# SOLUTIONS that don't fall from the sky

## New tools will aid future farmers

by Camille M Steber, PhD
*USDA-ARS, Wheat Genetics, Quality, Physiology, and Disease Research Unit*

Dr Scot Hulbert and technician Chris Hoagland plant drought trials in Lind

Have you ever had the experience of not receiving the rainfall you needed when you needed it? You're not alone.

Drought is one of the most common causes of yield loss in agriculture worldwide. You only have to drive through central Washington in the summer to understand why the *Genetic Arsenal for Wheat Production under Drought* project is near and dear to the hearts of wheat researchers Kimberly Garland Campbell, Scot Hulbert and the author.

The inland northwest is a major wheat-producing area containing three-quarters of the water-limited dryland farmland in the western United States. Much of the region receives less than 15 inches of rainfall per year. While soils in this region retain moisture well, low rainfall poses a constant challenge.

Drought has been a problem since humans began farming. Furthermore, it's anticipated that global climate change will only increase the environmental challenges faced by farmers due to warmer temperatures.

It's believed wheat breeders will be better able to support Washington growers if they are able to anticipate climatic changes and address them in their breeding programs. With this in mind, breeders have begun to work with WSU climate expert, Fok-yan Leung, and Jennifer Adam, who models atmospheric and hydrological processes including future weather and water patterns. Current climate change models predict that the northwestern US will see a 5 to 9 degree Fahrenheit increase in average temperatures by 2100. Although changes in rainfall are difficult to predict in the long term, it's clear that heat exacerbates yield losses under dry conditions. That's why USDA-ARS and WSU researchers are interested in developing drought- and heat-tolerant wheat for the next century.

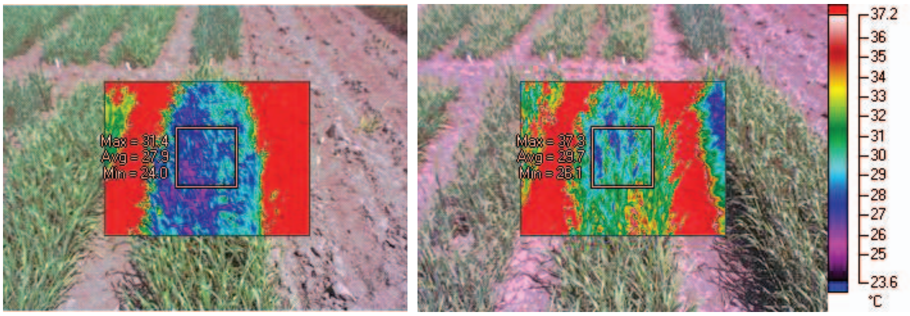
Above, Dr Camille Steber installs Decagon soil moisture sensors.
Below, drought trials at Lind Dryland Field Station 2009.

Creating wheat cultivars that can withstand challenging environments is critical in light of increasing population size and demand for food. It's estimated that one US wheat farmer produces enough to feed about 144 people for a year. While the human population has grown by an estimated 3 to 4 billion since the advent of agriculture more than 10,000 years ago, the current world population of 6.8 billion is expected to swell by another 2 billion by mid-century. If farmers are the unsung heroes of the modern world, then future farmers will need to achieve superhero status.

There are as many mechanisms of drought tolerance as there are forms of drought stress. Drought can strike at any time in the plant life cycle from the seedling stage through flowering and grain fill. Because of the variation in stress, drought tolerance is not a one-size-fits-all trait.

The inland northwest is a unique environment. Most of our rain falls during the winter and spring and very little during the summer months. This rainfall pattern resem-

*Current climate change models predict that the northwestern US will see a 5 to 9 degree Fahrenheit increase in average temperatures by 2100.*




Infrared photos of wheat plants show that water transpiration cools the plants. Cooler canopies suggest that roots are reaching deeper water.

Stomates/pores on the surface of a wheat leaf close to conserve water.

bles that seen in the Mediterranean area or Mexico. But unlike Mexico, our day length varies enormously with the season. Thus, the first step in improving wheat drought tolerance is to figure out which strategies work best for our environment. The Genetic Arsenal project has begun by characterizing the drought tolerance mechanisms in the spring wheat cultivar *Alpowa,* and by examining sources of drought tolerance from similar climates including germplasm from CIMMYT (International Maize and Wheat Improvement Center) in Mexico as well as from Colorado and Australia.

