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Impact of Climate Change on Wheat Production in Kentucky

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Summary:

- From 2002 to 2012, Kentucky winter wheat ranged in value from \$52 million to \$209 million.
- Climate change and variability have the potential to significantly impact this important economic enterprise within our state.
- This report summarizes the current state of knowledge of the potential of climate change to impact wheat production in Kentucky and surrounding states.

Soft red winter wheat is one of the major row crops in Kentucky, along with corn and soybean. Together these crops are valued at about \$1.4 billion, or 35% of all agricultural receipts in the Commonwealth. In Kentucky, from 2002 to 2012, winter wheat ranged in value from \$52 million to \$209 million. Revenue differences largely reflect fluctuations in wheat yield, both within the state and around the country. Wheat yields in Kentucky over this same period ranged from state averages of 48 to 71 bushels per acre. Wheat acres harvested in Kentucky in any given year fluctuated by 30% above and below the average acreage planted for that decade. In addition, over that decade, about 29% of the acres planted to wheat were not harvested for grain, with a range from 19 to 43%. In a normal year, about 10% of the crop is harvested for silage, which means a range from 9 to 33% was abandoned annually because of economically significant damage to the crop.

Climate change and variability have the potential to significantly impact this important economic enterprise within our state. Perhaps no year in recent history has seen as dramatic a negative impact of weather on annual crop yields as 2012. Kentucky experienced above normal temperatures during late winter and early spring that advanced wheat growth beyond normal levels. The warm weather was followed by a late spring freeze that severely damaged wheat yields. Following the late freeze, above normal spring temperatures encouraged farmers to plant corn early and most of the crop had an excellent start to the season. However, spring was followed by some of the hottest and driest weather in 50 to 70 years, depending on the location in Kentucky, and corn yields were devastated. Conversely, 2013 was relatively wet and cooler for most of the wheat, corn and soybean growing season, resulting in excellent yields of all three crops.

As scientists attempt to predict when and how climate will change in this region of the country, producers need to be aware of the ways in which those changes could impact crop production in Kentucky. Of the annual crops grown in the Commonwealth, wheat may be the most sensitive to changes in weather. Late spring frosts can dramatically reduce yields (resulting in up to 33% of the acres being abandoned), while warm and wet weather during seed fill can encourage disease development that diminishes yield and elevates toxin levels in the grain, in the case of Fusarium head blight.

This report summarizes the current state of knowledge of the potential of climate change to impact wheat production in Kentucky and surrounding states. Agricultural stakeholders within the state initiated this report by communicating their interest in understanding and planning for likely future changes in climate to faculty and administrators within the University of Kentucky College of Agriculture. A subsequent grant from the Kentucky Small Grain Growers Association, matched by the College of Agriculture's Research Office, supported the creation of this report, as well as a spring 2012 Symposium

on the topic. Efforts continue throughout the state to harness real-time weather data collection efforts (e.g., the Kentucky Mesonet) with agricultural decision support tools to enable farmers in the region to make sustainable, well-informed production decisions. Accurate weather data combined with historical trends will give a better understanding of how the regional climate will affect wheat crop yields throughout Kentucky.

Background on Climate Change Research

Summary:

- CO₂ in Earth's atmosphere has increased from about 280 to 390 μmol CO₂ per mol of atmosphere (0.039% CO₂) since 1800.
- Global temperatures are expected to warm 3 to 7 °F over the next century.
- Annual global precipitation is expected to increase by 5-25% as a result of a warmer atmosphere due to increases in atmospheric greenhouse gas concentrations.

Our knowledge of climate change and its potential impacts has grown in recent decades due to voluminous research, however there is much yet to learn. Recent reports have focused on a variety of issues that pose potential threats to crop yields and economic returns including: changes in temperature and precipitation within and among growing seasons, atmospheric gas concentrations and severe weather events (Hatfield et al., 2011, Hatfield 2012, IPCC 2007). Projections of climate effects on future crop productivity are based largely on the use of models. A climate model is a series of equations describing the energy exchanges among components of the climate system. Temperature and precipitation projections are numerical results of a climate model. Results come from projections of atmospheric concentrations of greenhouse gases and social conditions based on populations, land use, and economic development for a particular timeframe. For example, urbanization and increasing populations result in increased fossil fuel consumption, while globalization and industrialization result in intensification of agriculture and transportation. These sectors contribute heavily to carbon emissions and resulting atmospheric changes. Model projections are then downscaled to provide a more detailed spatial resolution from the global climate model results to increase relevance to regionally specific forecasts.

In 1988, the scientific community began an organized international effort to assess global climate change. The Intergovernmental Panel on Climate Change (IPCC) was created by the United Nations Environment Program and the World Meteorological Organization, and it serves as the leading international body for the assessment of climate change. The IPCC was established to produce

assessments of the Earth's climate system and uses global climate models and emission scenarios to project future climate patterns providing a scientific view on the current state of knowledge in climate change and its potential environmental and socio-economic impacts. A recent report from IPCC states that, "warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global sea level" (IPCC 2007).

Atmospheric Concentrations of Greenhouse Gases

Since 1800 the concentration of CO₂ in Earth's atmosphere has increased from about 280 to 390 μmol CO₂ per mol of atmosphere (0.039% CO₂) (Bloom et al., 2010). Future projections indicate the CO₂ concentrations for North America will likely reach 550 μmol by 2050 and possibly 700 μmol by 2100. In addition, levels of nitrous oxide (N₂O) and methane (CH₄) have reached levels beyond the values observed in the history of cultivated agriculture (Hatfield, 2012). According to the United States Global Change Research Program, the agricultural sector in the United States represents 8.6% of the nation's total greenhouse gas emissions, including 80% of the nitrous oxide emissions and 31% of the methane emissions. Globally, 13.5% of all human-induced greenhouse gas emissions are contributed from agriculture (Karl et al., 2009).

