AGRICULTURE, CLIMATE, CHANGE

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Agriculture, Climate, Change

Research crop scientist from the K-State Northwest Research-Extension Center, Professor Robert Aiken explores agriculture and crop research issues in the United States today

As an agricultural scientist, I consider it my duty to anticipate questions and problems which may confront farmers in the future. When I'm successful, designing and conducting effective field studies, we have the information needed to formulate feasible solutions, before problems get out of hand.

In my semi-arid region of the U.S. Central High Plains, our crop systems contend with heat stress, desiccating winds, lack of rainfall, flood-generating rains and unexpected arctic air masses, inducing winter-kill or bringing the season to a chilling conclusion. Adapting to climate change? In a sense, we prepare for climate change by helping farmers adjust to the challenges of the current growing season.

Our growers recognise long-term warming trends and shifts in weather patterns. A recent report[1], prepared by the State Climatologists of Texas, Oklahoma and Kansas, indicates climate change has been written into the historical weather record. Below are three quotes from the report:

"Both temperature and precipitation have increased across the Southern Plains since the beginning of the 20th century. Temperature increases so far have averaged about 1.5ºF (0.8ºC) over the 20th century and precipitation has increased by as much as 5%, albeit with large variations from year-to-year and decade-to-decade. Heavy rainfall events have increased in frequency and magnitude. Historical data for tornadoes and hail are not reliable enough to be used to determine whether a trend is present in these types of severe weather." [1]

"Variations in drought conditions from year-to-year and decade-to-decade are triggered by changes in sea surface temperature patterns in the Pacific and Atlantic oceans. The Dust Bowl drought is thought to have been exacerbated by poor land use practices, while precipitation may have been enhanced in recent decades by growth in irrigated agriculture and surface water."[1]

"Temperatures will continue rising over the long-term, as carbon dioxide and other greenhouse gases continue to become more plentiful in the atmosphere. By the middle of the 21st century, typical temperatures in the Southern Plains are likely to be 4ºF to 6ºF (2.2ºC to 3.3ºC) warmer than the 20th century average, making for milder winters (with less snow and freezing rain), longer growing seasons and hotter summers. Rainfall trends are much less certain. Most climate models favour a long-term decrease, but most projected changes are small compared to natural variability. Extreme rainfall is expected to continue to become more intense and frequent."[1]

I have specific concerns deriving from these warming trends: declining yield potential because of increased night temperatures, diminished photo-protection systems under persistent heat stress, increased risk of reproductive failure with heat stress at critical development stages, increased crop water requirements, degradation of soil with intensive rainfall events and increased potential for large-scale methane emissions unleashed by thawing permafrost[2]. These concerns rise to the top of my "watch list" for climate change impacts.

Crop productivity is expected to benefit from historic and on-going annual increases in global CO_2 concentrations. Assimilation rates can be maintained with modestly reduced crop water requirements. Cool-season grass crops and broadleaf crops will likely gain photosynthetic efficiencies. However, warming trends can detract from the beneficial effects of elevated CO_2 levels.

"When elevated temperatures exceed optimal conditions for assimilation, stress responses can include damage to the light-harvesting complex of leaves, impaired carbon-fixing enzymes, thereby reducing components of yield including seed potential, seed set, grain fill rate and grain fill duration. Field studies conducted under conditions of elevated CO_2 indicate that benefits of elevated CO_2 are reduced by heat-induced stress responses."[3]

Rural Nebraska landscape

Warmer temperatures, the most reliable feature of climate change, can extend the growing season, but also impair plant productivity. Persistent heat stress pushes plant metabolism to the edge of toleration. The complexity of plant metabolic processes can be astounding. Many of these processes are temperature-sensitive, with optimum temperatures for photosynthesis ranging from 25 to 30ºC (77 to 86ºF) for winter wheat[4], up to 32ºC (90ºF) for soybean[5] and up to 38ºC (100ºF) for maize[6]. Chronic heat stress, with daily temperatures exceeding this range, can accelerate the breakdown of thermo-protective mechanisms and can result in permanent damage to crop canopies.

