Response of Crops to Limited Water

Understanding and Modeling Water Stress Effects on Plant Growth Processes

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L.R. Ahuja, V.R. Reddy, S.A. Saseendran, and Qiang Yu, Editors

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Foreword

The launch of a new series is exciting, and the American Society of Agronomy, the Crop Science Society of America, and the Soil Science Society of America are proud to announce the new book series entitled Advances in Agricultural Systems Modeling. Our Societies believe that future breakthroughs in science and technology lie at the boundaries of disciplines, and this series is intended to encourage transdisciplinary and interdisciplinary research and its synthesis to solve practical problems.

Response of Crops to Limited Water: Understanding and Modeling Water Stress Effects on Plant Growth Processes is an excellent first book in this series. We believe that this book will be of great importance to all scientists, modelers, and students working in water-limited crop production systems. The cast of internationally known authors has done an excellent job of synthesizing the state-of-the-science in a straightforward and instructive manner. The volume should be of particular value for graduate-level teaching.

The Societies appreciate the efforts of series editor Dr. Laj Ahuja, who assembled an impressive group of authors and developed a thoughtful book, with the indispensable synthesis that is missing from many similar titles. We also thank co-editors V.R. Reddy, S.A. Saseendran, and Qiang Yu.

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Preface

The semiarid regions of the western United States, India, China, and other parts of the world produce a major portion of the world's food and fiber needs—from staple food grains of wheat, rice, and corn to vegetables, fruits, nuts, wine, cotton, and forage crops for cattle and poultry. Most of this production in the semiarid lands is achieved with irrigation. Over all agricultural land in the world, irrigation is practiced on about 20% of the area, but accounts for about 40% of the production. Many populous regions of the world, such as south and east Asia, are dependent on irrigation to meet food requirements. However, due to increased in population, urbanization, and environmental consciousness, the water demands for drinking, sanitation, urban irrigation, industry, and environmental uses are outbidding and reducing the water available for agriculture. Shrinkage of groundwater resources, such as the depletion of aquifers in India, China, and the United States, and prolonged drought in the last few years have aggravated the situation. The greater frequency of more severe droughts predicted by some global climate change models is cause for great concern. In addition, global warming appears to be increasing the water requirements (evapotranspiration demand) of plants. So, the questions for the world are: How can irrigated agriculture sustain productivity and meet the growing need for food and fiber with reduced water available for irrigation? What research knowledge and technologies are needed to accomplish this sustainability?

The answers lie, along with other supporting measures, in simultaneously achieving:

- the conservation of both rain and irrigation water in the field by managing to cut losses from runoff, deep percolation, and evaporation
- the preservation of the quality of groundwater and soil by preventing salinity development and nitrate and pesticide pollution
- achieving increased water use efficiency of crops by optimizing irrigation with respect to rainfall, critical growth stages, soil fertility, and weather conditions; smart allocation of limited water among crops; and advantageous selection of crops by region, with selection of alternate crops in drought years

These goals will require a whole-system quantitative approach to guide management and achieve optimization of water application and crop performance, while protecting water quality and the environment. The computer models of agricultural systems are the essential technology needed for this purpose.

The system modeling technology will also help conserve and make the most use of rainwater in rainfed agricultural areas, including water-limited cropping or forage–livestock systems. These areas comprise about 60% of the agriculture in the world. Prolonged drought in the last few years has especially stressed these dryland areas. The farmers and ranchers need simple tools to manage the systems during droughts. These tools can be derived from system models.

Our experience has shown that all key current models of agricultural systems, although adequate for some purposes, need further improvement in the area of simulating the response of crops to limited water under various management and application options required for the above-noted applications. For this purpose, we hosted the 36th annual conference of the Biological Systems Simulation Group here in Fort Collins, CO, April 11–13, 2006, and organized a one-day special session on "Recent Advances in Understanding and Modeling of Water Stress (Water Deficit) Effects on Plant Growth Processes." We invited and were fortunate to hear from the world's experts in various aspects of this topic. The speakers briefly provided the current state of science but emphasized more recent knowledge of the stress effects on processes that can be used to improve our models for crop responses to limited water applied at different growth stages. The purpose of this book then is to document this highly valuable knowledge and provide much needed synthesis and analysis, with the goal of improving these models and expanding the benefits of their use.