Temperature

The IPCC SRES projections estimate that global temperatures are expected to warm 3 to 7° F over the next century. From the 1970's to present day, all decades have been warmer than the average of the previous 100 years. The average global surface air temperature has increased by 1.08° F (±0.36° F) with the warmest five years on record in the previous 100 years occurring in the last decade (IPCC, 2007). The occurrence and duration of extreme heat events is likely to increase throughout the United States if greenhouse gas concentrations continue to rise.

The IPCC projects temperatures in the major grain growing regions of North America will increase 5 to 7° F by 2100 (Olmstead and Rhode, 2011). Future temperatures in the Southeast United States have been projected using two regional climate models. Temperatures are projected to increase from 5 to 9° F in the CSIRO¹ model with higher temperatures dominating in winter and spring months. The RegCM² model predicts average temperature increases in the Southeast United States ranging from 1.8-12.6° F across all seasons with largest increases in summer months but the model output is more variable both temporally and spatially than the CSIRO model (Mearns et al., 2003).

¹CSIRO model is a climate model developed by the Center for Australian Weather and Climate Research. ²RegCM is a Regional Climate Model developed by the International Center for Theoretical Physics.

Precipitation

Total annual precipitation and extreme precipitation events are likely to increase across much of the United States with increasing greenhouse gas concentrations. IPCC projects an increase in annual global precipitation of 5 to 25% which is directly related to an increase in atmospheric water vapor due to higher evapotranspiration as the earth warms. Winter temperatures are expected to increase disproportionately causing the hydrological cycle to further intensify. Winter precipitation is projected to be more rain than snowfall with decreased snowpack and spring runoff in mid to high latitudes.

Quantity and timing of rainfall will be a primary concern for crop production in the United States. Distribution of precipitation across the year is expected to shift, leading to wetter winters and dryer summers. The imbalance between less rainfall and higher evapotranspiration rates during the summer months, may lead to more soil drying at critical stages of crop production (Cherkauer, 2008). According to Mearns et al. (2003), the climate change scenario for agriculture in the Southeast U.S. predicts the largest decreases in summer precipitation (20% in the CSIRO and 30% in the RegCM models) and largest increases in spring precipitation in both models (35% in the CSIRO and 25% in the RegCM).

Although total rainfall is expected to increase in many regions, droughts are also projected to become more severe because rainfall events are expected to be more intense, with longer dry spells between them. The US Environmental Protection Agency (2010) reports an increase in one day extreme precipitation events in the lower 48 states between 1990 and 2008. As these one-day events increase it is projected that drought will become more prevalent in the United States. Conversely, wetter winters, a product of increased temperatures and rainfall, may result in increased winter flooding.

Background on Kentucky's Climate

Summary:

- Kentucky climate is defined by inter-annual variability with temperatures warming since the 1970's and annual precipitation displaying increasing trends.
- Kentucky has four climate divisions: West, Central, Bluegrass, and East.
- Winter temperature is more variable than other seasons from year-to-year.

The climate in Kentucky is highly variable and influenced by multiple drivers including the continental location with mid-level latitude (Foster, 2012). The annual range in temperature for the state can be as large as 95°F and is driven by warm (subtropical) and cold (polar) alternating air masses. The precipitation in Kentucky is generally considered evenly distributed with an annual range of 40-50 inches. While annual rainfall is typically adequate for agricultural production, mild to moderate droughts are not

uncommon. On the other hand, periods of excess rainfall and flooding are most frequent during late winter and early spring. Due to its location in the Ohio River Valley, Kentucky is in a regular path for tropical storm systems that come inland and can cause major extremes in rainfall patterns. The humid climate in Kentucky is primarily a result of southerly winds bringing water vapor from the Gulf of Mexico with local variations caused by the abundant surface water throughout the state (Hill, 2005).

Kentucky is divided into the following four climate divisions: West, Central, Bluegrass, and East.

Figure 1. Kentucky climate divisions.



Source: Kentucky Climate Center, Western Kentucky University.

Data from the West, Central, and Bluegrass climate divisions reflect the climate in the major grain growing regions of the state. The length of the growing season varies throughout the state and usually ranges from 200 days in the West division to 180 days in the Central division to 170 days in the Bluegrass division. Table 1 shows Kentucky’s climate has been warming since the 1970’s with the annual temperature in the West, Central and Bluegrass divisions exceeding that of the prior warmest period of the 1930-40’s (Foster, 2012). Average annual precipitation has also increased since 1970, with current levels near the highest on record since 1895 (Foster, 2012).

Table 1. Kentucky Climate Division Average Annual Temperature and Precipitation, 1970-2010.