Hot conditions prior to and during flowering can result in crop failure. Grain production requires effective pollination of ovules for 'seed set', followed by development and growth of the kernels, harvested as grain. Excessive temperatures (i.e., daily mean temperatures > 25ºC for grain sorghum[7], wheat[8]) for a few days in the ~15-day period around flowering can decrease yield potential due to impaired pollination and seed-set; complete failure can occur with daily mean temperatures of 35ºC (wheat) or 37ºC (sorghum).

Night temperatures drive the metabolic rates of a plant, with the associated respiratory release of CO_2[9] as well as cell degradation[10]. In a sense, plant respiration depletes the supply of carbohydrates available for plant growth and development. As a long-term trend, warmer night temperatures can sap crop productivity.

Chronic high temperatures add to the evaporative demand on crop systems. This increases the water requirement for crop growth. Warmer temperatures can sap yield potential by impairing heat-tolerance protective mechanisms; by reducing the duration of grain-filling; and by increasing the respiratory cost, the water requirement for growth and the risk of reproductive failure of cereal crops. Warmer temperatures carry a complex drum-beat of warnings for crop productivity. Needed research is underway to adapt crop cultural practices to avoid heat stress; and to seek genetic advances for crop cultivars that are capable of tolerating or resisting effects of warming temperatures.

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Texas 2012: An entire field of corn is lost due to drought conditions

Global research on drought

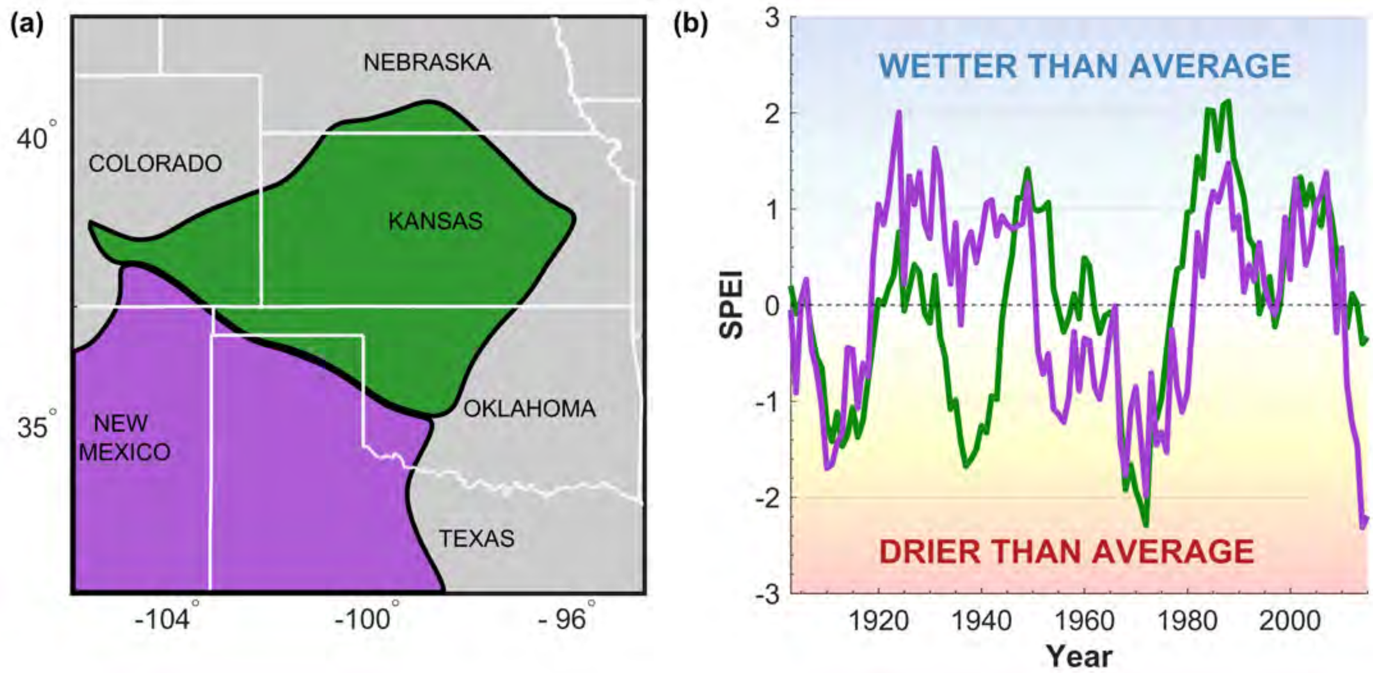
Professor Robert Aiken, Research Crop Scientist from Northwest Research–Extension Center provides his expert thoughts on the fascinating global research taking place on drought, including the vital role of satellite imagery

