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Squeezing More Crop from Each Drop – An Interdisciplinary Approach to Crop Improvement in Drought-Prone Environments

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Abstract

Improving crop yields in rain-fed environments will be central to food security in a climate-changed world where rain, temperature and drought will be increasingly erratic. Yield improvement in such environments based on selection for yield per se has been slow due to large genotype by environment interactions ($G \times E$). In this paper, we present an interdisciplinary approach to crop improvement that links physiology with plant breeding and simulation modelling to enhance the selection of high yielding, drought-tolerant varieties for the water-scarce environments.

In a series of field experiments in Queensland, Australia, we found that the yield of CIMMYT wheat line SeriM82 ranged from 6 to 28 % greater than the current adapted cultivar Hartog. Physiological studies on the adaptive traits underpinning this advantage revealed that SeriM82 and Hartog differ in root architectural traits. In large soil-filled chambers, SeriM82 had a narrower root system architecture and extracted more soil moisture per soil volume, particularly deep in the profile, late in the growing season when marginal water use efficiency (WUE) is high. To quantify the value of these adaptive root traits, we conducted a simulation analysis with the cropping systems model APSIM for a range of rain-fed environments contrasting in soil water-holding capacity in southern Queensland using long-term historical weather data. The analysis indicated a mean relative yield benefit of 14.5 % in water-deficit seasons and that each additional millimetre of water extracted during grain filling generated an extra 55 kg ha^{-1} of grain yield.

Further root studies of a large number of current Australian and CIMMYT wheat genotypes in small gel-filled chambers revealed that wheat root system architecture is closely linked to the angle of seminal root axes at the seedling stage - a trait which is suitable for large-scale and cost-effective screening programmes.

Overall, our results suggest that an interdisciplinary approach to crop improvement based on identification of physiological traits conferring tolerance to drought stress, evaluation of drought-adaptive traits in the target population of environments using simulation modelling, and development of efficient screening methods is likely to enhance the rate of yield improvement in rain-fed crops in a changing climate.

Keywords: APSIM, root characteristics, simulation modelling, water use efficiency, wheat

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