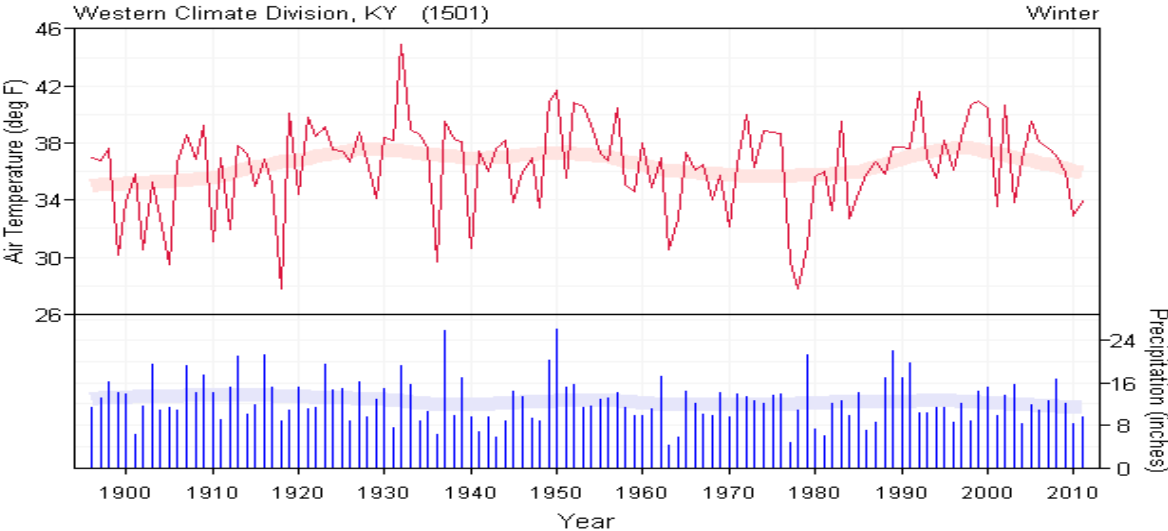
Climate Division	Average Annual Temperature (°F)				
	1970	1980	1990	2000	2010
West	56.7	57	57.3	57.5	58.2
Central	55.6	55.8	56.2	56.6	56.8
Bluegrass	54.1	54.3	54.8	55.2	55.5
Climate Division	Average Annual Precipitation (in.)				
	1970	1980	1990	2000	2010
West	48.99	50.14	48.77	49.51	50.98
Central	50.18	51.16	49.36	50.54	52.51
Bluegrass	45.42	45.63	45.22	46.54	47.15

Source: S. Foster (2012).

The following figures focus on the West Climate Division showing the historical averages by seasons (note the temperature range on the axis changes for each season) for data collected from 1890-present. This data is collected daily, from approximately 30-40 locations by volunteer observers and averaged on a monthly scale. As a result of the number of locations and collection techniques, important patterns of climate change that evolve gradually may be difficult to detect. A smoothing curve is added based on a locally weighted regression curve that follows data for a 30-year margin and centers the data around the average.

Winter-

Figure 2. Historical averages for winter months (December, January, February) in West Kentucky climate division.

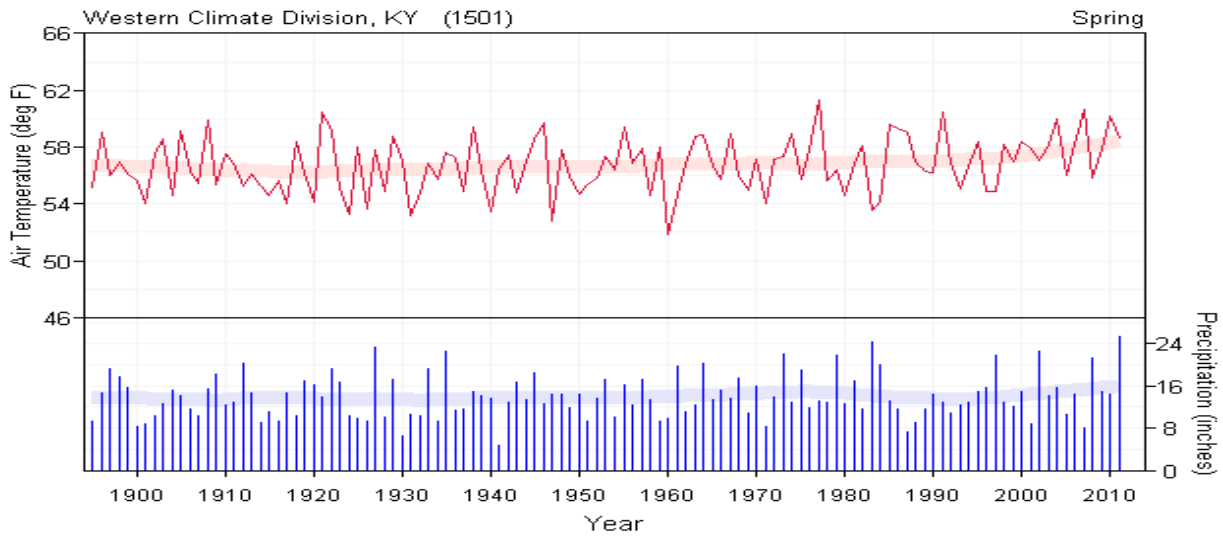


Source: Kentucky Climate Center, Western Kentucky University.

Year to year variability is displayed in every season but is more discernible in the winter months. The range between the coldest and warmest winters was about 16° F which is wider than the range for any other season (Figures 2, 3, 4, and 5). Wide variations of temperature can occur throughout the winter months with January usually having the coldest temperatures annually. Snowfall is generally limited accounting for less than 5% of total moisture annually. Skies are more frequently cloudy in the winter months with only 40% of available sunshine reaching the surface (Foster 2012).

Spring-

Figure 3. Historical averages for spring (March, April, May) in West Kentucky climate division.

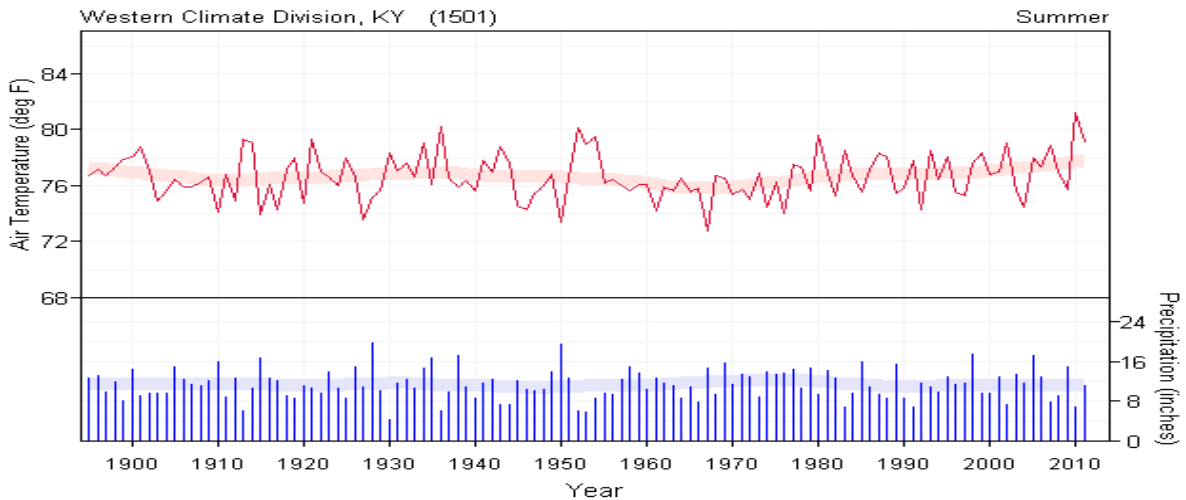


Source: Kentucky Climate Center, Western Kentucky University.

