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WATER USE OF TALL AND DWARF CROP PLANTS

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TECHNICAL COMPLETION REPORT

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ABSTRACT

The recurrent California drought necessitates investigation of the relationship between water application, crop yields, and management practices. The majority of cultivars in many crops are genetically dwarfed which allows the application of larger amounts of water and fertilizer in return for higher yields and ease of harvesting. This project used bread wheat as a model system to investigate the water use and water-use efficiency of tall and dwarf cultivars. Four near-isogenic lines, *rhtrht* (tall), *Rht1Rht1* (semidwarf), *Rht2Rht2* (semidwarf), and *Rht3Rht3* (dwarf), in 'Maringa' bread wheat background and four of their near-isogenic F_1 hybrids derived from crossing the original lines were used to determine the effects of dwarfing genes on plant height, water use, grain yield, total dry matter, and water-use efficiency in well-watered and droughted pot experiments in the glasshouse. The near-isogenic lines and their six F_1 hybrids were also grown in well-watered and droughted field conditions. The glasshouse season lasted 158 days, whereas the field season took 149 days between planting and harvesting. Carbon isotope discrimination was determined as a measure of transpiration efficiency. The near-isogenic lines used similar amounts of water in well-watered (12 kg per 158 days) and droughted (9 kg per 158 days) pot experiments. The *Rht3Rht3* dwarf line actually used 3% less water than the tall line in a well-watered situation, and 5% less water than tall line in a droughted situation, but these differences were not significant in this experiment. Plant height ranged from 60 to 124 cm and from 53 to 121 cm in well-watered and droughted pot experiments, and it varied from 50 to 94 cm and from 49 to 90 cm in well-watered and droughted field experiments, respectively. Total dry matter, grain yield, transpiration efficiency (total dry matter/water used), and water-use efficiency (grain yield/water used) declined with plant height in well-watered glasshouse conditions. No significant relationships were found between plant height and these traits in droughted glasshouse conditions. Carbon isotope discrimination was negatively correlated with transpiration efficiency, but significantly so only in well-watered pot experiments. Plant height was negatively associated with carbon isotope discrimination in both well-watered and droughted pot and field experiments. Grain yield and aboveground dry matter also declined with plant height in field conditions. In most cases, the dwarfing genes reduced shoot dry matter more than grain yield, therefore, harvest index of the semidwarf and dwarf lines was higher than that of the tall standard line. The dwarfism caused by *Rht1*, *Rht2*, and *Rht3* genes had, in general, depressing effects on transpiration efficiency, water-use efficiency, total dry matter, and grain yield. An optimum range for plant height was determined (90-100 cm) using these near-isogenic lines, below which shoot dry matter, grain yield, and water-use efficiency were significantly reduced.

Key Words: drought, crop water use, plant growth, plant stress, water-use efficiency.

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TECHNICAL COMPLETION REPORT OUTLINE

PROJECT NUMBER:	UCR-W-788	START: July 1991
TITLE:	Water Use of Tall and Dwarf Crop Plants	
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Problems and Research Objectives

Most annual and some perennial crops in California include popular cultivars that are dwarfed genetically. Dwarf cultivars are common in most cereals, beans, and other legumes, cotton, peaches, and some fruit crops. These genetically-dwarfed cultivars use large inputs of water and fertilizer, which generally increase yield, and they are usually easier to harvest. On the other hand, too much fertilizer depresses yield and causes groundwater pollution. In spite of their popularity, the water-use efficiency of dwarfed cultivars has not been investigated.

The objectives of this project were to: (*i*) investigate growth, water use, and seasonal water-use efficiency of a set of near-isogenic lines differing in plant height in the bread wheat cultivar Maringa as a model system for other crops; (*ii*) determine the relationship between the plant height and water-use efficiency under well-watered and droughted glasshouse and field conditions; and (*iii*) measure the effects of the dwarfing genes on total dry matter and grain production.

Materials and Methods

Pot Experiments. A set of near-isogenic lines for dwarfing genes *Rht1*, *Rht2*, and *Rht3* in the genetic background of a Brazilian spring bread wheat cultivar, Maringa *rht*, was used. The four homozygous isogenic lines, *rhtrht*, *Rht1Rht1*, *Rht2Rht2*, and *Rht3Rht3*, were crossed to produce four heterozygous isogenic F_1 hybrids, *rht1Rht1*, *Rht2Rht2*, *rht3Rht3*, and *Rht2Rht3*. The eight homozygous and heterozygous isogenic lines were planted in plastic pots under a well-watered and a drought-stressed treatment using a randomized complete block design with four replicates in each treatment. There were four unplanted pots in each treatment to quantify evaporative water loss from the pots. All pots were weighed every 2 or 3 days, and the amount of water equal to the loss in weight was added.

In the well-watered treatment, pots were irrigated, as described until plants reached physiological maturity. In the droughted treatment, drought was initiated at the boot stage by adding half of the amount of water needed to equal the loss in pot weight. The flag leaves of main tillers were collected after maturity for carbon isotope discrimination (Δ) which is negatively associated with transpiration efficiency (ratio of total dry matter to water transpired). The experiment ran for 158 days from seed planting to harvest.

Plant characters were measured on a plant basis and included plant height, shoot dry matter, root dry matter, total dry matter, grain yield, harvest index, total water used, water transpired, transpiration efficiency (ratio of total dry matter to water transpired), and water-use efficiency (ratio of grain yield to water used).