The book will be indispensable for scientists, researchers, modelers, and students working in crop production under limited water. The state-of-the-science syntheses given in each chapter will be highly useful, especially for graduate-level teaching. The new models or component codes will be valuable for graduate-level teaching, research, and training in the use of models.

All the chapters in this volume have been reviewed by two or more independent reviewers and by the editors for originality and quality. We ensured that even the review chapters made original contributions to synthesis of knowledge and/or development of new and improved concepts.

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Conversion Factors for SI and Non-SI Units

To convert Column 1 into Column 2 multiply by	Column 1 SI unit	Column 2 non-SI unit	To convert Column 2 into Column 1 multiply by
		Length	
0.621	kilometer, km (10^3 m)	mile, mi	1.609
1.094	meter, m	yard, yd	0.914
3.28	meter, m	foot, ft	0.304
1.0	micrometer, μm (10^{-6} m)	micron, μ	1.0
3.94×10^{-2}	millimeter, mm (10^{-3} m)	inch, in	25.4
10	nanometer, nm (10^{-9} m)	Angstrom, Å	0.1
		Area	
2.47	hectare, ha	acre	0.405
247	square kilometer, km^2 (10^3 m)^2	acre	4.05×10^{-3}
0.386	square kilometer, km^2 (10^3 m)^2	square mile, mi^2	2.590
2.47×10^{-4}	square meter, m^2	acre	4.05×10^3
10.76	square meter, m^2	square foot, ft^2	9.29×10^{-2}
1.55×10^{-3}	square millimeter, mm^2 (10^{-3} m)^2	square inch, in^2	645
		Volume	
9.73×10^{-3}	cubic meter, m^3	acre-inch	102.8
35.3	cubic meter, m^3	cubic foot, ft^3	2.83×10^{-2}
6.10×10^4	cubic meter, m^3	cubic inch, in^3	1.64×10^{-5}
2.84×10^{-2}	liter, L (10^{-3} m^3)	bushel, bu	35.24
1.057	liter, L (10^{-3} m^3)	quart (liquid), qt	0.946
3.53×10^{-2}	liter, L (10^{-3} m^3)	cubic foot, ft^3	28.3
0.265	liter, L (10^{-3} m^3)	gallon	3.78
33.78	liter, L (10^{-3} m^3)	ounce (fluid), oz	2.96×10^{-2}
2.11	liter, L (10^{-3} m^3)	pint (fluid), pt	0.473
		Mass	
2.20×10^{-3}	gram, g (10^{-3} kg)	pound, lb	454
3.52×10^{-2}	gram, g (10^{-3} kg)	ounce (avdp), oz	28.4
2.205	kilogram, kg	pound, lb	0.454
0.01	kilogram, kg	quintal (metric), q	100
1.10×10^{-3}	kilogram, kg	ton (2000 lb), ton	907
1.102	megagram, Mg (tonne)	ton (U.S.), ton	0.907
1.102	tonne, t	ton (U.S.), ton	0.907

Table cont.