Less year to year temperature variability is observed in the spring months than in other seasons (Figure 3). In recent years fewer cold spring seasons have been observed and the date of the last freeze in spring has been occurring earlier than the historical median for each climate division. The last freeze varies from year to year around the median which ranges from April 5 in the West division to May 1 in the East division of the state (Hill 2005).

Summer-

Figure 4. Historical averages for summer months (June, July, August) in West Kentucky climate division.

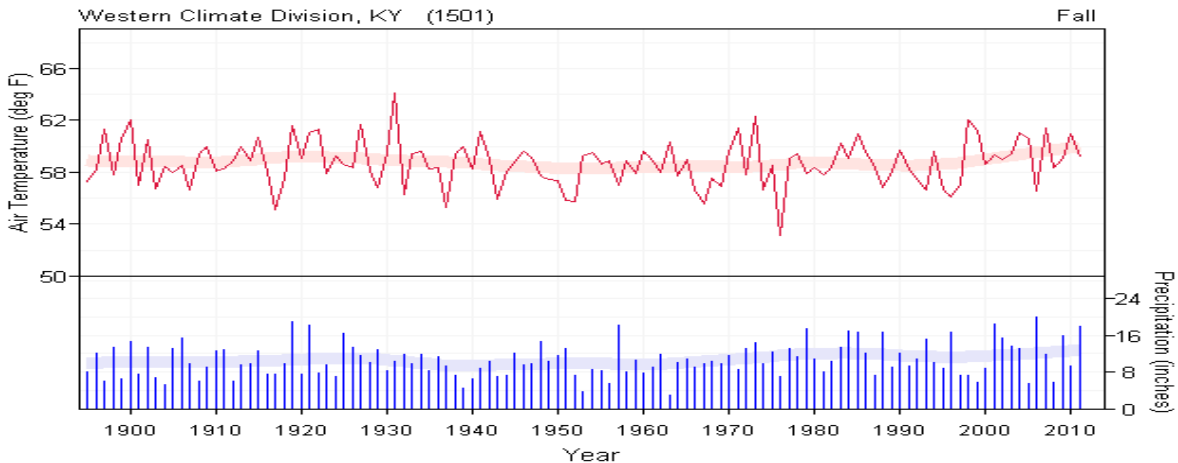


Source: Kentucky Climate Center, Western Kentucky University.

Summer months also display considerable year to year variability with warm and humid conditions and 60% available sunshine hours prevailing in most areas of the state. Average daily high temperature ranges from 86 °F in the East division to 90 °F in the West division. High temperatures exceed 90 °F for an average 40+ days in the West division and 20+ days in the Central and East divisions.

Fall-

Figure 5. Historical averages for fall months (September, October, November) in West Kentucky climate division.



Source: Kentucky Climate Center, Western Kentucky University.

Fall is typically Kentucky’s driest season and can have diurnal temperature ranges of 25°F with warm days and cool nights. The average date of the first fall freeze varies across the state with median dates of October 12 in the East division and October 30 in the West division.

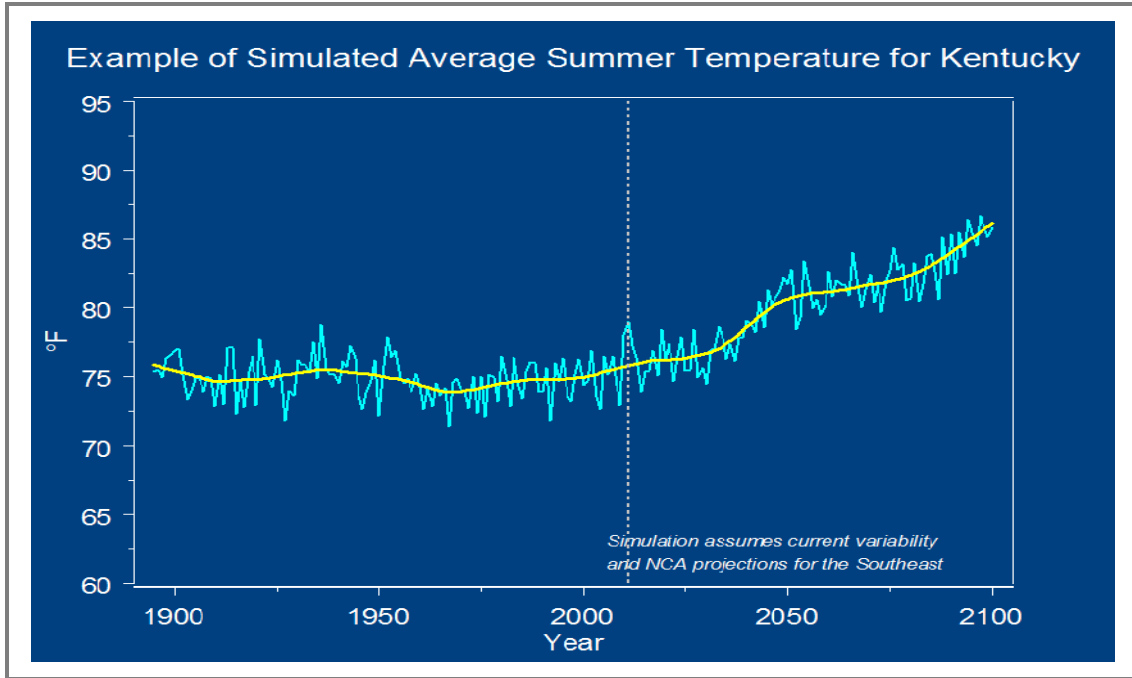
Future Projections:

