Climate Change impacts on Agricultural Production and Farm Incomes in Texas

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Introduction:

Recent prolonged droughts and floods in Texas and other states in the Southwestern United States have brought increased attention to the implications of climate variability on agricultural production and farm incomes. In 2011, prolonged drought led to over $5 billion of lost agricultural sales in Texas alone (AgriLife Today), with more than half attributed to a loss in cattle and hay sales. The year to year drought events which caused significant damage to plant biodiversity in the region, were succeeded by massive flooding in the 2015 production year. The bio-geophysical impacts of the recent droughts may last years beyond the actual period of drought incidence, with concomitant impacts on the financial viability of agricultural operations. Coupled with the adverse climate events, global market pressures are forcing farmers to manage their operations with very thin profit margins in most years.

The aforementioned climate extremes have only served to raise interest in opposing viewpoints on whether these variations are due to natural geological forces or rather of anthropogenic causes. Notwithstanding the politically sensitive backdrop of climate science, significant resources have been invested in forecasting weather patterns at least a few decades into the future. Due to these efforts, weather projections are now widely available through the end of the 21st century. However, little empirical attention has been given to the implications of these projections on food production and farm incomes. The purpose of this paper is to help fill that void. We use the most widely accredited compilations of climate projections to determine the corresponding impacts on agricultural production assuming current market conditions and crop production potential. We also use the production estimate to infer what farm incomes would look like over the next 30 years and then over another 30 years further into the future. To obtain these projections, we use a well-tested and calibrated bio-geophysical model, the Agricultural Policy Environmental eXtender (APEX) and a similarly well tested and calibrated farm-economic model. Our results indicate, as expected, that current climate projections will have variable and significant impacts on farm production and incomes in Texas.

Background:

Climate variability is a phenomenon farmers are accustomed to. Historical time series of precipitation and temperature show marked year to year variations that are far more pronounced than any underlying long-term trends. However, if current climate science projections are true, a steeper warming trend may result in significant shifts in agricultural production regimes that have not been experienced in recent times. The generally warming trend is projected to be accompanied by changes in precipitation patterns across vast landscapes of all continents. The implications for food security are obvious concerns as some nations may produce more while others produce less of various commodities.

It is well known that farm production and climate/weather are closely related. Several plant scientists, agronomists and economists have studied this relationship using scientific data and biological theories. For example, Jerry Hatfield (Hatfield, 2010) a plant physiologist traced how high temperatures in both day and night time will impact plant growth by adding stress to plants, reducing yield potential. He further recognized that increase is CO2 levels promotes weeds and other climate changes such as high humidity levels promotes diseases and insect growth (Hatfield, 2010).

In addition, studies in the academic literature has documented that agricultural production is strongly correlated with biophysical attributes of farms as well as weather and management practices (e.g., Machado et al., 2002, Lambert, 2014, Dell et.al 2014). Dell et.al in a survey article evaluated the role that climate change has influenced economic outcomes in general including the impacts in the Agricultural sector. The primary approaches applied in evaluating the impact of weather include using weather related inputs such as precipitation rates, temperatures, humidity levels as inputs in a production function. Previous studies used cross-sectional regressions, utilizing panel data and applying a hedonic approach (also adopted by Lambert (2014) which includes weather variables). The main conclusion of these studies confirms that adverse weather negatively impacted U.S. agriculture. Similar results were also observed in studies conducted in other parts of the world such as India, Mexico and Indonesia. Besides, Lambert (2014) also concluded that weather devastations were associated with greater impacts on Net farm Income than on the value of farm products. The role of offsetting price movements, crop insurance payments to farmers buffers farmers from revenue losses but results in government payments subsidized by taxpayers. Such payments are typically not available for farmers in third world countries.

Given that farmers and supporting industries have a well-established trajectory of increasing agricultural productivity through improved farm inputs and technologies in the United States, the remaining factors that heavily impact future production are weather and soil attributes. In general, soil attributes are more stable once proper management practices are in place. Thus weather patterns, precipitation in particular, are the key variables driving agricultural productivity in every nation, and more so in Texas, which is characterized by a definite precipitation gradient from the east to the western portion of the state.

