react very differently to the change growing conditions under our climate projections. This slide illustrates the biophysical impacts of climate change on corn on the left and on wheat on the right. Impacts are differentiated by farm production region and by irrigation method where D refers to dry land and I refers to irrigated. Results are averaged across climate projections and declines in yields relative to the reference yields are indicated with the red shading. And as a side note in these tables we've isolated the biophysical impacts of climate change by fixing acreage at reference, at reference land use acreage patterns thereby we prevent farmers from adapting through any type of land use change.

So these reflect purely the biophysical impacts of climate change on yields. The corn table indicated that corn yields generally decline across both dry land and irrigated production. Furthermore, irrigated yield declines are larger than dry land yield declines across a number of regions. That dynamic suggests that higher temperatures are limiting crop growth and are a significant driver of yield reduction and that irrigation alone is not sufficient to offset the temperature effects on yields. Wheat yields by contrast as shown on the right tend to increase across important wheat producing areas and the increases are often proportionately greater in dry land wheat production than in irrigated production. These results suggest the beneficial impacts of carbon dioxide fertilization on water use efficiency and photosynthetic efficiency in wheat together with increases in precipitation across several important wheat producing regions are sufficient to drive increases in regional wheat yields despite the fact that wheat may also be experiencing some amount of increased heat stress.

Okay, so we've seen the biophysical yield impacts associated with climate change, now let's look briefly at the implications of those biophysical impacts for irrigation demand. Again in this graph we've isolated the biophysical impacts by fixing production acreage at, at reference levels and preventing farmers from engaging in any sort of adaptation behavior. So these graphs illustrate an interesting phenomenon that diverges over time. Each, each graph shows the relationship between change in precipitation and change in irrigation demand and the bubbles on the graph represent regional observations of irrigation demand in precipitation under the different climate scenarios. In 2020 irrigation response is roughly as one might expect to see where precipitation increases we see a general decline in irrigation demand, that's the lower right quadrant and similarly where precipitation declines irrigation demand often rises, that's the upper left quadrant but that relationship shifts significantly after mid-century. In 2080 we generally see declining irrigation demand even in many regions that are experiencing declining precipitation and that's shown be the regions that are here in that lower left quadrant. Furthermore, the declines in irrigation demand has become more significant with time with regions in general dropping much more deeply below the X axis despite significantly warming temperatures over the century. The dynamic behind that decline appears largely driven by heat stress and limits to crop growth. As I mentioned earlier higher temperatures can be expected to increase crop water demand for crops of a given size but changes in temperature over the course of the growing season can reduce biomass production and plant size and that reduction in plant size is in some cases sufficient to reduce transpiration and crop water demand despite the warmer temperatures.

So if we look at the implications of that for what's happening nationally in terms of irr, irrigated, per acre irrigation demand we see an initial increase in average irrigation demand in 2020 relative to the reference which is shown in the dotted black line followed by a smooth decline over the century despite the fact the temperatures are warming over the century. These national numbers reflect both the factors that were illustrated in the prior slide. The changes in precipitation and the changes in crop water demand arising as a result of the biophysical changes. And as noted earlier you, we again see increasing variability as you move further out into the century reflecting increasing uncertainty associated with the results that we project so far out.

Okay, so we've explored in more detail the biophysical impacts driving crop growth and yield changes, let’s return to the second important dynamic that contributes to determine climate change impacts which is farmer response to those biophysical crop changes. We explore the farmer’s behavior adaptation response to climate change using our economic model REAP. Farmer land allocation decisions in REAP are driven fundamentally by changing patterns of relative profitability among crops and crop production methods or systems. As climate change shifts those patterns of compared advantage in crop production farmers respond by changing the crops they grow or the rotation, rotations they grow them in or the meth, methods they use to grow them including whether they grow them under irrigated or dry land production. In this analysis we're particularly interested in this decision about dry land versus irrigated production and the potential for increased extent or intensity of irrigation as an adaptation strategy. And the incentive to change out acreage allocation between the irrigated and dry land production depends on how returns to irrigation compare to returns of dry land production and more specifically how those relative returns changed under the different climate projections we'll address that in more detail shortly. However even in the presence of incentives to shift into irrigated production farmers may not have the flexibility to shift if irrigation shortages exist or are exacerbated by climate change. So adaptation behavior may also be affected by constraints on irrigation supply and we explicitly accounted for two potential shortages or sources of shortage in irrigation supply. The first was changes in surface water availability under climate change and the second was projected reductions in ground water pumping and ground water availability.