Simulation projections in the National Climate Assessment (NCA) for the Southeast (2010) project that Kentucky will experience greater increases in temperatures during all four seasons than what has been observed in previous years (Foster, 2012, Kunkel et al., 2013). The coolest summers will be warmer than the hottest summers of the past. The coldest winters will be about the same as the warmest winters in the past. This suggests that we need to focus our decision making in the future on these projections rather than historical trends. The NCA projections are based on “high” and “low” emission scenarios. Under the “high” scenario economic development is the primary consideration, while sustainability is the primary consideration under the “low” scenario (IPCC, 2007). For 2035, temperature increase values range from about 1.5 to 3.5°F for both emission scenarios. For 2055, warming in low emission scenarios ranges from 1.5-4.5°F while high emission scenarios range from 3.5 to 5.5°F. (Kunkel et al., 2013)

The following figures are meant to provide a visual representation of the nature of our climate based on future projections of warming and current patterns of inter-annual variability. These projections

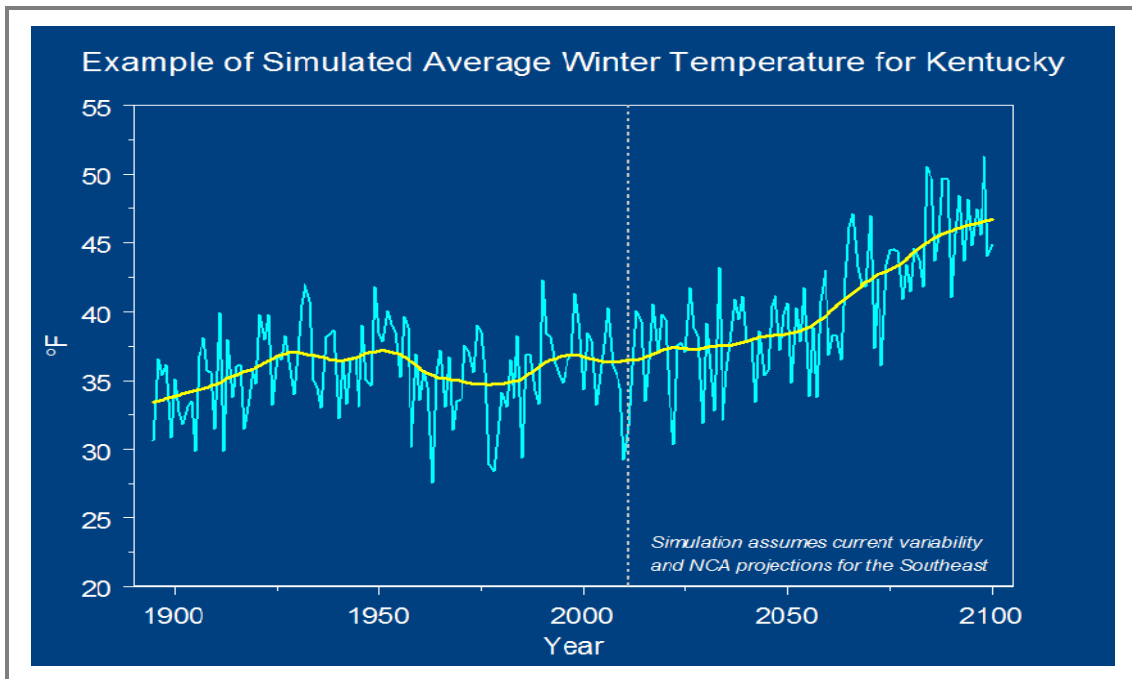
are descriptive and based on mid-range historical temperatures provided in the National Climate Assessment (Foster, personal communication, December 2013).

Figure 6. Summer temperature simulations for Kentucky based on historical averages until 2100.



Source: Kentucky Climate Center, Western Kentucky University

Figure 7. Winter temperature simulations for Kentucky based on historical averages until 2100



Source: Kentucky Climate Center, Western Kentucky University

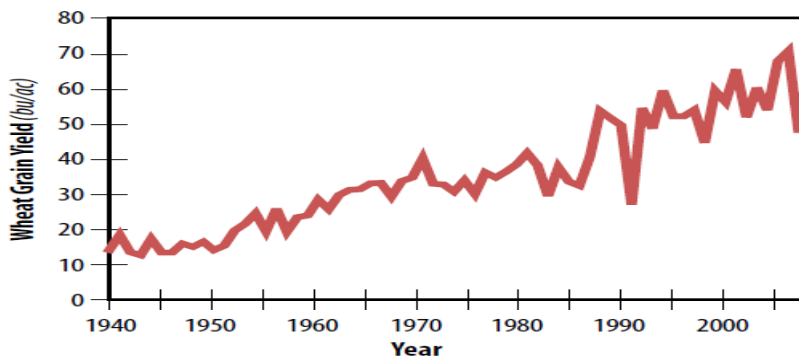
Kentucky Wheat Profile

Summary:

- Kentucky is ranked 19th in the United States for wheat production with 1.5% of total US production and a value of \$69,011,400.
- By 2020, the global demand for wheat is expected to increase by 1.6% per year.