As a field agronomist from Northwest Kansas, I'm attending the 15th Ogallala Aquifer Program workshop in Lubbock, TX with irrigation engineers, hydrologists, economists and other water scientists, focused on extending the life of the aquifer to sustain rural economies (https://ogallala.tamu.edu/). The tension in the conference is palpable. "164 days since last measurable precipitation in the Texas High Plains." "This wheat crop is on the ropes." "If we don't get rain soon…"

We all recognise drought. The dull green vegetation; the pallor of dust-filled skies; the dry scratchy throat and persistent cough. Agriculture? Drought stops agriculture in its tracks. Here in the High Plains, agriculture affects a third of the regional economy. In Sub-Saharan Africa, drought affects the core food supply, leading to rural exodus and civil unrest. In Northwest India, drought amplifies the frequency of heat-related deaths. In Cape Town, South Africa, a two-year drought threatens the water supply for the four million residents. Drought touches our lives and communities in myriad ways.

Wayne Palmer published his drought index in 1965, considering drought cycles of the 1930s and 1950s. His metric uses monthly precipitation and atmospheric demand for water, contrived to report the deviation of soil water supply from 'normal' conditions. The concept of 'normal', or the long-term average weather is central to many drought indices used today. The United States Drought Monitor displays its index using fire colours – yellow, orange, red. Drought metrics provide early warning of impending disasters.

The American Meteorological Society hosted four sessions on drought and food security in its 2018 meetings. One of several global-scale drought monitoring programmes utilises satellite imagery to calculate and map the energy



(a) Two selected sub-regions in the Great Plains for spring drought variability and (b) their corresponding drought time series (filtered using a 10-year running average) for the period 1903-2015. Climate data used to calculate the drought index was retrieved from the Climatic Research Unit (CRU) TS v. 3.24.01 (Harris et al. 2014[1]). The drought index is the Standardized Precipitation Evapotranspiration Index (SPEI) on a three-month time scale (Vicente-Serrano et al. 2010[2]). Positive values of the SPEI represent wetter than average conditions and negative values represent drier than average conditions. There are notable differences in the drought conditions of these adjacent sub-regions during the 1930s (Dust Bowl era) and the period 2010-2015 (b). These temporal differences in drought variability across relatively short spatial distances provide evidence for the delineation of each sub-region and consideration in drought monitoring and climate change analyses.

balance for land surfaces. This accounting scheme uses physics to sum inputs and outputs in terms of radiation, evaporation and warming/cooling of air and land. The thermal band from satellites, representing the surface temperature, conveys critical information of surface water availability. Warmer sectors indicate dry surfaces, while the wet regions display cooler temperatures.

Globally, agencies use these techniques to detect and report incipient and ongoing drought. These early warnings and updates inform emergency drought responses. Earth scientists recognise drought as an integral component of the hydrological cycle. The question remains: Has climate change affected the frequency, duration or extent of drought?