The effort to map surface water irrigation shortages arising under climate change built on research completed by the Forest Service in support of the 2010 RPA and, which, which projected water shortages by watershed sub-base and under each of the climate projections. These shortages were estimated by comparing trends in water withdrawals across multiple sectors with projected water supplies by region and those water supply projections took into account climate related changes in precipitation patterns and water cycling by region. Our research team then used those overall water shortage estimates to derive and map implied irrigation shortage estimates for the field crop sector. The resulting maps look something like this one and a different map series is derived for each of the nine climate projections. Ground water aquifers are also expected to decl, to decline in several regions where ground water represents an important source of irrigation supply and we wanted to explicitly account for those reductions in estimating the additional impacts that we might expect as a result of the climate related surface water supply changes. However, the science of climate change impacts on ground water dynamics is still developing so for the purposes of this analysis we included a single projection of future ground water withdrawal reductions based largely or USGS data on county level withdrawals and maps indicating where water tables are likely declining. Those projections are not sensitive to the climate projection used or this projection is not sensitive to that, there's only one projection for ground water reductions. Our estimation of those reductions are mapped here and you can see that the ground water withdrawal reductions primarily affect portions of the Plains states and the Southwest as well as some portions of the Delta region and that the most extreme projected rejections are visible across the Ogallala aquifer region. Now that we've seen how the potential constraints to irrigation decision making map out let's return to the question of incentives for irrigation in our analysis.

Relative profitability of irrigation is what drives the irrigated acreage decisions within our economic model. So if climate change decreases the average profit derived from irrigated production relative to the average profit derived from dry land production incentives will exist for the contraction of irrigated acreage even though irrigated acreage continues to be more profitable on average within a region than dry land acreage. As shown on the left side of this figure the average regional premium received from irrigation under reference climate conditions forms a baseline against which premiums received under alternative climate scenarios are measured. If that premium increases as shown in the middle set of columns it creates and incentive within the model for the expansion of regional irrigated acreage. However, if that premium declines as shown in the final set of columns the model translates that decline into an incentive for the contraction of regional irrigation acreage even though irrigation remains more profitable in absolute terms. So it's the relative profitability of irrigated versus dry land production in our modeling system and how the magnitude of that premium changes relative to a reference case that drives the irrigated acreage allocation within our model.

So what actually happens to the relative profitability of the irrigated production under climate change in our analysis? For a measure of relative profitability, we used the ratio of irrigated to dry land returns and we very roughly aggregated across crops and production systems up to the level of farm production region to get an idea of how that ratio changes between the reference case and the climate change projections. If we average the resulting changes over all nine climate change projections for the year 2060 we get the results that are shown in this table. Although changes in the returns to irrigation vary across the climate scenarios average declines in the relative profitability of the irrigation as a result of climate change are shown here with red shading. In general, we see declines in the relative profitability of irrigated production across most regions including heavily irrigated regions such as the Northern Plains and the mountain region. One notable exception to that pattern is the Delta region where crop growth conditions under climate change result in continued incentive for irrigation expansion in 2060.

To explore how those changes in relative profitability play out in terms of changes in irrigated acreage we can look at the results of the irrigated acreage allocation decision under climate change. In the case where farmers are freed up to make acreage re-allocation decisions in response to climate change but are not given any additional constraints on irrigation availability. So in this scenario farmers are free to adapt to climate change and they are not constrained in how they adapt by any irrigation shortage.

In the first column which represents irrigated acreage change in 20... I skipped a slide, excuse me, let me go back.

Okay, so in the first column the first column represents irrigated acreage change in 2020 and we can see that there's significant incentive for increased irrigated acreage with an average of close to seven million acres of new irrigated production popping up under the climate change scenarios when the farmer is able to adapt and is not given any irrigation constraints. The Northern Plains, the Corn Belt, the Delta and the Southern Plains account for most of that expansion. If you look forward to 2060 however you see results that might be contrary to expectations in the much warmer world of 2060 we observed substantially less incentive for increased irrigation with the extent of irrigated acreage actually declining in some regions. Much of that reduction is accounted for by changing dynamics within the Northern Plains which goes from significant expansion of irrigated acreage in 2020 to significant contraction of irrigated acreage in 2060 even in the absence of any constraints on the availability of irrigation water. This dynamic is attributable to the change in the relative profitability of irrigated versus dry land production. Both the Corn Belt and the Southern Plains also experienced declines in the incentives to expand while its incentives for expansion in the Delta region remain fairly high.