The project is primarily focused on mechanisms that support better yield when drought occurs during flowering and grain fill, including efficiency of water use, deeper roots, healthier photosynthesis and the ability to utilize stem carbohydrates for grain fill. Water-use efficiency (WUE) refers to the yield obtained for the water used. This trait depends on control of water loss through pores in wheat leaves called stomates, and on the waxy layer that coats the leaves. When stomates are open, water is transpired out and carbon dioxide enters the leaf.

Keeping stomates closed a fraction longer helps to conserve water. But if stomates are closed too long, lack of carbon dioxide can reduce grain yield. Thus, achieving drought tolerance through water use efficiency is a delicate balancing act.

The transpiration of water also cools the leaves, just as perspiring cools our skin. This cooling mechanism can becomes more important as temperatures rise — which is why heat can increase the water required for crop production. In situations where water-use efficiency is the best form of drought tolerance, it is going to be important to include genes for heat tolerance.

The plant hormone ABA (abscisic acid) is the signal from drying roots to the shoots that it's time to close the stomates. In plants that are more sensitive to ABA, stomates will close earlier and water use efficiency will be higher. Thus, ABA mutants serve as a source of genes for increased WUE.

WUE is measured in wheat by a method called carbon-isotope discrimination, developed by Australian physiologists. The technique was used to breed the drought-tolerant Australian cultivars *Drysdale* and *Reese.* Higher water use efficiency can be especially helpful when coupled with the ability to put more of the plant's energy into producing grain than into biomass.

When rain is scarce, but deep soil moisture is available, the ability to grow deeper roots provides a clear advantage. As drought progresses, the ability to reach deeper moisture can result in cooler leaves in the canopy because the plants are still able to reach and transpire water. An infrared camera can detect such deep-rooted wheats based on cooler canopy temperatures (see picture).

Unfortunately, the ability to grow deeper roots offers no advantage in places with shallow soil. If the moisture isn't there, deeper roots aren't going to help. In such instances, water use efficiency is still a good way to maintain yield. Another important consideration is the pattern of water use over the life of a wheat plant. For example, a cultivar that uses less water early in life may have more soil moisture available as it moves into grain fill.

Another strategy is to choose wheat lines that mature earlier. According to spring wheat breeder Michael Pumphrey, most of Washington's spring wheat lines have been selected to mature as late as possible. These late-bloomers have higher yield potential because they have more time to accumulate energy for grain production. But in dry years, early bloomers have the advantage since they can complete grain fill before the soil becomes too dry, a mechanism called "drought avoidance." To investigate this phenomenon, the Genetic Arsenal project is investigating the importance of genes controlling flowering time.

As wheat plants endure drought stress, the plant itself becomes

Kimberly Garland Campbell, Scot Hulbert and Camille Steber at the Lind Field Day.



dehydrated and wilts, leading to several types of damage. As the quantity of water inside cells decreases, the concentration of salts and other damaging compounds rise, leading to progressive damage to photosynthesis proteins, damage to cellular structures and cell death. Plants can prevent this damage by inducing protective sugars, proteins and antioxidants. An example of this class of drought tolerance protein is the Monsanto CspB. This type of tolerance (also known as desiccation tolerance) is selected by looking for plants that maintain higher levels of photosynthesis during drought stress or that "stay green." The health of the plant's photosynthetic apparatus can be determined by measuring the fluorescence emitted by leaves during photosynthesis.

When leaves die under drought stress, the plant can compensate by using energy stored in the stems as sugar to support grain fill and yield. In fact, the photosynthesis in the stem itself can keep plants alive.

It has been shown that if there are more water-soluble carbohydrates in the stems during drought stress, then the plant will show better grain fill and yield. The Genetic Arsenal project is selecting lines that accumulate these yield-supporting water soluble carbohydrates under dry conditions. For example, *Alpowa* stems accumulate more water-soluble carbohydrates under drought stress than under well-watered conditions.

The main goal of the Genetic Arsenal project is to identify genes involved in each strategy for drought tolerance and to incorporate these genes into our breeding programs. No one drought tolerance mechanism or gene (GMO or otherwise) will ever provide the magic solution to yielding well with limited water. That's why the wheat drought tolerance team at Washington State University is working to weave together multiple genes and mechanisms of drought tolerance to help those who farm on the dry side. ■