Zach Zambreski, a young, bright, dedicated meteorologist, tackled the problem of long-term drought dynamics in his graduate research (Kansas State University, Agronomy). He employed Empirical Orthogonal Functions (EOF, a type of principal component analysis) to characterise monthly drought metrics of the U.S. Great Plains over the 20th century (1903 to 2015). He then correlated the EOF with each of the localised time series of drought metrics to identify regions with similar historic patterns of wetting and drying cycles. Analyses such as this provide benchmarks against which climate change trends can be usefully compared.

This afternoon our groundwater conference closes. The overnight thunderstorm relieves the tension – for the moment. We muse about La Nina effects, the wet winter conditions in the Northern Great Plains and prospects for wheat harvest. Likely, there are similar conversations within the railroad companies, considering where to position their box cars to transport the wheat crop to export shipping terminals. As earth scientists, we recognise the tools at our disposal to identify and quantify drought. Collectively, as a global society, are we prepared to mitigate the effects of drought?

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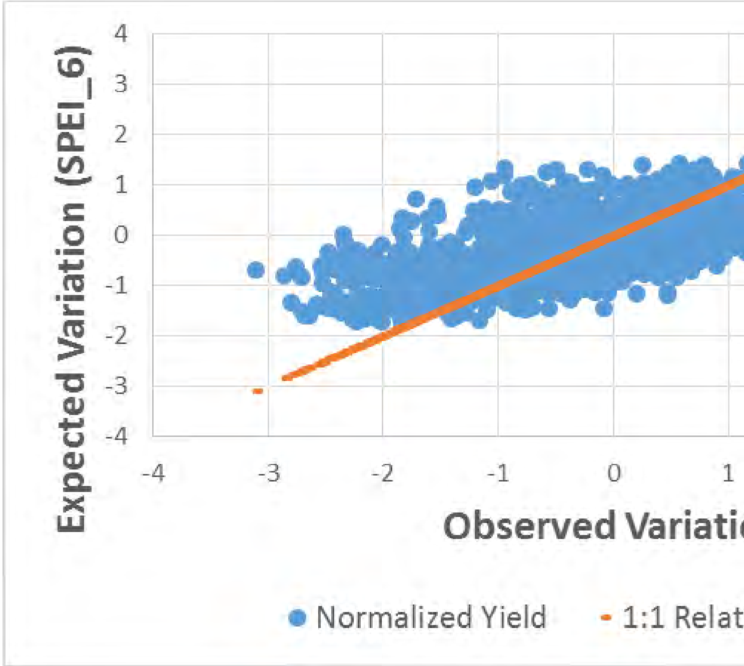

Figure 1: The in-sample predictive ability for wheat yield variation of multiple r temperatures of the Equatorial Pacific is compared against observed yield vari W of the 99th Meridian. Observed variation represents variation after remova period) as normalised by dividing by the standard deviation of the time series

Water, temperature and crop productivity research

Prof Robert Aiken, research crop scientist at Northwest Research—Extension Center tells us about his fascinating research into water and temperature, including the extent to which they limit crop productivity

Planting an agricultural crop requires a degree of optimism. In the semi-arid region of Kansas, which I study, water and temperature frequently limit crop productivity. These components of weather, along with sunshine and relative humidity, comprise the weather-related risks which limit the productivity of the crop just planted. As an agricultural scientist, I query the climate scientists: Are there periodic behaviours in weather patterns? Are there long-distance signals indicating wetting and drying trends? Is long-term weather forecasting feasible? If so, accurate forecasts can inform the optimism required to plant that crop, infusing an additional hope that the bet has been hedged.