Okay, so our comprehensive analysis of the potential impacts of climate change on AG production combines all the elements I've just described here, the biophysical yield impacts, the producer adaptation response and then the potential constraints on adaptation arising from irrigation shortages. Given all of those elements the projected impacts of climate change on production of field crops averaged over future climates is shown in this table. We see declines in production relative to potential reference production levels for most crops for every year with increasing severity of impact across major crops such as corn and soybeans. The exceptions to declining production are seen in wheat, hay and by the end of the century barley. We can explore the relative importance of the different elements of our analysis in determining production levels for various crops by presenting incremental results from a series of analysis as we've done in this chart. We start with a fixed acreage analysis so no adaptation allowed and that, this reflects only biophysical impacts on production and it's shown in the blue column for each crop. If we then allow farmers to adapt at will to production impacts, we see the results shown in the green column and finally if we introduce potential irrigation constraints we can observe the additional impacts on production by crop sector due to those irrigation constraints as shown in the purple column. As you can see by comparing the bars the results of this disaggregation of impact suggests that while adaptation behavior and irrigation constraints do affect national production levels at the margin the magnitude of adjustment in production due to those elements is generally small relative to the production impacts attributable to the fundamental biophysical changes in growing conditions and impacts on yields. Exceptions to this observation arrived by crop however so for instance we see that production levels of rice are quite responsive to adaptation behavior and production of hay is relatively sensitive to the introduction of irrigation constraints.

We can do a similar type of analysis to look at the impacts of climate change on price also disaggregating those impacts into each of the elements described. We find substantial variability in price impacts across crops. This is, this chart shows the year 2060 and in 2060 we see significant price increases in rice and soybeans and moderate price declines in the hay and wheat sector. Again the relative importance of the different elements in driving price change differs across the crops but prices again are generally more sensitive to the initial change in biophysical growing conditions than to subsequent adaptation behavior or constraints due to irrigation shortage.

The final economic indicator of climate change impact that we look at is a measure of net returns to producers to explore the variability in climate changes impacts on producers we present returns results that are disaggregated first by crops and then by regions. In this graph we illustrate that the variable impacts of climate change across crop sectors in 2040. In that year corn, soybeans, barley, cotton and silage producers generally experienced declines in net returns as a result of climate change while oats, rice and sorghum production generate increased returns for producers under the new field and market conditions. The final slot, results slide illustrates how those impacts on farmer returns vary by region in 2060. There's considerable variability across climate scenarios but most regions experience declines in total producer returns when aggregated over crops and averaged across the climate scenarios. The exceptions are the Pacific region and the Southern Plains where producers actually experienced significant increases in returns under some of the climate scenarios. Notably the Corn Belt experienced decline, experiences declines in per acre net returns across all of the climate scenarios that we explored.

So just to reiterate our conclusions we found that with the exception of wheat, hay and barley yields decline under climate change across most major crops whether they're irrigated or not. Irrigation is an important adaptation option for farmers but beyond the year 2020 the incentive for irrigation expansion under climate change decline in a number of regions due to a combination of factors that include changing precipitation patterns and declining relative profitability of irrigation. Significant declines in crop yields even under irrigated production suggest that heat tolerance is a critical area for agricultural research and development in the effort to increase agriculture’s resilience to climate change.

Despite these observed declines in the relative profitability of irrigated production in some regions irrigation remains an important adaptation strategy in many regions and irrigation shortages do represent a constraint on production decisions. Climate related surface water shortages are often an important constraint on irrigated acreage in the Pacific and mountain regions while ground water constraints which are considered independent of climate change in this analysis are important constraints in the plains and Delta regions. Prices for many crops increased but in many cases not sufficiently to compensate producers for lost yields under climate change and as a result in aggregate return to producer’s decline though as we saw that effect is highly variable across both crops and regions. So, thank you for your attention during this lengthy presentation I encourage you to check out the report online for more details but I'm happy to take questions now as well.

Thank you Liz, we have some questions already but I'm going to remind everybody that if you have a question you can enter it into the chat feature in the left hand lower corner of your screen. So first off Liz you were talking about carbon dioxide, the carbon dioxide fertilization effect in your simulation and someone was asking what approximately was its magnitude, what was its effect on your simulation?

Well we did perform a sensitivity analysis as part of our crop growth modeling to determine the relative sensitivity of crops to the temperature changes we looked at and the precipitation changes that we looked at and then the carbon dioxide changes that we looked at, that sensitivity varies highly across crops and across regions so there in the technical appendix for the, in the technical appendix for the report there's a description of that sensitivity analysis that I encourage the interested participants to look at. I will say that some crops responded very strongly to carbon dioxide fertilization and as I mentioned corn and sorghum responded less strongly because of the, they have a different sort of synthetic pathway than the other crops that we consider.