The pattern between temperature and agriculture output appears to follow a non-linear relationship. A threshold temperature represents a range which is considered optimal for plant growth. Schlenker and Roberts (2009) examining temperature data and plant growth discovered optimum temperature in output yields ranging from 29 to 32 C. The ideal temperatures varies from one crop to another; for example, for Corn, it is 29 C, for Soybeans, it is 30 C while for Cotton it is 32 C. When temperatures dip below these ranges, output increases moderately (perhaps with less stress on the plant and decrease in soil evaporation). However, even a small increase above the threshold levels significantly reduces output yields. Thus, the relationship between temperature and yields follow a non-linear path.

Changes in precipitation also appear to have an impact on yields. This is true especially for rain-fed crops and also mostly in third-world countries where irrigation systems are neither fully developed nor farm practice always follow conservations methods such as drip irrigation. For example, in Mexico (which typically relies on low and variable rainfall), warmer and dryer conditions results in nutritional and economic disaster. Even with irrigation reservoirs, water can becomes scarce under dryer conditions (Liverman). In addition, dry and warmer climates in agricultural regions also accelerate out-migration from these disaster prone areas (Feng et. al, 2010). Generally, increases in rainfall results in higher yields while decreases produce lower yields (Jayachandran, 2006, Levine and Yang, 2014).

The effects describes so far are short term and some economists have argued that in the long run, adaptation and mitigation techniques such as developing drought-resistant crops and farm practices such as no-till farming could mitigate the impacts of short run fluctuations in weather patterns (Deschena and Greenstone). Nevertheless, prolonged drought and long run impacts of climate change is likely to have an adverse relationship between climate change and agriculture output.

Projected increased variabilities in climate are expected to impact agriculture and have significant implications for policy and food security of Texans and the entire nation, but the specific impacts have not yet been quantified. This paper helps to meet that need. We employ an integrated modeling system comprising APEX (Williams et al., 2000) and Farm-level Economic Model (FEM) to determine the likely future trajectory of agricultural production and farm incomes in Texas contingent upon the most likely medium-term (30-year) global circulation model (GCM) climate projections for Texas. The results of this study indicate that current counter-cyclical government-funded farm income support programs will be subject to significant stresses if projections of warmer and dryer spring weather patterns materialize.

Methodology:

Climate impacts crop production directly through its impacts on rates of photosynthesis, evapotranspiration, nutrient cycling and transformations, and timeliness of field operations. In addition, temperature extremes have a direct bearing on livestock growth and maintenance and the production of livestock products. In this study, we used an integrated computer modeling system comprising APEX and FEM to estimate the impacts of 30-year climate projections for the period 2016 through 2045 on crop and livestock production in Texas and consequent impacts on farm incomes and government support programs. The results of the model simulations were used to develop projections of agricultural production and farm income for the state of Texas, and to determine implications for farm policy and food security in Texas.

<u>Modeling System:</u>

For this paper, two calibrated computer simulation models were used to project future agricultural production in Texas in response to plausible climate patterns. Both models were calibrated using historical weather and agricultural production data and farm cost and returns summaries. APEX, a well-established biophysical model, was then used to simulate crop production levels under future climate patterns over the course of 30 years. The crop productivity data obtained from the APEX simulations were then be used as input in the FEM (Osei et al., 2000; Osei et al., 2012), an annual economic simulation model for agricultural operations, to estimate the farm income and cost implications of the crop and livestock production levels indicated by the APEX model. FEM and APEX have been linked in previous work and have been used in numerous simulations (Osei et al., 2008). FEM is an annual economic simulation model that includes numerous subroutines and algorithms for simulating farm economics.

The two computer simulation models were calibrated and used for the present study. FEM was used to determine the impacts of baseline and drought scenarios on farm incomes, costs, and net income. The APEX model was used to estimate crop yields and selected edge-of-field water quality metrics, namely sediment, total nitrogen and total phosphorus in surface and subsurface flow. APEX and FEM have been linked in a previous effort to enable seamless transfer of data between the two models (Osei et al., 2008). In this study the two models were applied in fully linked mode (Figure 1) to enable transfer of biophysical parameters to the economic simulation model. The two models were calibrated separately prior to their use in the simulations.