Seeking information about weather forecasting skill, I learned about 'teleconnections' at recent American Meteorological Association meetings. The El Nino-Southern Oscillation (ENSO) phenomena serves as an example. Warming and cooling trends in the surface waters of the equatorial Pacific Ocean impact fisheries and rainfall in coastal Peru. Indeed, ENSO trends impact the productivity of winter wheat growing in the Texas High Plains. Louis Baumhardt, a USDA-ARS soil scientist and his colleagues found a degree of association between ENSO patterns and winter wheat yields in the Texas Panhandle[1]. Does this ENSO signal convey information about wheat productivity further north, in the central U.S. High Plains?

We know that winter wheat is vulnerable to drought conditions; wheat can also respond positively to wet conditions, though subject to disease impacts[2]. The Standardized Precipitation-Evapotranspiration Indicator (SPEI) provides a metric for wetting and drying conditions, generally varying between values of -4 and 4 to indicate drying (negative) and wetting (positive) conditions. We compared wheat yields, reported for counties[3] in Kansas (1970

regression based on the NINO_3 surface ation for wheat yield in Kansas counties l of a linear historic trend (1970 – 2007 for each county.

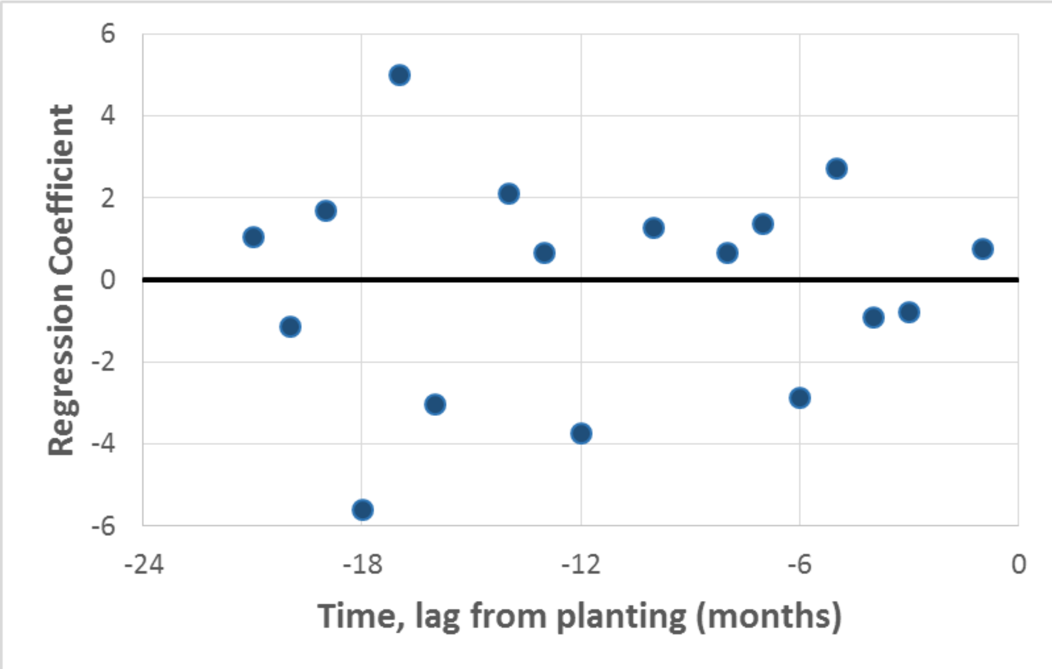

Figure 2: Regression coefficients of the NINO_3 multiple regression model is shown in relation to corresponding time lag (months prior to a September planting period for winter wheat in Kansas). Positive coefficient values for a given time lag indicate a positive association with expected wheat yields for that lag interval; negative coefficient values indicate a negative association.

through 2007) against monthly SPEI values, after removing linear historic trends attributed to improved genetics and production technologies.

A moderate relationship (R^2 = 0.41)[4] emerged for wheat yields reported for counties in W Kansas, indicating positive effects of weather conditions in February, March and April. A weaker relationship (R^2 = 0.25) resulted for counties in sub-humid E Kansas, indicating both positive (October, February, April) and negative (August, December, May, June) relationships with the SPEI metric. This regression analysis quantified the relationship of winter wheat productivity to weather variation during the growing season. However, the utility of forecasting skill depends on the information available prior to planting decisions.