Okay, did you see any differences in the results depending on, I know you're looking at regions but they're asking about specific states. Did you see any differences in the northern or southern portion of states?

We, well, we didn't look, we didn't look specifically at northern ver, northern results versus southern results in any specific state. We do see significant differences across, across our REAP sub-regions which were, were shown in that initial early map, early map and so I imagine that there are cases for sure where there are significant differences across states but I don't have, I don't have those results tabulated by state.

And somebody missed, I'm sorry go ahead.

Oh, I was just going to say there are very, there are significant differences in precip, in changes in precipitation pattern across the regions in particular and because crop growth is so sensitive to precipitation patterns there are, there are certainly states where the precipitation, the impacts of climate change on precipitation pattern vary significantly across different regions within the state and that would have huge implications for the yield impacts and yield implications.

Okay, someone missed I guess the early part of the presentation and was wondering if you could explain a little bit more what the reference point is in each of those comparisons you were making, what did you use as the reference?

Yeah, so we had to develop in order to, in order to have something to compare our climate change impacts against. We had to develop what we call the reference scenario for each of our years of interest, the 2020, 2040, 2060 and 2080 years and so that reference scenario is a counter factual scenario that assumes that production and technology changes continue out into the future sort of as an extrapolation of historical trends but that there's no climate change impacting them. So for instance the, the reference scenario includes assumptions about what crop yields will be in the future and those crop yield assumptions are based on projections of what technological development in yields has been historically but I can say that it works out roughly in this analysis to about a .6 percent increase in yields per year between now and 2080 which is a considerable increase in yields that we attribute to technology alone and that changes over our, over our reference scenarios, over our, the years from 2020 to 2040 to 2060 to 2080 in our reference scenarios. So includes, it includes assumptions about yields, it includes assumptions about exports and imports, assumptions about domestic demands and those assumptions are extrapolated out from historical, from historical trends and they therefore incorporate implicitly assumptions about population change and those sorts of things.

Okay, we have a question on about your REAP model. Is the REAP model an agent based model that allocates optimally within each private land holding or does it, or does it do the optimization at a larger regional spatial scale?

Yes, it does, it does the optimization at the regional scale so it's almost as if each region is a farm that is choosing among all of the potential crops and rotations that it can grow for that region. So within a region we assume homogeneous soils, homogeneous weather or, yeah weather patterns and then when the model optimizes it selects for each region a pattern of crop land allocation that, that contributes to the, the optimization of economic surplus across the, across the entire US. But yeah, it's not agent based at the field level one could say it's agent based at the, at the region level but there, there's 267 regions so they’re, they're lar, certainly fairly large.

Okay, we have a question about the oats crop. Why do oats not follow the production trend increases of wheat, hay and eventually barley by 2080?

I, the, we saw some odd patterns of what was happening with yields for oats, I would have to look back. Specifically, we do have some coverage of that in the, in the report but I, I can't off the top of my head remember. Oats, oats decline signif, oats yields decline significantly as a result of climate change, more significantly than the other, than the other crops and I suspect that because of that and because of price changes associated with it there's some switching going on within the model about what production would drop significantly and so there's probably some switching going on in terms of oats as a feed stock but that's sort of a vague answer I, I, for more detail I would have to, I'd have to look back at our results and I'm happy to follow up if that participant would like to send me an email.

Or, she can put her email on the chat feature and I'll, I'll get back to here on that too. Okay, on slide number 10 and I'll bring that up. There's a question about you suggest that unirrigated wheat yields in the Southern Plains will increase by 8.5 percent by 2060 could you explain that further?

So this is an increase in yields relative to what the reference yields would have been in 2060 so wheat yields relative to current yields are probably already in 2060 much higher than they are now. So I just want to clarify what the comparison point is and so on top of the reference yields for 2060 this slide says that climate change will result in an additional eight and a half percent change and, in the southern plains, and it could be due to a variety of, we would have to look in detail at our in, at our output files to determine exactly what's happening but in the, in many cases the change in wheat, increases in wheat or dry land wheat I should say are due to changing precipitation patterns and that can either be increases in precipi, in growing season precipitation in wheat producing regions within the Southern Plains or it can be shifts in precipitation patterns from summer or what we consider traditional growing season precipitation which is May to October. Shifts from May to October precipitation towards winter/spring precipi, precipitation which can benefit winter wheat or wheat, wheat that, that is held over, on fields over, over the winter so those increases could, are likely due to that. Wheat also responds well to carbon fertilization so a portion, a fairly significant portion of the yield increases that you see nationwide not just in the Southern Plains are due to wheats response to car, the carbon dioxide fertilization impact.

