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Plant-Plant Allelopathic Interactions III

Partitioning and Seedling Effects of Phenolic Acids as Related to their Physicochemical and Conditional Properties

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This volume is dedicated to Mary Ann Blum,
Amy Blum Grady, and Nicole Blum.

Preface

The first volume (Blum 2011) contains a retrospective analysis of the author's research program at North Carolina State University on plant-plant allelopathic interactions involving simple phenolic acids such as cinnamic and benzoic acids and their potential role in the inhibition of broadleaf weed emergence in cover crop debris no-till crop systems. It was written for researchers, students, farmers, as well as layman interested in science, reduced tillage, and plant-plant allelopathic interactions. The second volume (Blum 2014) contains a detailed description and discussion of the underlying features, issues, and suppositions associated with seed and seedling laboratory bioassays presented in the first volume. It is, however, broader in scope and substance in that the information provided is relevant to all water-soluble compounds released to soil by putative allelopathic living plants and their litter and residues. It updates and expands the practical guidelines for designing laboratory bioassays provided previously in the literature with the hope that the designs of future seed and seedling bioassays would become more relevant to field systems. It was written specifically for researchers and their graduate students interested in studying plant-plant allelopathic interactions, although a layman interested in science may also find it beneficial in understanding the benefits and limitations of laboratory bioassays in exploring the causes and effects of putative allelopathic compounds.

This volume continues the retrospective analysis but goes beyond that in an attempt to understand how phenolic acids are partitioned in seedling-solution and seedling-microbe-soil-sand culture systems and how their effects on seedlings may be related to the actual and conditional physicochemical properties of simple phenolic acids. It does this by presenting hypothetical analyses for the relationships between physicochemical properties and conditional properties of phenolic acids, such as cinnamic and benzoic acids, and the behavior of phenolic acids in seedling-solution culture systems and seedling-microbe-soil-sand culture systems. Hypothetical in that the raw data was not always readily available and thus published means, data points generated by regression analyses and data points for published figures were also utilized in combination with published physicochemical properties of phenolic acids to establish these relationships.

Specifically, it explores the quantitative source-sink relationships of phenolic acids in cucumber seedling-solution and cucumber seedling-microbe-soil-sand systems. It contains the following:

(a) Chapter 1 describes the potential relationships, where they may exist, for direct transfer of organic compounds between plants, plant communication, and allelopathic interactions, defines the boundaries for allelopathic interactions, summarizes terminology, and outlines standard approaches to the study of allelopathic interactions.
(b) Chapter 2 describes sources, sinks, turnover rates, modifying elements and identity, mobility, distribution, states, and effects of the potential allelopathic compounds.
(c) Chapter 3 describes the conceptual models for system sources (inputs) and partitioning (sinks) of hydrophilic, hydrophobic, and volatile organic compounds for seedling-microbe-soil systems and the physicochemical properties of organic compounds with an emphasis on phenolic acids that may be useful in understanding and quantifying the behavior of individual organic compounds, actually molecules, in seedling-microbe-soil systems.
(d) In Chap. 4, the author explores the potential roles of solution pH, pK_a of phenolic acids, and pH-pK_a relationships in modifying the behavior of cucumber seedlings (*Cucumis sativus*) treated with simple phenolic acids and/or mixtures of simple phenolic acids in solution culture.
(e) In Chap. 5, the author explores the potential roles of log P (hydrophobicity), log D (pH-adjusted log P), and molecular structures of phenolic acids in modifying the behavior of cucumber seedlings (*Cucumis sativus*) treated with phenolic acids and/or phenolic acid mixtures in solution culture.
(f) In Chap. 6, the author explores whether the conditional properties of K_d and K_{oc} (sorption coefficients) for phenolic acids could assist in determining how phenolic acids are partitioned in sterilized Cecil and Portsmouth A and B horizon soils and compares the merit of using sorption K_d and K_{oc} values based on the batch equilibrium and desorption techniques with that of sorption K_d and K_{oc} values based on water, neutral EDTA, and/or Mehlich III extractions.
(g) Chapter 7 describes how biological processes, such as microbial utilization and root and/or mycorrhizal uptake, may influence the available (reversibly sorbed and free) phenolic acids in Cecil and Portsmouth A and B horizon soil and soil-sand systems.
(h) Chapter 8 describes the source (input)-sink relationships, processes, mechanisms, and causes and effects of phenolic acids, such as ferulic acid, *p*-coumaric acid, *p*-hydroxybenzoic acid, and/or vanillic acid, by means of a conceptual and hypothetical sub-models for a cucumber seedling-solution culture system.