Thus, we evaluated a hypothesized ENSO signal: is winter wheat grain productivity in W Kansas related to equatorial Pacific Ocean surface temperatures in preceding years? We tested the null form of this hypothesis using multiple regression for W Kansas county yield reports and monthly ENSO data for the 24-month period prior to wheat planting (September, a year prior to harvest). We found a positive result. A moderately strong relationship (R^2 = 0.53) resulted from regression analysis (Figure 1). Interestingly, the strongest influences were ENSO values 18- and 16-months prior to the wheat planting period (Figure 2). This indicates that complex patterns in equatorial Pacific Ocean temperatures can convey information which is pertinent to subsequent winter wheat yields in W Kansas. There is an opportunity to develop climate-informed decision-support for cropping systems in the U.S. central High Plains.

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3 National Agricultural Statistics Service

4 'R' squared (R2) indicates the fraction of observed variation which can be accounted for by a regression relationship.

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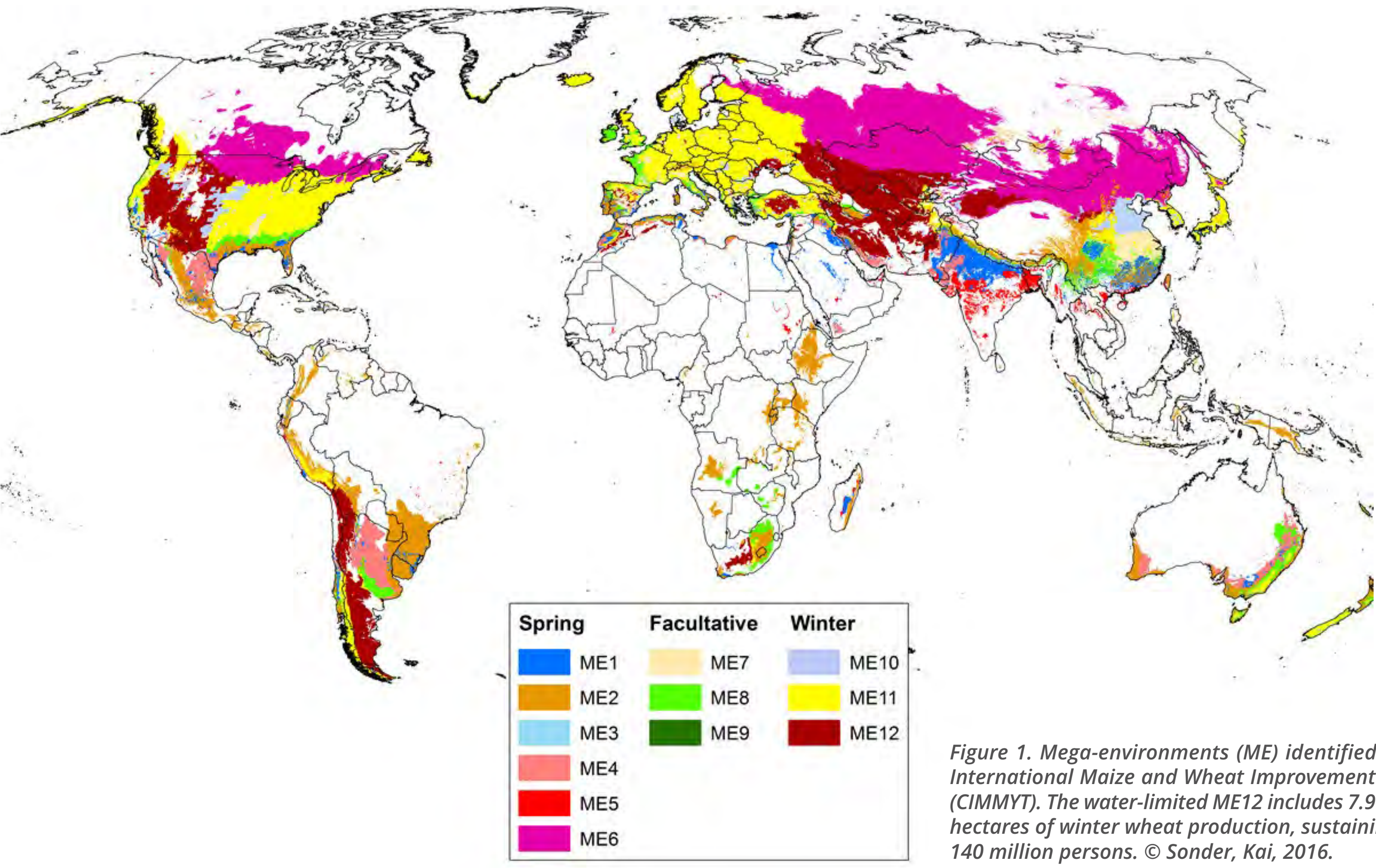