Okay, I believe this next question is on slide 17 so I'll bring that one up. She had a question about can you repeat what you attributed to the difference in the changes for the Delta area compared to other regions? Why is the Delta area in a better position by 2060?

Well, I would say it's not necessarily in a better position it just has continued incentives for increase in irrigation and one of the reasons for that is if you, if we look back at the corn slide in the Delta region or if we look back at the corn yield slide, let me see if I can bring that slide up, the yield impact slide... It doesn't seem to want to bring up, let's see, I'll go back this way. Okay, if we look at the corn impact slide, if you look at the Delta region we see that dry land yields, yields of dry land corn decline significantly whereas yields of irrigated corn don't actually decline very much so in order to keep corn production up one of the incentives that you're likely to see within the Delta is movement out or dry land production and into irrigated production and that, so that's a crop specific driver of that increased incentive for irrigation expansion but in order to determine whether that holds true across all the crops we'd have to look at a crop by crop analysis of that but those are the types of dynamics that drive that increased incentive or maintained incentive or irrigation expansion.

Okay, we have a question about are you, are you saying that farmer adaptation practices will not affect outcomes and if so what, what can farmers do then about it?

Well, so a couple caveats here, we, our conclusion was definitely that adaptation has less of an impact on some of the indicators that we looked at like production and prices than the initial fundamental biophysical impacts. So you get this sort of massive impact from climate change and then farmers adapt to that but they can't adapt their way out of the impacts is sort of the conclusion that we've come to however I need to caveat that by saying we looked at a limited range of adaptation strategies in this report and but we were specifically interested in irrigation, adoption of irrigation or expansion of irrigation as a, as an adaptation strategy so we looked in detail at that but there are a lot of adaptation strategies we were not able to consider such as, some things as simple as changing, changing dates of field operations like, like planting and harvesting and other things that are much, that are more complicated including development of drought and heat tolerant cultivars and those sorts of things and, and those, some of those crops varieties are already being introduced and starting to be experimented with so we weren't able to look at a, at a full range of adaptation options.

This is kind of a related question. Could technical advancements and adaptations to irrigation such as drip tape prolong the period of comparatively profitable irrigation returns?

Yes, anything that, anything that brings down... well I would say in general in the absence separating the question from our analysis yes, anything that brings down the cost of irrigation is going to, is going to prolong the period of comparatively profitable irrigation returns. In our case we did not look at changes in irrigation efficiency so irrigation becomes if, let's see, under climate change if more water is required on the field irrigated production becomes more, becomes more expensive because more water costs more but yes if we had incorporated the consideration as technological change that allowed you to put more water on the field or, or put less water on the field and get the same benefit to the plant because you're reducing losses then yes you would, you would see, you would be moderating that cost increase due to increased demands for water and you could maintain, and you could maintain the profitability of irrigation that way.

Okay, has this same analysis been done for fruit and vegetable crops?

We have not done this analysis, historically the REAP model has not included fruit and vegetable crops and so we had to make assumptions within this analysis about what portion of your, of irrigation water within each region would go to fruit and vegetables versus to our field crops and how that would change under climate change and basically we assumed that higher valued fruit and vegetable crops would have first dibs on irrigation water and so the bulk of irrigation shortages would be borne by the field crops but we are for the, for, as part of our expansion of, of, of capacity in model capacity here we're building fruits and vegetables into our REAP model now so we are hoping to maintain the possibility of doing climate analysis on, or climate change analysis on the fruit and vegetable sector in the future.

And one final question, do you have any thoughts on what this might mean for future feed production or animal production?

Well, we, REAP does include, I didn't talk about it detail because we didn't have a lot of time but REAP does include a livestock sector so we are able to, the livestock sector and the field crop sector are linked through the feed markets so we can look at what the implications of changing feed prices or changing feed availability is on, on livestock. We're in the, we did not focus on the livestock sector because we're in the process of updating that entire portion of the model but clearly it would depend on the assumptions that you make about, about, well, a lot of things, demand for, how demand for meat will change over time what's happening to the, the feed prices relative to the price of the output and we have not looked carefully at that question yet and we hope to as I said as part of our expansion of modeling capacity we, we would hope to look at something like that in the future.

Okay, thank you Liz, I think that's all the questions that we have time for today. Thank you all for joining us for this webinar and we hope you have a wonderful afternoon.