Field Experiments. The above eight near-isogenic lines with two more F_1 near-isogenic lines, *Rht1Rht2* and *Rht1Rht3*, were planted in two field experiments at the Moreno Farm of the University of California Agricultural Experiment Station, Moreno Valley, CA. One of the experiments was irrigated with sprinklers as needed to minimize water shortage until plants reached maturity. Irrigation was terminated in the other experiment when plants were at the early boot stage. A randomized complete block design with three replicates was used in each experiment.

Within each plot in each experiment, five plants were randomly chosen from the center of the plot, and the following characters were measured on a single plant basis: plant height, shoot dry matter, grain yield, and harvest index. Mean of the five plants was used in the analysis.

In the droughted experiment, the rachises of the last spikes of the five randomly chosen plants in each plot were bulked for Δ analysis. In the well-watered experiment, the rachises of the main spikes were used. The data from the glasshouse and field experiments were subjected to analysis of variance and regression analysis. Association among the characters were determined by correlation analysis using mean values. The field experiments ran for 149 days from seedling emergence to harvest.

Results and Discussion

Plant height among the isogenic lines ranged from 60 to 124 cm and from 53 to 121 cm in well-watered and droughted pot experiments, respectively. The *Rht1* and *Rht2* dwarfing genes reduced plant height by 20% and *Rht3* by 52% of the tall standard line in both well-watered and droughted pot conditions. The different isogenic lines reached maturity within 1 to 3 days of each other and they used similar amounts of water throughout the growing season in well-watered (12 kg) and in droughted (9 kg) pot experiments. In well-watered pot conditions, grain yield and total dry matter (including roots) of the tall (120-125 cm) and semidwarf lines (90-100 cm) were similar, but higher than those of dwarf lines (50-60 cm). Therefore, water-use efficiency of the tall and semidwarf was the same but it was higher than that of dwarf lines. In droughted pot experiments, drought reduced grain yield and total dry matter of the lines, but no significant differences were found among the lines for grain yield, total dry matter, and water-use efficiency. Regression analyses between plant height and other traits under well-watered pot conditions indicated that there exists an optimum range for plant height (90-100 cm) for these isogenic wheat lines. Plant height below 90 cm was associated with reduced total dry matter, grain yield, transpiration efficiency, and water-use efficiency. Plant height above 100 cm did not result in significant improvement in these traits.

Plant height among the isogenic lines ranged from 50 to 94 cm and from 53 to 121 cm in well-watered and droughted field experiments, respectively. The *Rht1* and *Rht2* dwarfing genes reduced plant height by 12% and the *Rht3* by 46% of tall standard line under both well-watered and droughted field conditions. Grain yield and shoot dry matter of the isogenic lines were similar under well-watered field conditions, but were different under droughted field conditions. Plant height was positively correlated with shoot dry matter and grain yield, indicating that as plant height was reduced, grain yield and aboveground dry matter were also reduced under drought. Since reduction in shoot dry matter was more pronounced than grain yield, semidwarf and dwarf lines exhibited higher harvest index compared to the tall line. A negative association between plant height and carbon isotope discrimination was observed, indicating that as plant height increased, transpiration efficiency was also increased.

Conclusions

This study indicated that grain yield and shoot dry matter of the wheat isogenic lines used were significantly reduced by drought. The tall, semidwarf, and dwarf wheat lines used similar amounts of water. An optimum range for plant height was determined for these near-isogenic lines (90-100 cm), below which shoot dry matter, grain yield, transpiration efficiency, and water-use efficiency are significantly reduced.

Summary

Plant height among the near-isogenic spring bread wheat lines ranged from 60 to 124 cm and from 53 to 121 cm in well-watered and droughted pot experiments; and it varied from 50 to 94 cm and from 53 to 121 cm in well-watered and droughted field experiments, respectively. The near-isogenic lines used similar amounts of water in well-watered (12 kg) and droughted (9 kg) pot experiments which lasted 158 days. Total dry matter, grain yield, transpiration efficiency (ratio of total dry matter to water transpired), and water-use efficiency (ratio of grain yield to water used) declined with plant height in the well-watered experiment. Carbon isotope discrimination (Δ) was negatively correlated with transpiration efficiency, but significantly so only in the well-watered pot experiment. Plant height was negatively associated with Δ in both well-watered and droughted pot and field experiments. Grain yield and shoot dry matter also declined with plant height in field conditions. The dwarfism caused by the dwarfing genes *Rht1*, *Rht2*, and *Rht3* had, in general, depressing effects on transpiration efficiency, water-use efficiency, total dry matter, and grain yield of bread wheat Maringa cultivar. An optimum range for plant height was determined (90-100 cm) using the isogenic lines, below which these characters are significantly reduced. This study suggests that tall and genetically dwarfed annual plants would use similar amounts of water over a growing season of 158 days between November and May, although there was a nonsignificant trend for dwarf plants to use from 3% to 5% less water. This may suggest that dwarf perennial plants may use significantly less water over a 12-month growing season.

Publications

Ehdaie, B. and J. G. Waines. 1993. Genetic and water-use efficiency among lines nearly isogenic for three reduced height genes. Proc. Intl. Wheat Genet. Symp., 8th, Beijing, China, 19-25 July 1993 (in press).

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