Figure 1. Mega-environments (ME) identified by the International Maize and Wheat Improvement Center (CIMMYT). The water-limited ME12 includes 7.9 million hectares of winter wheat production, sustaining over 140 million persons. © Sonder, Kai, 2016.

The creeping trends of climate change

Like the proverbial frog in the heating pot of water, we may not notice the creeping trends of climate change. The farmers I serve in the semi-arid U.S. Central High Plains encounter dramatic year-to-year fluctuations in weather patterns, which tend to overwhelm the long-term trends. We're just learning how to recognize and interpret long-term climate signals, such as the El Nino-Southern Oscillation[1]. What's to be done to ensure global food security in the face of climate change?

Semi-arid cropping systems, the focus of this series, include 7.9 million hectares of winter wheat production in western U.S., Argentina, western and central Asia (Figure 1); here the evaporative demand for water can exceed annual precipitation by factors of three to five. Is there opportunity to increase crop productivity, given limited and untimely water supply? My thinking falls along two lines: improving crop water productivity and increasing stress tolerance of critical processes such as ovule fertilization by pollen.

The fundamentals of carbon-water exchange, which underlie crop water productivity, are 'managed' by leaf stomata – gateways permitting carbon dioxide (CO_2) entry to leaf biochemistry as well as the exit route for water vapor diffusing into the atmosphere. This linked diffusion of CO_2 and water vapor supports the theory that the carbon-water exchange rate is closely regulated, affected by biochemistry and atmospheric humidity.

Greenhouse and field studies (Xin et al., 2009; Narayanan et al., 2013) indicate that sorghum cultivars do differ in carbon-water exchange rates (Figure 2) with parallel differences in radiation use efficiency (Figure 3). This evidence supports accelerated investigations into the mechanisms driving differences in plant carbon-water exchange rates

