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Methods of Introducing System Models into Agricultural Research

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Foreword

Agricultural systems are by nature complex ecosystems. Numerous interacting factors involving soil, plant, climate, and management components must be taken into account. These systems also need to consider production, environmental, and societal issues for the sustainability of agriculture. Because of the complex nature of agricultural systems, modeling is a key tool that aids in understanding the intricacies of the interactions and delivers a myriad of potential outcomes to users world-wide. This book is designed to guide scientists and other professionals in methods of parameter estimation, calibration, and validation of agricultural system models. As these models become more available to explore new management strategies and to extend information to larger scales, proper parameterization, calibration, and validation are critical to their use. This book is essential because as models are more widely used, they help advance research and guide producers and policy makers on agricultural systems that impact societal issues and needs. Because system modeling is vitally important to the understanding of agricultural systems, the American Society of Agronomy, the Crop Science Society of America and the Soil Science Society of America support the objectives of this book, which will help model users apply the proper techniques when using system models.

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Preface

Potential Value of System Models in Agricultural Research and the Need for Helping Field Researchers in Using Models

To develop sustainable agricultural systems that address environmental challenges, the field of agricultural research needs to develop more quantitative guidance and site-specific decision tools to help producers. To this end, field research requires a quantitative whole-system approach to help optimize the complex interacting factors. The process level models of cropping systems, based on synthesis and quantification of disciplinary knowledge and important interactions among the system components, meet this challenge. These models integrated with cutting-edge field research will greatly enhance the value and efficiency of research for developing sustainable agriculture, enable a fast transfer of technologies to farmers, and inform policymakers and the general public on the major issues and tradeoffs of alternatives.

These system models require some input data about the system and need to be parameterized, calibrated, and validated correctly with good field experimental data at selected locations in the region. They can then be used to: (i) synthesize all other experiment data, (ii) extend current research results to multiple years of historical climate beyond the limited experimental years and to other soils in the area to evaluate the long-term sustainability of cropping and management systems in the area, (iii) derive the new optimum cropping and management strategies for future selective field testing, and (iv) derive simpler management guides or tools for producers. Furthermore, to prepare for projected climate-change effects on water availability and agricultural production with increased temperatures and carbon dioxide, there is an urgent need for validated models to project the effects of these changes on agricultural systems in the United States and the world.

A major difficulty that field scientists, students, and other users of agricultural system models face is the appropriate parameter estimation and correct model calibration. Many models are often misused and the results published without proper parameterization, calibration, and validation. Reviewers seldom look into parameterization, calibration, and validation of all important system components (e.g., water balance, N balance, phenology, yield components) other than the yield and some measured variables. Model users are not properly trained, often due to a lack of good documentation and guidance on systematic parameterization and calibration for a model. With development of Windows based user interfaces, it becomes easy for model users to run a model, but it does not guarantee correct use of a model. In most cases, a model user focuses more energy on the system components that he/she is most familiar with and leaves the rest untouched, using default values. There are science documentations available for some models, but how to interpret the science in terms of measurable or derivable model parameters in a given agricultural system is another, totally different process.

The knowledge and experience of model parameterization largely resides with the model developers. They are the ones who truly know the weaknesses and strengths of their models and the best ways to estimate and calibrate the model parameters. When the developers made the decisions on what components to include in their models and at what level of detail, they had an idea of the parameters needed and where to get them. This knowledge is usually not available to users in a systematic way and is scattered in many publications (usually, not in detail). Therefore, the concept of systematic parameterization and calibration, and even validation, of a system model is not fully comprehended by users. Furthermore, the processes and model parameters are well related in the user interfaces, and users have difficulty identifying the ones related to their particular studies. In addition, a lack of methodology in model parameterization makes model results not reproducible and least likely to generate new knowledge beyond what experimentalists already have gained in the field.

Objectives of this second volume of the Advances in Agricultural Systems Modeling series, therefore, were to create a "methodology volume" that contains the above much-needed information for model users. One objective of this book series is to promote the use of system models to enhance and extend field research. To accomplish this goal, it is vitally important to devote a volume to helping field scientists and other model users in proper methods of parameter estimation, calibration, validation, exploring new management options, and extension of experimental results to other weather conditions, soils, and climates. The proper methods are the key to realizing the great potential benefits of modeling an agricultural system. This volume contains information on the input data required and step-by-step procedures for parameter estimation, calibration, validation, and extended applications for the major models, illustrated with examples. To avoid duplication, we tried to describe these procedures in detail for one major model, and then special features of other models. This information will help users to correctly parameterize and use each model component without the need to fully understand the theory. This book also contains chapters that address further improvement of parameterization methods, field sampling and measurement of model inputs and parameters, effective properties for spatially variable soils, quality control of weather and other inputs, automatic parameter estimation software, and some new innovative methods to create simple management guidelines for farmers. We hope this book will serve as a linkage between models and field research. It will not only promote correct model application to complement and quantify field research, but also create new knowledge and identify knowledge gaps. We tried to have a user friendly and uniform format in presenting the methods as much as possible, to make it easier and attractive for the field scientists, currently not exposed to models, to start using them. Many of the models are provided on a companion CD.

The final synthesis chapter seeks to identify: (i) the best set of current procedures from across the models; (ii) knowledge gaps and research needed to further improve parameter estimation, calibration, and validation methods for users; (iii) required research to improve concepts in the models so as to make the parameters more biophysically based and less of empirical coefficients, and either directly measurable or related to some easily measured data; (iv) the means to balance the complexity of process and parameters; (v) determination of effective parameters for a spatially variable field and for temporally variable conditions; (vi) relationships of model results across different soils, climates, and scales; and (vii) simpler ways of documenting model components for users.

We wish to convey one important feature of the volumes in the new series Advances in Agricultural Systems Modeling. We have made an utmost effort to ensure the quality of each volume, with two to three (in some cases even more) anonymous peer reviews of each contribution. We have tried to ensure originality of each contribution in terms of new synthesis and quantification of knowledge in the topic area, which would be useful for further improving and advancing system models as well as advance science and further research. Each contribution is, therefore, treated as a review and synthesis paper, much like a review paper in a journal.

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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