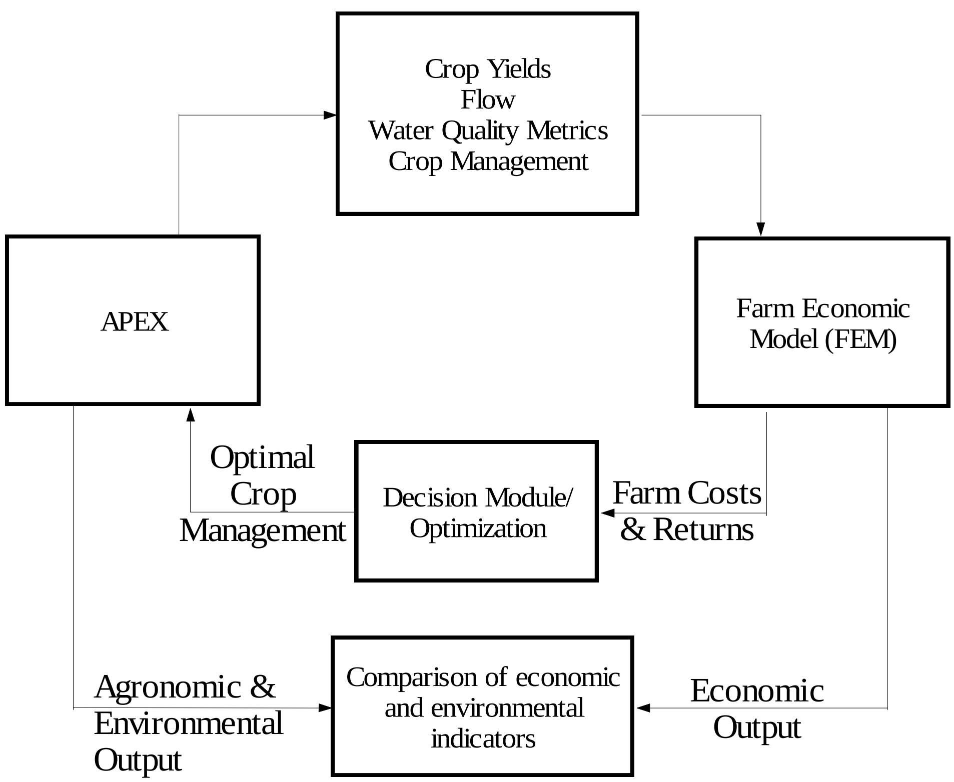

Figure 1. Schematic of FEM and APEX linkage for scenario simulation and analysis

FEM is a whole-farm simulation model that is used to simulate farm-level economic impacts in response to alternative agricultural policy and practice scenarios. FEM operates on annual time step and can be executed for extended periods of 30 years or more. Key categories of input data required to simulate a farm in FEM include type of livestock system, manure management methods, cropping systems and cultural practices, facilities and equipment, field attributes, input and output prices, and other external factors. Economic outputs generated by FEM include total revenue, total cost, net farm returns, livestock rations, crop and livestock sales, costs of individual production components (crop and livestock enterprise costs, fertilizer expenses, labor costs, etc.), debt payment, and owner's equity (Osei et al., 2000).

Prior to the simulations performed in this paper, FEM was calibrated against current (2013 and 2014) farm custom rates tabulated for many states in the continental U.S. Estimated costs of planting, tillage, nutrient, and chemical application operations and harvesting costs from the FEM model were all found to be consistent with corresponding custom rates data reported for recent years. A comparison of FEM output to selected custom rates data is shown in Table 1.

Table 1. Comparison of custom rates and FEM model output ($/acre).

		FEM Model Output	
Field operation	*Custom rate*	*Fixed Cost*	*Total*
Moldboard plow	18.68	13.37	19.79
Tandem Disk	13.46	7.36	15.13
Chisel Plow	14.32	7.35	16.33
Field Cultivator	11.36	2.88	11.76
Offset Disk	14.4	5.96	16.23
Rotary Hoe	7.56	4.89	8.06
Row Crop Cultivator	10.42	4.99	11.68
Bulk Fertilizer Spreader	6.61	1.14	5.69

APEX (Williams et al., 2000) is a comprehensive field-scale model that was developed in the 1980s to assess the effects of management strategies on crop growth, livestock grazing, and water quality. APEX is designed for whole farm or small watershed analyses and can also be used for applications such as filter strip impacts on nutrient losses from manure application fields that require the configuration of at least two sub-areas. Various components of the model include weather, hydrology, soil temperature, erosion-sedimentation, nutrient and carbon cycling, tillage, dairy management practices, crop management and growth, pesticide and nutrient movement, and costs and returns of various management practices.

