Plant Responses to Atmospheric Forcings

Literature Review and Model Comparisons

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This research assesses how plant physiology influences crop responses to atmospheric forcings affecting transpiration, biomass production and yield.

Mission Issue

Understanding crop water use and yield responses to changing atmospheric conditions is fundamental to the long-term viability of Reclamation projects. By modeling crop physiology, this study demonstrates that it is possible to better understand how future conditions may affect these key components of long-term planning.

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Problem

The assessment crop water requirements and yields are important for managing current water demands as well as planning for future water needs. This information is commonly employed in both hydrologic and economic models that Reclamation and many others use to make operational and infrastructure investments decisions.

These evaluations are often performed with modeling tools or methods that use empirically determined coefficients based on historic conditions. However, assuming these coefficients remain valid if atmospheric conditions change significantly is questionable. An example of this type of problem is using crop coefficients that have been determined empirically under historic atmospheric conditions in a long-term planning study. Since these coefficients are measured as ratio of a particular crop's evapotranspiration to a standard reference crop, using these coefficients assumes the evapotranspiration of both crops must change by equal amounts. By employing a physiologically based plant growth model, this study evaluates the validity of such an assumption.

Solution

In this study, the physiological responses of plants to environmental conditions are reviewed in detail at scales ranging from molecular to global in order to describe how transpiration, biomass and yield interact with atmospheric forcings. The literature review includes a discussion of experimental and modeling studies which have been performed to understand and quantify the effects of changes in atmospheric forcings on these crop responses. Finally, a modeling study based on six atmospheric scenarios representing a wide range of potential changes in temperature, solar radiation, carbon dioxide and vapor pressure deficit was performed to elucidate relationships between these atmospheric forcings and the transpiration, biomass and yield responses of six major crops commonly grown in Reclamation service areas throughout the western United States.

This was accomplished by calibrating a physiologically based crop model, WEAP-PGM, to simulate daily evapotranspiration and biomass production as well as annual crop yields in California's Central Valley. Simulation results were evaluated, and statistical methods applied to determine the significance of crop responses and how they were related to changes in the atmospheric forcings.

"Plant physiology is the most fundamental way to assess crop responses to environmental conditions. Unlike empirical methods based on historic conditions, physiologically based modeling is capable of simulating dynamic crop responses to significantly changing atmospheric conditions."

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More Information

https://www.usbr.gov/research/projects/detail.cfm?id=1858

https://www.usbr.gov/research/projects/researcher.cfm?id=181

Application and Results

The atmospheric forcings used in the assessment are based climate scenarios developed by Reclamation for the Sacramento and San Joaquin Basins Study. Six climate scenarios were selected to characterize a wide range of potential atmospheric forcings occurring over an eighty-nine-year study period. To characterize plant responses four atmospheric forcings were selected including temperature, solar radiation, carbon dioxide and humidity expressed as the vapor pressure deficit. A correlation coefficient analysis was performed to evaluate the relationships between these atmospheric variables so that plant responses to them could be better understood. The correlation analysis was also used as a tool in the assessment of the transpiration, biomass and yield results from modeling study.

The effects of atmospheric forcings also were variable depending on nature of the crop. For example, increasing temperature could result in increased transpiration, biomass production and yield up to the point in which temperature exceeds the optimal growth range of the crop. Further increases would reverse the trend. Crops responses to carbon dioxide also exhibit opposing effects. For example, increasing carbon dioxide may result in increased canopy vegetative growth which contributes to increased transpiration and at the same time increasing carbon dioxide may contribute to reduced transpiration because of its effect on water vapor exchange between the plant's leaves and the atmosphere.

Future Plans

A variety of future developments could be useful to Reclamation and other agricultural water managers. First, a crop model with additional capabilities to simulate nutrient responses could assess how soil management practices interact with atmospheric forcings. Additional applications of physiologically based crop models in other Reclamation regions could also be beneficial. Another useful application would be the integration of a crop model into a meteorological forecast system.

Irrigated vineyard located in the Dunnigan Hills near Woodland, California.