(i) Chapter 9 describes how conceptual sub-models for soil and soil-sand-culture bioassays in conjunction with quantitative relationships described in the previous chapters and the literature may be used to model how various system elements of soil and soil-sand cultures can potentially modify or control the actions and effects of simple phenolic acids on cucumber seedlings.
(j) Chapter 10 describes the physicochemical and biotic partitioning of phenolic acids in Cecil soil and Cecil soil-sand systems plus or minus microorganisms and cucumber seedlings (*Cucumis sativus*) treated with phenolic acids with an emphasis on *p*-coumaric acid and presents quantitative data for how phenolic acids may be partitioned in hypothetical cucumber seedling-microbe-Cecil A horizon soil-sand systems. The hypothetical models for the two types of systems are provided, a continuous-input column system and a multiple-input cup system.
(k) Chapter 11 describes the physicochemical and biotic partitioning of phenolic acids in Portsmouth A and B horizon soil and soil-sand systems plus or minus microorganisms and cucumber seedlings (*Cucumis sativus*) and the ways that various system elements, such as soil type, pH, and phenolic acid mixtures, affect this partitioning and/or seedling behavior and provides quantitative data for ways that phenolic acids may be partitioned in a hypothetical cucumber seedling-microbe-Portsmouth B soil-sand model system treated with ferulic acid.
(l) In Chap. 12, the author reexamines the underlying assumptions of the conceptual and hypothetical models of this volume and attempts to answer the questions: Can physicochemical properties of phenolic acids be used as tools to help understand the complex behavior of phenolic acids and the ultimate effects of phenolic acids on sensitive seedlings? What insights do laboratory bioassays and the conceptual and hypothetical models of laboratory systems provide us concerning the potential behavior and effects of phenolic acids in field systems? What potential role may phenolic acids play in broadleaf weed seedling emergence in wheat debris no-till cover crop systems?

The third volume was written specifically for researchers and their students interested in understanding how a range of simple phenolic acids and potentially other putative allelopathic compounds released from living plants and their litter and residues may affect soil chemistry, microbial biology, and seedling behavior in seedling-solution and seedling-microbe-soil-sand culture systems.

Note 1: Because of the dynamics of the Internet, any web addresses or links contained in this volume may have changed since its publication and may no longer be valid. The reader will find some subject matter and data from references repeated in several chapters. This is because the chapters are written to be stand-alone as much as possible. Thus, the subject matter and references are described or discussed more than once but each time in the context of the topic of the chapter.

Note 2: Correction – In Volume 1 (Blum 2011) for Fig. 2.25 and Fig. 3.19, the units for the colony-forming units (CFU) should have been CFU/g root dry weight instead of CFU/g soil.

Raleigh, NC, USA
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References

Blum U (2011) Plant-plant allelopathic interactions: phenolic acids, cover crops and weed emergence. Springer, Dordrecht

Blum (2014) Plant-plant allelopathic interactions II: laboratory bioassays for water-soluble compound with an emphasis on phenolic acids. Springer, Cham

Acknowledgments

It appears appropriate for the final volume of this series to recognize the funding sources and the contributions of all the faculty members, technicians, graduate and undergraduate students, and family members who contributed to making this series possible. I have thus included slightly modified acknowledgments for both the first and second volume.

Volume I (Blum 2011)

Although my research interests in allelopathy have been a primary focus for most of my academic career, I did take several excursions into other research areas (e.g., air pollution biology and salt marsh ecology) before returning full time to the subject matter of allelopathy. In retrospect, these excursions turned out to be extremely beneficial to my understanding of stress physiology and ecosystem biology, the important insights needed when studying plant-plant allelopathic interactions. My teaching of beginning and advanced undergraduate botany courses and graduate courses in plant physiology, ecology, plant physiological ecology, and root ecology also proved to be invaluable in my pursuit of understanding the mechanisms of plant-plant allelopathic interactions by providing me with an opportunity to develop a much more in-depth appreciation of plant morphology, anatomy, physiology, and population biology and soil physics, chemistry, and microbiology.

Equally as important as a solid understanding of plant, microbial, and soil biology and chemistry was an appreciation of the scientific method. The importance of the scientific method as a tool for studying biological systems was instilled within me by EL Rice, my PhD mentor at The University of Oklahoma, and was reinforced by my teaching of botany courses using the Socratic method at both the University of Oklahoma and at North Carolina State University.

I also want to acknowledge the help of several statisticians at North Carolina State University who over the years provided me with the opportunity to develop and refine my skills in experimental design, data analysis, and modeling. In particular, I would like to express my appreciation to Professors RJ Monroe, JO Rawlings, and TM Gerig of the Department of Statistics.

Along the way, there were numerous faculty members, graduate and undergraduate students, and technicians who influenced, shaped, and reshaped my research program in allelopathy. A deep felt thank you to all of them. In particular, I would like to express my appreciation to faculty members C Brownie, RC Fites, TM Gerig, F Louws, LD King, SR Shafer, SB Weed, TR Wentworth, and AD Worsham; visiting scientist S-W Lyu; technicians/graduate students BR Dalton and K Klein; graduate students MF Austin, CL Bergmark, FL Booker, LJ Flint, AB Hall, LD Holappa, M Kochhar, ME Lehman, JV Perino, KJ Pue, J Rebbeck, JR Shann, K Staman, ER Waters, and AG White; and the assistance of CG Van Dyke in processing the samples and taking the electron micrographs of microbial populations on cucumber root surfaces.