APEX is a modified version of the Erosion Productivity Impact Calculator (EPIC) model that has been used widely to simulate alternative management scenarios such as variations in manure and fertilizer application rates, tillage options, and adoption of other cultural and structural management practices. APEX operates on a daily time step and can be applied for a wide range of soil, landscape, climate, crop rotation, and management practice combinations. It can be executed for a single field or used for a wide range of multi-filed configurations including whole farms or small watersheds. APEX is detailed enough to simulate precise management practices such as filter strip impacts on nutrients losses from waste application fields. The main APEX components are weather, hydrology, soil temperature, erosion-sedimentation, nutrient cycling, tillage, management practices, crop management and growth, and pesticide and nutrient fate and transport. Choice of simulated cropping system, manure and/or fertilizer nutrient characteristics, tillage practices, soil layer properties, and other characteristics are input for each simulated subarea. Key outputs include crop yields, edge-of-field nutrient and sediment losses, and other water and nutrient balance indicators.

APEX was calibrated against annual county-level crop yield data assembled by the USDA National Agricultural Statistics Service (USDA-NASS) and available on the USDA-NASS web site. The model is included in USDA's web-based Nutrient Tracking Tool (Saleh et al., 2011) and has been calibrated extensively by many other authors for use to assess edge-of-field water quality impacts across a wide variety of agricultural lands in the U.S. and other nations (Gassman et al., 2010).

Data Sources:

A number of data sources were used for this study. Many of the following datasets are incorporated into the web-based NTT tool. Others were assembled specifically for this study.

Various Geographic Information Systems (GIS) data layers were overlaid in order to determine the distribution of winter wheat growing areas in Texas, Oklahoma and Kansas. Once the data layers were constructed, it was assumed that all winter wheat areas would support winter grazing pastures for cattle.

Cropland data layer (CDL): A four-year GIS history of cropland cover for the entire United States was obtained from the USDA-NRCS data server. The cropland data used for this study covered the time period of 2010 through 2013. The CDL data is available at a 30-meter level of precision. However, to reduce the number of computations required, the CDL data layer was scaled up to a 900-meter level of precision for use in this study.

SSURGO soils data: The USDA-NRCS SSURGO soils data for each survey area have been assembled and uploaded onto the NTT server. For this study, the SSURGO data layer was overlaid on the CDL data in order to determine the soil types applicable to winter wheat production fields in Texas, Oklahoma and Kansas. A total of almost 2,200 unique soils were identified as winter wheat growing areas within the study area for 2013. For the economic evaluations reported here, a typical cow-calf representative farm typical of Oklahoma operations was simulated across all unique soils to determine the impacts of the drought scenario on farm incomes.

Weather data: Precipitation, minimum and maximum temperature, solar radiation, and other key weather variables were obtained from the USDA Parameter-elevation Regressions on Independent Slopes Model (PRISM) database. The weather data are available on the NTT server and were used for the present simulations. The PRISM data used for this study are available at a 4-kilometer resolution for the continental U.S. The simulations presented here were performed with a 30-year history of weather data from 1977 through 2006 to adequately reflect typical weather patterns in Texas.

Input and output prices: Additional data sources included wheat grain and forage prices, prices of various beef cattle, forage supplements, farm equipment, and crop chemical inputs. All crop chemical price data were obtained from USDA's Agricultural Prices Summary database. Equipment prices were based on current retail prices of the same types of equipment, tractors and other farm machinery.

Climate Projections: Climate projections were obtained from the National Center for Atmospheric Research's Earth System Grid portal. Climate projections chosen represent a middle ground, an approximate average of a best case lower emissions scenario and an opposite scenario wherein the current greenhouse gas emissions trajectory is maintained. The climate data used for this study included data on precipitation, minimum temperature, and maximum temperature for the period of 2006 through 1999. Specific climate projections used were downscaled Coupled Model Intercomparison Project (CMIP 5) weather projections from NCAR and the Lawrence Livermore National Laboratory at 1/8th degree Latitude and Longitude grid for the entire conterminous United States. The data were obtained from the Bureau of Land Reclamation server at a one-eighth degree latitude and longitude grid for the entire continental United States. Grid points were then associated with each land area simulated simply by proximity.

Weather data on precipitation, minimum and maximum temperature were extracted from the database for the 30-year period from 01/01/2016 through 12/31/2045. Data on all other biophysical attributes (soil data layers, land cover, and topography) were readily available from previous and ongoing research efforts in the Southern Great Plains. Crop and livestock management information and economic input data including input prices and producer prices of crop and livestock commodities were all assumed to be exogenous and to follow current trends. Furthermore, crop productivity was assumed to remain static at current levels.