Wheat (*Triticum aestivum*) accounts for 21% of the world's food supply and is grown on 200 million hectares (494 million acres) of farmland globally. By 2020, the demand for wheat is expected to increase by 1.6% per year meaning the average yield will need to increase in the next 25 years from 39 bu/acre to 52.5 bu/acre (Ortiz et al., 2008). Kentucky is ranked 19th in wheat production in the United States with 1.5% of the total US production the average acres planted in Kentucky from 2000-2009 was 513,000 with 356,000 acres harvested for a total value of \$69,011,400 (USDA 2010). Wheat yields in the state have increased dramatically since 1940 (Figure 8) even with the acres planted decreasing since 1981 (ID-125 2009). In Kentucky, wheat is primarily produced for grain as part of a corn-wheat-double crop soybean rotation with more than 50% of wheat produced currently in a no-tillage management system.

Figure 8. Kentucky average wheat grain yields (bu/ac), 1940-2008.



Source: ID-125. Comprehensive Guide to Wheat Management in Kentucky, Kentucky Agricultural Statistics

Climate Effects on Wheat Development and Grain Quality-

Summary:

- Increases in winter and spring temperatures up to 3.5 °F will accelerate early development of tillers and increase straw yield.
- High temperatures greater than 86 °F can cause stress and reduce grain set or grain fill.
- C₃ plants, like wheat, will experience increased rates of photosynthesis and growth by as much as 35% from increased CO₂ levels
- Exposure to elevated levels of CO₂ will cause nutritional and processing quality of flour to be reduced.

Coupled with the challenge of increasing yields to meet global food demands is the need to produce crops in a sustainable manner while maintaining end use quality and value. To understand the potential effects of climate change on grain production we must consider the effects of temperature, precipitation and atmospheric gas concentrations on plant growth and development.

Temperature:

Temperature and precipitation affect plant growth directly and can induce or alleviate stress, while alterations in atmospheric gases and temperature will effect assimilate supply and grain quality (Hatfield et al., 2011). Increases in winter and spring temperatures can accelerate early development of tillers and is positively correlated with straw yield (Chmielewsky and Potts, 1995). Simulation experiments using crop growth models have shown temperature increases up to a 3.5°F maximum will stimulate early development of tillers. Increases greater than 3.5°F may result in premature senescence and less dry matter production (Miglietta and Porter, 1992). However, warmer temperatures are also associated with lower grain weights due to the fact that the increased rate of growth is offset by reduced grain set or shorter grain fill period.

Temperatures greater than 86°F can cause stress and reduce grain set or grain fill for winter annual crops like wheat. High temperatures (>86°F) before flowering can decrease seed number and after flowering can reduce duration of grain fill leading to yield loss in wheat. Research has shown that low grain fertility was induced by exposure to temperatures above 86°F for as little as one day during critical periods between booting and flowering (Ferris et al., 1998). Plants at mid-flowering are particularly sensitive to even brief exposures of high temperatures Ferris et al. (1998) observed that eight days with temperatures above 87°F at flowering was related to a 50% reduction in grain yields. Production of pollen grains and transfer to stigma, as well as germination and fertilization of the zygote are all temperature-sensitive events. Male and female sterility can occur in wheat at high temperatures (>86-89°F) (Saini and Aspinall, 1982).

According to the US Global Change Research Program, nighttime temperatures have been rising more rapidly than daytime temperatures and are expected to continue to rise in the future (Karl et al., 2009). Increased nighttime temperatures are particularly critical for the reproductive phase of development due to increased respiration rate and the reduction in the amount of carbon uptake from photosynthesis during the day being retained in the grain. Increased nighttime temperatures resulted in decreased photosynthesis after 14 days of stress (nighttime temperatures above 57.2°F) causing grain yields to decrease linearly. Nighttime temperatures above 68°F caused a decrease in spikelet fertility, grains per spike, and grain size (Hatfield et al., 2011).

Atmospheric Gas Concentration:

C₃ plants, like wheat, will experience increased rates of photosynthesis and growth by as much as 35% from increased CO₂ levels. This enhanced photosynthesis is due to the decrease in rates of photorespiration. According to Lobell (2007), each additional ppm of CO₂ results in ~0.1% yield increase for C₃ crops so a ~17% increase in wheat yields would be predicted if CO₂ levels increase from the current 380 ppm to 550 ppm as expected by 2050.

Spiertz and Schapendonk (2001) reviewed wheat experiments across multiple sites and years and reported an increase in average yield of 30% due to doubled CO₂ levels (550 ppm) while simulation models predicted an average increase of 25-40%. Higher CO₂ is expected to increase the rate of photosynthesis, resulting in higher biomass yield coupled with increased water use efficiency due to stomatal regulation.

Wheeler et al. (1996) observed 15-55% increases in wheat yields under doubled CO₂ concentrations (550 ppm). Rate of grain growth per ear was increased 21-24% in the doubled CO₂ concentration compared to the normal CO₂. However, a high frequency of undeveloped grains were found when temperatures were above 86 °F for 5 days at normal CO₂ concentrations just before flowering compared to ambient conditions.

Exposure of wheat to elevated levels carbon dioxide and ozone can result in significant trade-offs between grain yield and grain quality (Pleijel and Uddling, 2012). Research has demonstrated that grain protein concentrations are primary determinants for nutritional value, flour properties and dough quality (Erbs et al., 2010). Under projected elevated CO₂ concentrations increased nitrogen fertilization will be necessary to maintain grain quality due to evidence of CO₂ - induced impairment of nitrate uptake (Kimball et al., 2001). This result occurs when the increase in biomass is larger than the increase in N acquisition. The lag in N acquisition is caused by a failure of the root system and shoots to keep pace with the necessary nutrient uptake required for the increased growth seen in higher CO₂ gas concentrations (Pleijel and Uddling, 2012). Under realistic agronomic conditions future grain quality is likely to decline with projected increases in CO₂ and could be further exacerbated by decreased nitrogen supply.