To convert Column 1 into Column 2 multiply by	Column 1 SI unit	Column 2 non-SI unit	To convert Column 2 into Column 1 multiply by
		Yield and Rate	
0.893	kilogram per hectare, kg ha^{-1}	pound per acre, lb $acre^{-1}$	1.12
7.77×10^{-2}	kilogram per cubic meter, kg m^{-3}	pound per bushel, lb bu^{-1}	12.87
1.49×10^{-2}	kilogram per hectare, kg ha^{-1}	bushel per acre, 60 lb	67.19
1.59×10^{-2}	kilogram per hectare, kg ha^{-1}	bushel per acre, 56 lb	62.71
1.86×10^{-2}	kilogram per hectare, kg ha^{-1}	bushel per acre, 48 lb	53.75
0.107	liter per hectare, L ha^{-1}	gallon per acre	9.35
893	tonne per hectare, t ha^{-1}	pound per acre, lb $acre^{-1}$	1.12×10^{-3}
893	megagram per hectare, Mg ha^{-1}	pound per acre, lb $acre^{-1}$	1.12×10^{-3}
0.446	megagram per hectare, Mg ha^{-1}	ton (2000 lb) per acre, ton $acre^{-1}$	2.24
2.24	meter per second, m s^{-1}	mile per hour	0.447
		Specific Surface	
10	square meter per kilogram, m^2 kg^{-1}	square centimeter per gram, cm^2 g^{-1}	0.1
1000	square meter per kilogram, m^2 kg^{-1}	square millimeter per gram, mm^2 g^{-1}	0.001
		Density	
1.00	megagram per cubic meter, Mg m^{-3}	gram per cubic centimeter, g cm^{-3}	1.00
		Pressure	
9.90	megapascal, MPa (10^6 Pa)	atmosphere	0.101
10	megapascal, MPa (10^6 Pa)	bar	0.1
2.09×10^{-2}	pascal, Pa	pound per square foot, lb ft^{-2}	47.9
1.45×10^{-4}	pascal, Pa	pound per square inch, lb in^{-2}	6.90×10^3
		Temperature	
1.00 (K – 273)	kelvin, K	Celsius, °C	1.00 (°C + 273)
(9/5 °C) + 32	Celsius, °C	Fahrenheit, °F	5/9 (°F – 32)
		Energy, Work, Quantity of Heat	
9.52×10^{-4}	joule, J	British thermal unit, Btu	1.05×10^3
0.239	joule, J	calorie, cal	4.19
10^7	joule, J	erg	10^{-7}
0.735	joule, J	foot-pound	1.36
2.387×10^{-5}	joule per square meter, J m^{-2}	calorie per square centimeter (langley)	4.19×10^4
10^5	newton, N	dyne	10^{-5}
1.43×10^{-3}	watt per square meter, W m^{-2}	calorie per square centimeter minute (irradiance), cal cm^{-2} min^{-1}	698

Table cont.

To convert Column 1 into Column 2 multiply by	Column 1 SI unit	Column 2 non-SI unit	To convert Column 2 into Column 1 multiply by
	Transpiration and Photosynthesis		
3.60×10^{-2}	milligram per square meter second, mg m^{-2} s^{-1}	gram per square decimeter hour, g dm^{-2} h^{-1}	27.8
5.56×10^{-3}	milligram (H_2O) per square meter second, mg m^{-2} s^{-1}	micromole (H_2O) per square centimeter second, μmol cm^{-2} s^{-1}	180
10^{-4}	milligram per square meter second, mg m^{-2} s^{-1}	milligram per square centimeter second, mg cm^{-2} s^{-1}	10^{4}
35.97	milligram per square meter second, mg m^{-2} s^{-1}	milligram per square decimeter hour, mg dm^{-2} h^{-1}	2.78×10^{-2}
	Plane Angle		
57.3	radian, rad	degrees (angle), °	1.75×10^{-2}
	Electrical Conductivity, Electricity, and Magnetism		
10	siemen per meter, S m^{-1}	millimho per centimeter, mmho cm^{-1}	0.1
10^{4}	tesla, T	gauss, G	10^{-4}
	Water Measurement		
9.73×10^{-3}	cubic meter, m^3	acre-inch, acre-in	102.8
9.81×10^{-3}	cubic meter per hour, m^3 h^{-1}	cubic foot per second, ft^3 s^{-1}	101.9
4.40	cubic meter per hour, m^3 h–1	U.S. gallon per minute, gal min^{-1}	0.227
8.11	hectare meter, ha m	acre-foot, acre-ft	0.123
97.28	hectare meter, ha m	acre-inch, acre-in	1.03×10^{-2}
8.1×10^{-2}	hectare centimeter, ha cm	acre-foot, acre-ft	12.33
	Concentration		
1	centimole per kilogram, cmol kg^{-1}	milliequivalent per 100 grams, meq 100 g^{-1}	1
0.1	gram per kilogram, g kg^{-1}	percent, %	10
1	milligram per kilogram, mg kg^{-1}	parts per million, ppm	1
	Radioactivity		
2.7×10^{-11}	becquerel, Bq	curie, Ci	3.7×10^{10}
2.7×10^{-2}	becquerel per kilogram, Bq kg^{-1}	picocurie per gram, pCi g^{-1}	37
100	gray, Gy (absorbed dose)	rad, rd	0.01
100	sievert, Sv (equivalent dose)	rem (roentgen equivalent man)	0.01
	Plant Nutrient Conversion		
	Elemental	Oxide	
2.29	P	P_2O_5	0.437
1.20	K	K_2O	0.830
1.39	Ca	CaO	0.715
1.66	Mg	MgO	0.602