Climate Scenarios:

Climate projections exist for the continental United States through the 21st century. Predominantly used projections are based on one of three scenarios depending on assumptions about GHG emissions. Each climate change scenario is based on a representative concentration pathway (RCP) that represents a trajectory of GHG concentrations anticipated in response to corresponding mitigation assumptions. Four RCPs (RCP2.6, RCP4.5, RCP6.0, and RCP8.5) were adopted by the Intergovernmental Panel on Climate Change (IPCC) and have been widely used in climate projections. The nomenclature of the RCPs correspond to projected radiative forcing by 2100 under these scenarios as compared to the preindustrial era. The radiative forcing values are expressed in Watts per square meter (Wm^{-2}). Of the four, the following are the three scenarios considered for this study:

RCP 26: This scenario corresponds to a radiative forcing of 2.6 Wm^{-2} as compared to the pre-industrial era and is projected to result in a 1^oC increase in mean global temperatures by the 2046 to 2065 period. This represents the most optimistic scenario among the four, for reducing global warming.

RCP 45: This scenario corresponds to a radiative forcing value of 4.5 Wm^{-2} as compared to the pre-industrial era and is projected to result in a 1.4^oC increase in mean global temperatures by the 2046 to 2065 period.

RCP 85: This scenario corresponds to a radiative forcing value of 8.5 Wm^{-2} as compared to the pre-industrial era and is projected to result in a 2.0^oC increase in mean global temperatures by the 2046 to 2065 period. This represents the most pessimistic scenario among the four, for reducing global warming.

Each major crop grown in Texas was simulated on all applicable soils on which that crop was grown, based on the 2014 CDL data. These crops collectively account for a significant component of total farmland in Texas, though a smaller fraction of total land area since a significant portion of land area in Texas is shrub land.. The following (Table 2) are the major crops that were included in the simulations and the percentage of total land area in Texas they account for.

Each major soil type applicable to each crop was simulated for the projected weather scenarios. The results were compared to a status quo baseline that entailed current climate patterns. Crop production and farm economic impacts are presented in this paper, aggregated across all simulation within each county, and across the entire state.

Table 2. Crops simulated across Texas farmlands

CDL Code	Crop	Percent area
1	Corn	1.37
2	Cotton	4.59
3	Rice	0.09
4	Sorghum	1.48
5	Soybeans	0.08
10	Peanuts	0.04
24	Winter wheat	4.25
31	Canola	0.01
36	Alfalfa	0.04
37	Other hay	1.29
176	Grassland/pasture	27.49

Results and Implications:

Results from model simulations indicate that current medium-term (30-year) climate projections for Texas will result in moderately significant reductions in crop and livestock production within the state. Farm production and incomes are also likely to experience greater variability due to anticipated increases in the frequency of extreme weather events. Impacts of the projected climate change are shown here for grassland/pastureland use (Table 3) due to its predominance among agricultural land uses. The results shown here are also limited only to one climate change scenario – RCP 45. The impacts on production as shown in Table 3 translate to income since we are assuming no change in the overall price level for farm commodities. The consequent implications are that farm incomes before government payments will be significantly lower, and the frequency and magnitude of government income support payments will increase noticeably. The results of this paper suggest that mitigation strategies need to be developed to assist farmers in addressing income risks associated with prolonged weather extremes. Farmers may be well served to consider diversifying their enterprises by incorporating crop and livestock options that reduce overall farm income risk and enhance profitability.

Table 3. Climate change impacts on pastureland/grassland production in Texas

	Units	Minimum	Maximum	Weighted average
Current	t/acre	0.45	3.80	1.94
RCP45 (2016 - 2045	t/acre	0.40	3.87	1.81
Percentage change from current	%	-11.11	1.84	-6.70

The results shown here do not reflect potential year to year variabilities; neither do they indicate variations from one geographic area to another. The overall impact suggests a roughly 7% reduction in production and net incomes based on an average climate change scenario (RCP45).

Conclusions:

While climate change science is highly debatable, it is insightful to evaluate the potential implications of projected changes in climate patterns on agricultural production and farm incomes. This paper used the generally accepted climate model projections currently available to determine the implications of these projections on farm production levels and incomes in Texas. The limited results shown here suggest a moderate decline in farm production, on average across the entire State of Texas. Impacts on individual counties or regions may be more or less marked depending on the projected changes in weather patterns. Additional results will highlight regional differences and will also look at the impacts of other climate change scenarios on farm production and income.