Studies suggest that reductions in grain protein concentrations as a result of increased CO₂ will have consequences for the wheat processing industry. Specifically nutritional and processing quality of flour will be reduced for cereals grown under elevated CO₂ and lower nitrogen fertilizer. Increases have also been reported in lipid concentrations at high levels of CO₂ but appear to be negated by the associated increase in temperatures. (Williams et al., 1995) Gluten quality has also been observed to vary depending on mean temperature during grain filling (Moldestad et al., 2011). A reduced gluten quality was observed

when diurnal temperature was below 64 °F from heading to midway through the grain fill period. Higher temperatures were positively related to gluten quality.

Climate Effects on Wheat Management-

Summary:

- Sowing crops earlier is one strategy to avoid periods of heat stress but in wheat early-sowing could cause an increased risk of frost at the flowering stage.
- Predicted climactic changes would likely favor seed dispersal and provide a habitat suitable for new weed species in the state while possibly harboring insect and pathogens.
- Breeding for earlier-maturing wheat or tolerance to elevated temperatures may become an appropriate strategy for adaptation to climactic changes.
- There is a need for improvement in accuracy of seasonal forecasts and the increased knowledge of cultivar response to certain climatic conditions.

Crop management practices will be important in adapting agriculture to climate variability. Shifts in planting date can have significant impacts on the growth and development of winter wheat crops due to the range of temperature at planting. Early planted crops displayed larger shoot and root systems prior to January and were retained until flowering (Vincent and Gregory, 1989). Soil moisture, nutrient supply, pest pressure and climate conditions all contribute to the rate of shoot growth and canopy development. Sowing crops earlier is one strategy to avoid periods of heat stress but in wheat it could increase risk of freeze damage from jointing to flowering. However, with daily minimum temperatures increasing at rates greater than maximum temperatures this strategy may become more useful.

Spiertz and Schapendonk (2001) offer advice for future research to focus breeding on adaptation to milder temperatures during winter and spring with more temperature extremes during flowering and grain fill. Selection for extended early development, particularly from spike initiation to flowering may aid in making use of increased supply of photosynthates under increased CO₂ conditions by increasing the number of grains. This strategy is further based on the notion that the nitrogen demand of a high yielding crop under a changed climate will only be partially covered from reallocation of vegetative growth supply.

Temperature-tolerant varieties are thought to differ from temperature-sensitive varieties by maintaining higher rates of kernel growth (Wheeler et al, 1996). The authors hypothesize that wheat cultivars developed for adaptation to the warmer conditions will not be limited at seed set. Cultivars with adaptive traits will not experience shortened duration of ear development or duration of post-flowering crop growth. With this adaptation, yields may increase under both higher temperatures and increased CO₂

conditions. However, with the increase in yield will come the need to adjust fertility management to maintain grain quality. Other potential management tools that may be available to growers in the future include the pairing of certain cultivars with seasonal forecasts; this is contingent on the improvement in accuracy of seasonal forecasts and the increased knowledge of cultivar response to certain climatic conditions. It is anticipated that the use of crop models and historical weather data in combination with genotypic data will lead to this increased knowledge (Asseng et al., 2012)

Climate Change Effects on Pest Management-

Summary:

- Changes in temperature will likely cause shifts in pest populations and severity.
- Earlier springs and warmer winters are likely to allow proliferation and higher survival rates of disease causing pathogens.

In Kentucky there is great variability in date of first frost, onset of continuous cold weather late in the fall, and the onset of warmer temperatures in the spring. Warmer temperatures bring the concern of increased generations of insects, improved conditions for survival and transmission of diseases, and movement and competitive ability of weeds (Johnson, 2005).

Primary Insects in Wheat:

Due to the seasonal patterns in Kentucky and the fact that wheat is a winter crop, producers must contend with three groups of insect pests: Fall pests, spring pests, and those that either overwinter or do not overwinter (Figure 9). While insects in wheat rarely cause any significant economic damage in Kentucky, a change in weather patterns could cause the appropriate conditions for damage (Johnson, 2005).

Figure 9. Small Grain Insect Scouting Calendar (Johnson and Townsend, 2009)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Aphids ^{a,b}	Red	Grey				Grey	Red		
Armyworm							Grey	Red	
Fall Armyworm ^b	Red	Grey							
Cereal Leaf Beetle							Grey	Red	
Hessian Fly ^b	Red	Grey					Grey		

*Red indicates possible economic impact.
^aWarm fall weather favors these species.
^bPlanting before October 15 favors these species.

Hessian Fly (*Maylota destructor*) - Currently control of this insect is achieved by planting after the “fly free” date. If fall temperatures remain warmer longer, thus delaying the first frost, wheat planting may occur prior to the period of overwintering for this insect.

Aphid Complex: English Grain Aphid (*Sitobion avenae*), **Corn Leaf Aphid** (*Rhopalosiphum maidis*), **Rice Root Aphid** (*Rhopalosiphum rufiabdominalis*), **Bird Cherry Oat Aphid** (*Rhopalosiphum padi*) - These insects are primarily vectors of Barley Yellow Dwarf Virus (BYDV) and do not typically cause direct damage. For aphids to be active temperatures must be at or above 50°F; temperatures below 30°F increase aphid mortality. However, even at very low temperatures some aphids will survive. A warm, dry winter will aid aphid survival and BYDV spread while a cold, wet winter will reduce aphid survival and movement. (Johnson and Townsend, 2009).

Cereal Leaf Beetle (*Oulema melanopus*) - This beetle will occur from about mid-April until wheat maturity. The beetles over-winter as adults, and re-enter fields when warm-up occurs. If spring temperatures trend upward earlier this insect may enter fields earlier than current temperatures allow. Damage early in the heading period, particularly to the upper leaves, is of more economic concern than later in the heading period.