I would also like to acknowledge the following organizations for providing research support and/or funding: the North Carolina Agricultural Research Service, USDA Competitive Research Grants Program, Southern Region Low-Input Agricultural Systems Research and Extension Program, North Carolina Agricultural Foundation Graduate Research Assistantship Program, and Departments of Botany (now Plant Biology and Microbial Biology), Crop Science, Soil Science, and Statistics.

Finally, I wish to thank MA Blum, SO Duke, JR Troyer, JD Weidenhamer, and AD Worsham for editing and reviewing and for the thoughtful and constructive comments.

Volume II (Blum 2014)

I wish to thank RG Belz, MA Blum, AN Blum, LF Grand, SO Duke, JD Weidenhamer, LA Weston, AD Worsham, and D Xie for editing and reviewing and for the thoughtful and constructive comments; A Blum Grady for the following illustrations, Figs. 1.1, 2.1, 3.1, 4.4, and 4.5; and the Department of Plant and Microbial Biology and the College of Agriculture and Life Sciences at North Carolina State University for their support. I would like to especially acknowledge the contribution of my wife, Mary Ann, and our two daughters, Amy and Nicole, for their continued support throughout the years and for their contributions to this volume. I also wish to acknowledge the contributions of the faculty, students, and technicians at North Carolina State University and the researchers worldwide who over the years contributed to the research upon which this volume is based. Writing this volume was truly a cooperative venture. Finally, in the previous volume (see Blum 2011) under acknowledgments, I neglected to specifically acknowledge the contributions of TM Gerig, C Brownie, and JO Rawlings for their help in the statistical analysis and modeling of data described in that volume and to also include FL Booker under the list of the faculty members who influenced, shaped, and reshaped my research program in allelopathy.

For volume (Volume III)

I would like to acknowledge the contributions of the following: MA Blum and several anonymous reviewers for editing and reviewing and for the thoughtful and constructive comments, the assistance of CG Van Dyke in processing the samples and taking the electron micrographs of microbial populations on cucumber root surfaces and for the support provided by the Department of Plant and Microbial Biology and the College of Agriculture and Life Sciences.

References

Blum U (2011) Plant-plant allelopathic interactions: phenolic acids, cover crops and weed emergence. Springer, Dordrecht

Blum (2014) Plant-plant allelopathic interactions II: laboratory bioassays for water-soluble compound with an emphasis on phenolic acids. Springer, Cham

Contents

Abbreviations

AGR	Absolute rates of leaf expansion
BE	Batch equilibrium technique
BE-D	Batch equilibrium-desorption technique
CAF	Caffeic acid
Cecil A and/or B	Cecil A and/or B horizon soil
CONC	Concentration
CFU	Colony-forming units
D	Desorption
Debris	Plant litter and residues
EDTA	Ethylenediaminetetraacetic acid
W-EDTA	Water-EDTA extraction technique
FAST BAC	Fast-growing bacteria
FER	Ferulic acid
GLU	Glucose
H	Hydrogen
HPLC	High-performance liquid chromatograph
IPA	Identified putative allelopathic compound
K_d	Soil sorption (distribution) coefficient
$K_{d,i}$	Soil sorption (distribution) coefficient for ionized molecules
$K_{d,n}$	Soil sorption (distribution) coefficient for neutral molecules
K_f	Soil Freundlich sorption coefficient
K_i	Concentration required for 50% inhibition
K_{oc}	Soil organic carbon normalized soil-water partition coefficient
$K_{oc,i}$	Soil organic carbon normalized soil-water partition coefficient for ionized molecules
$K_{oc,n}$	Soil organic carbon normalized soil-water partition coefficient for neutral molecules

K_{om}	Soil organic matter normalized soil-water partition coefficient
K_{ow}	Soil-water partition coefficient
Log D	pH-adjusted log P
Log K_{oc}	Log soil organic carbon normalized soil-water partition coefficient
Log P	Log n-Octanol-water partition coefficient
Log P_n	Log n-Octanol-water partition coefficient of the neutral fraction
MES	2-(N-morpholino) ethanesulfonic acid
MET	Methionine
N-CONC	Neutral concentration
NUT	Nutrient solution
OH	Hydroxy
OMe	Methoxy
P	n-Octanol-water partition coefficient
PHE	Phenylalanine
pK_a	Acid dissociation constant
PA	Phenolic acids
PCO	*p*-Coumaric acid
POH	*p*-Hydroxybenzoic acid
Portsmouth A and/or B	Portsmouth A and/or B horizon soil
PRO	Protocatechuic acid
RGR	Relative rates of leaf expansion
SIN	Sinapic acid
SYR	Syringic acid
VAN	Vanillic acid
Φ_n	Neutral fraction

List of Figures