References:

AgriLife Today. 2011. Available at http://agrilife.org/today/2011/08/17/.

Decker, J.E., F.M. Epplin, D.L. Morely, and T.F. Peeper. 2009. Economics of five wheat production systems with no-till and conventional tillage. Agron. J. 101:364-372.

Dell, M, B.F. Jones,and B. Olken. 2014. What do we learn from the Weather? The New Climate-Economy Literature. Journal of Economic Literature, 52(3), 740-798

Deschena Olivier and Michel Greenstone. 2007. The economic impacts of climate change; evidence from Agricultural output and random fluctuations. American Economic Review, 97 (1) 354-85.

Feng Shuaizhang, Alan B Krueger and Michel Oppenheimer. 2010. Linkages among climate change yields and Mexico-US cross border migration. Proceedings of the National Academy of Sciences, 107 (32) 14257-62.

Gassman, P. W., J. R. Williams, X. Wang, A. Saleh, E. Osei, L. M. Hauck, R. C. Izaurralde, and J. D. Flowers. 2010. The Agricultural Policy/Environmental Extender (Apex) Model: An Emerging Tool for Landscape and Watershed Environmental Analyses. Trans. of the ASABE 53:711-740.

Jayachandran, Seema 2006. Selling Labor Low: Wage Responses to Productivity Shocks in Developing Countries. Journal of Political Economy, 114 (3), 538-75

Lambert, D.L. 2014. Historical Impacts of Precipitation and Temperature on Farm production in Kansas. Journal of Agricultural & Applied Economics, 46(4), 439-456

Levine, David and Dean Young, 2014. The Impact of Rainfall on Rice Output in Indonesia. NBER Working Paper No: 20302, July 2014

Liverman, D.M. 1990. Vulnerability to drought in Mexico; the cases of Sonara and Pubela in 1970. Annals of the Association of American Geographers 80(1) 49-72

Machado, S., E. D. Bynum, JR., T. L. Archer, J. Bordovsky, D. T. Rosenow, C. Peterson, K. Bronson, AND D. M. Nesmith, R. J. Lascano, L. T. Wilson, E. Segarra. 2002. Spatial and Temporal Variability of Sorghum Grain Yield: Influence of Soil, Water, Pests, and Diseases Relationships. Precision Agriculture, 3, 389–406, 2002

Osei, E., B. Du, A. Bekele, L. Hauck, A. Saleh, and A. Tanter, 2008. Impacts of alternative manure application rates on Texas animal feeding operations: a macro level analysis. Journal of the American Water Resources Association (JAWRA) 44(3):562-576. DOI: 10.1111/j.1752-1688.2008.00182.x

Osei, E., D. Moriasi, J. L. Steiner, P. J. Starks, and A. Saleh. 2012. Farm-level economic impact of no-till farming in the Fort Cobb Reservoir watershed. Journal of Soil and Water Conservation, 67(2): 75-86.

Osei, E., P. Gassman and A. Saleh. 2000. Livestock and the Environment: A National Pilot Project: Economic and Environmental Modeling Using CEEOT. Report No. PR0002. Stephenville, TX: Texas Institute for Applied Environmental Research, Tarleton State University.

Osei, E., B. Du, A. Bekele, L. Hauck, A. Saleh, and A. Tanter, 2008. Impacts of alternative manure application rates on Texas animal feeding operations: a macro level analysis. Journal of the American Water Resources Association (JAWRA) 44(3):562-576. DOI: 10.1111/j.1752-1688.2008.00182.x

Osei, E., P. W. Gassman, and A. Saleh. 2000. Livestock and the Environment: Economic and Environmental Modeling Using CEEOT. Report No. PR0002. Stephenville, TX: Texas Institute for Applied Environmental Research, Tarleton State University. 2000.

Schlenker Wolfram and Michael J. Roberts 2009. Non-linear temperatures effect indicate severe damage to US crops under climate change PNAS, Sept 15 Vol 106 # 37.

Williams, J.R., J.G. Arnold, and R. Srinivasan. 2000. The APEX Model. BRC Report No. 00-06, Texas A&M, Blackland Research and Extension Center, Temple, Texas