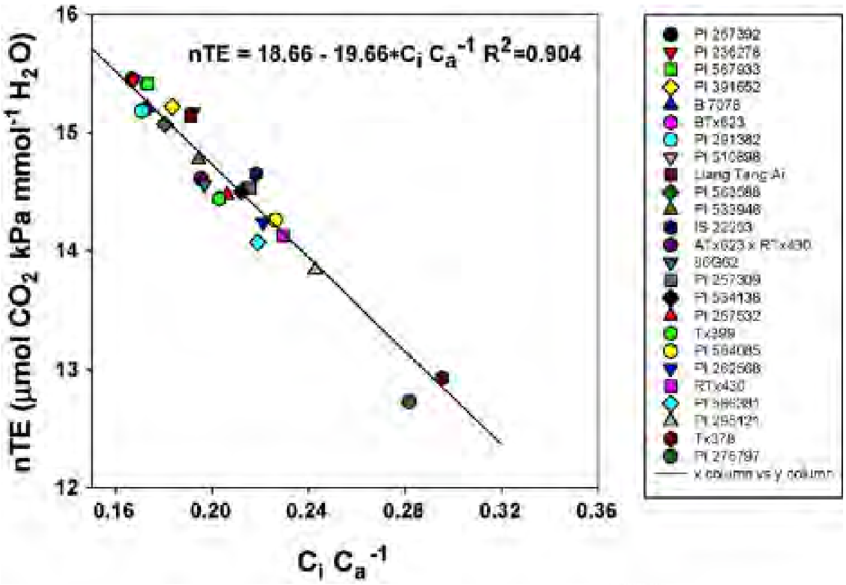

Figure 2. Evidence that sorghum cultivars can differ in the carbon-water exchange rate. Here, instantaneous transpiration efficiency (nTE), normalized by vapor pressure deficit (VPD)—a measure of atmospheric aridity, is shown in relation to the ratio of leaf internal CO_2 concentration to air (Ci/Ca-1). © Xin et al., 2009.

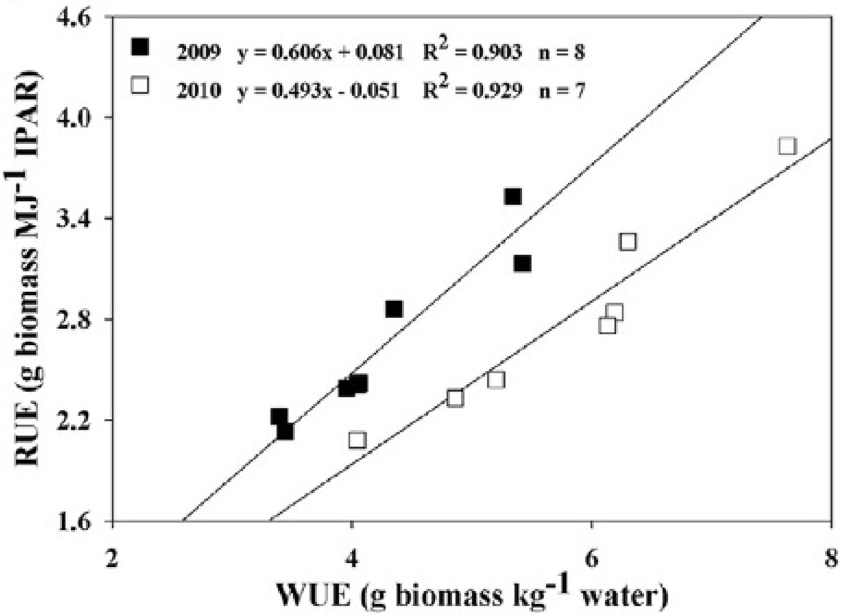

Figure 3. Field evidence that sorghum cultivars differ in biomass productivity in relation to use of water and radiation. Relationships are shown between water use efficiency (WUE) and radiation use efficiency (RUE) among sorghum genotypes; WUE was derived as the slope of the regression of above-ground biomass on cumulative water use, while RUE was derived as the slope of the regression of above-ground biomass on cumulative intercepted photosynthetically active radiation (IPAR). © Narayanan et al., 2013.

as well as development of high-throughput screening tools to identify desirable germplasm.

Heat stress and water deficits impair pollen development and fertilization of ovules, thereby reducing the 'seed-set' required for grain production, according to careful studies conducted in the laboratories of Dr. Vara Prasad[2]. Species of Aegilops, a relative of wheat, provide sources of genetic traits conveying heat and drought tolerance to pollen development and ovule fertilization. Scientists in the Wheat Genetics Resource Center[3] are systematically integrating these traits with elite breeding lines, developing wheat varieties with increased stress tolerance.

Sustaining the increased crop productivity to provide global food security will require continued innovation, collaboration, and vision.

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