Fall Armyworm (*Spodoptera frugiperda*) – Fall armyworm does not overwinter, rather it migrates from the gulf coast in mid-summer infesting corn as the primary host and in early fall it can infest small grains. Damage is primarily on seedlings before roots are established. Warmer fall weather could delay the first killing frost allowing fall armyworm a longer period of survival in Kentucky.

True Armyworm (*Pseudaletia unipuncta*) – True armyworm is a spring pest for wheat in Kentucky as the adult moths begin flights and lay eggs in late April and May. Damage is primarily on leaves and immature heads. If spring temperatures increase earlier particularly in areas to the south this insect may appear earlier than current temperatures and could become a greater economic concern due to leaf feeding reducing yields.

Primary Diseases in Wheat:

Earlier springs and warmer winters are likely to allow proliferation and higher survival rates of pathogens. Pathogens may change their host specificity through ‘green bridges’, a term that refers to the situation whereby a pathogen that commonly infects one species, when given the appropriate conditions, adapts to infect other species. For example, in the spring of 2011, wheat blast (*Pyricularia grisea*) was discovered for the first time in any location outside of South America in Kentucky at the University of Kentucky Research and Education Center in Princeton, KY. However, the genetic structure of the pathogen found in Kentucky was different from that of the South American pathogen but very similar to the pathogen that causes gray leaf spot in annual ryegrass in Kentucky. Researchers believe that the

annual ryegrass pathogen gained the genetic ability to infect wheat, rather than the pathogen being imported on grain from South America (Pratt 2012). This fungal pathogen thrives in warm, wet conditions, and as Kentucky's climate becomes warmer and wetter the risk from this pathogen will continue to increase. Examples of other diseases in wheat that may be affected by a changing climate are listed below:

Speckled Leaf Blotch (*Septoria tritici*) – This disease may be associated with frost injury and later season development in cool, wet springs. Intense rain events may favor spread of the disease to the upper leaves and head later in season causing economic damage.

Stagonospora Leaf and Glume Blotch (*Stagonospora nodurum*) – This pathogen causes important diseases of wheat in Kentucky that occur mid to late-season and are most severe under warm, wet conditions. Historically, these have been the most consistent yield limiting disease in the state. Both diseases would be expected to increase in incidence and severity under a warming climate.

Powdery Mildew (*Erysiphe graminis*) - Early to mid-season disease that is favored by cool and wet conditions. Excessive free moisture or late spring freezes can slow disease progress, and therefore this disease would be expected to diminish in importance as temperature increases.

Leaf Rust (*Puccinia graminis* f. sp. *tritici*) – Typically a late season fungal disease due to lack of overwintering in Kentucky. When conditions allow over-wintering the disease may cause epidemics and yield loss in susceptible varieties, and thus a warming environment favors this disease.

Stripe Rust/ Yellow Rust (*Puccinia striiformis* f. sp. *tritici*) - Mild winters and moisture favor overwintering in susceptible varieties. The outlook under a changing climate is similar to that of leaf rust.

Wheat Streak Mosaic Virus - Requires the wheat curl mite as a vector which is capable of overwintering in the state in mild winters. Normally not a problem in Kentucky, the threat from this potentially devastating disease will increase if a warming environment favors the development of green bridges.

Fusarium Head Blight (FHB; *Fusarium* spp. esp. *F. graminearum*) – This fungus infects the spike tissue primarily at flowering and favors temperatures between 75-85 F with prolonged periods of high humidity or prolonged wet periods. In recent years, Kentucky has escaped serious FHB damage when cool temperatures have prevailed during flowering. This may change with a warming climate.

Barley Yellow Dwarf Virus- Requires an aphid vector which may be favored with delayed frost in fall and milder winters. Hot, dry summers may aid in control of aphid vectors.

Primary Weeds in Wheat:

The major weeds found in wheat fields in Kentucky are winter annuals and perennials. Examples of weeds commonly found in wheat: Italian Ryegrass (*Lolium multiflorum*), Cheat (*Bromus secalinus*), Common Chickweed (*Stellaria media*), Henbit (*Lamium amplexicaule*), Shepherds-purse (*Capsella bursa-pastoris*), Field pennycress (*Thlaspi arvense*), Mustard (*Brassica spp*), Horseweed (*Conyza canadensis*), Curly Dock (*Rumex crispus*), Wild Garlic (*Allium vineale*), Wild Onion (*Allium canadense*). Weeds are not the primary pest of wheat in Kentucky primarily due to the growing season and the narrow row spacing allowing quick ground cover in early spring. The primary concern is that climate change would shift weed species ranges since it would alter temperature, precipitation distribution and wind patterns (Chen and McCarl, 2001). Climactic changes would likely favor seed dispersal and provide a habitat suitable for new weed species in the state which may additionally harbor insects and pathogens.

Conclusions-

Based on the future climate projections for Kentucky from the Kentucky Climate Center and the National Climate Assessment for the Southeast it seems appropriate to continue to explore the effects of climate change on wheat production in Kentucky. Jerry Hatfield (unpublished), USDA Plant Physiologist, states “the combination of short-term weather and long-term climate presents a challenge in terms of being able to assess the potential adaptation and mitigation strategies possible to increase the resilience and long-term stability in production”. Despite rather minor changes occurring to date, the potential for climate change to impact wheat production remains evident. This review of scientific literature indicates that climate change may impact management decisions, cultivar development, crop-pest interactions, and economic potential for wheat.

Projections of increased temperatures, precipitation, and CO₂ concentrations will no doubt challenge the wheat industry, yet it appears that the climate in Kentucky will remain favorable for profitable wheat production. However the impact of a warming climate on wheat pests introduces uncertainties. A more diverse and robust suite of cultivars with heat tolerance, freeze tolerance and resistance to an array of pests will likely be required. Successful adaptation strategies will require input from wheat growers, agronomists, plant pathologists, entomologists, climate scientists, ecologists and crop physiologists.

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