Nitrogen in Crop Production
Nitrogen in Crop Production

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DEDICATION


A native of Wisconsin, Kilmer obtained his B.S. and M.S. degrees in soil science at the University of Wisconsin-Madison. During World War II he spent four years in the armed forces, mostly in the Pacific. His entire professional career was devoted to service in U.S. Governmental agencies, starting in the Soil Conservation Service as a soil scientist at the Upper Mississippi Valley Experiment Station at LaCrosse, Wisconsin in 1941. After the war he worked as a soil surveyor, also in Wisconsin. In 1947, he transferred to the National Soil Survey Laboratory at Beltsville, Maryland, at that time a part of the Bureau of Plant Industry, Soils, and Agricultural Engineering.

In 1955, Kilmer shifted his professional interests from soil and water management by joining the Soil and Water Research Division of the Agricultural Research Service. In 1961, he joined the Office of Agricultural and Chemical Development of the Tennessee Valley Authority at Muscle Shoals, Alabama, serving first as assistant to the manager and then, until his retirement in 1979, as Chief of the national important Soils and Fertilizer Research Branch.

Kilmer’s greatest accomplishment was probably in fostering meaningful and needed research in soils and fertilizers in his own organization and also in institutions cooperating with TVA. His own research of greatest impact dealt with losses of plant nutrients from soils through erosion, runoff, and leaching. Kilmer was a key individual in the 20-year joint effort of the American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America and TVA’s National Fertilizer Development Center in conducting symposia dealing with plant nutrition, fertilizers, and crop production. This joint effort resulted in an important series of highly authoritative and widely used books, of which *Nitrogen in Crop Production* is the latest.

Kilmer was honored as Fellow, both of the American Society of Agronomy and the Soil Science Society of America. He served as President of the Soil Science Society of America during 1976–1977. Kilmer was highly regarded, both as a professional soil scientist and as a person.

Victor James Kilmer
1913–1981

March 1984

Louis B. Nelson (retired)
Director, Division of Agricultural Development
National Fertilizer Development Center
Tennessee Valley Authority
Muscle Shoals, Alabama
FOREWARD

The realization of this book stems from a national symposium, Nitrogen in Crop Production, held in Sheffield, Alabama, 25–27 May 1982, jointly sponsored by the Tennessee Valley Authority National Fertilizer Development Center, the American Society of Agronomy, the Crop Science Society of America, and the Soil Science Society of America. The symposium was organized to provide a comprehensive summary of current knowledge about nitrogen as it relates to crop production. Each of the presentations had a practical orientation that focused on alternative means to improve plant use of nitrogen in different cropping systems. Those presentations as well as several additional closely related topics comprise the chapters of this volume. Our understanding of the role of nitrogen and the continual improvement of management alternatives for its optimal use in crop production as documented here represents an integrated effort of nearly 100 scientists and technologists. Because of their unique effort, we expect that this book will be of interest to farm managers, agronomists, crop and soil scientists, crop ecologists, and cooperative extension specialists.

We want to express our appreciation to the editorial committee, headed by Dr. R. D. Hauck; the authors and reviewers; and the ASA Headquarters staff for the time and effort they have spent in making this publication possible.

November 1984

K. J. FREY, president
American Society of Agronomy

W. F. KEIM, president
Crop Science Society of America

D. R. NIELSEN, president
Soil Science Society of America
PREFACE

*Nitrogen in Crop Production* provides an authoritative review of the principles and practices of nitrogen use in agricultural cropping systems. It was planned as a companion work to *Nitrogen in Agricultural Soils* (Agronomy no. 22, 1982), with focus on the interrelationships of nitrogen and other crop production factors. Topics discussed include (i) how plants use nitrogen, (ii) sources and supply of plant-available nitrogen, and (iii) the management of crops, fertilizers and fertilizer amendments, manures and other waste products, plant residues, and soils for maximum, economic crop production. Other topics discussed are the relationship between nitrogen use and plant diseases, insect invasion, water stress, and weed infestation. Separate chapters are devoted to crop quality and the quality of the environment, as affected by nitrogen use. The last section of the book describes recommended nitrogen management practices for regions of the United States differing in climate, soils, and cropping systems.

Authors of chapters were asked to prepare overviews rather than comprehensive reviews of their assigned topics and to cite mainly key articles and reviews. Where data on a particular topic were lacking and definite conclusions could not justifiably be drawn, a statement of informed opinion was solicited. The restrictions placed on the authors were necessary because of the many topics that the editorial committee thought desirable to discuss. Even so, relevant topics that might have been included were omitted. We apologize for these omissions and for the omission of references to important work that might have been included, had volume size not been a practical consideration.

The editorial committee expresses appreciation to the authors and the organizations they represent. We acknowledge Richard C. Dinauer, Susan Ernst, David M. Kral, Rodney A. Briggs, Matthias Stelly, and other members of the headquarters staff for assistance in editing and preparing the manuscripts for publication. We pay special tribute to Victor J. Kilmer, whose administrative support during the planning of this book was most helpful; to George Stanford, coauthor of Chapter 17, and to A. G. Norman, author of the Perspective, whose untimely deaths occurred while the book was in progress.

March 1984

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W. J. Wiltbank Professor (Horticulturist), Department of Fruit Crops, University of Florida, Gainesville, Florida
<table>
<thead>
<tr>
<th>Non-SI Units</th>
<th>Multiply</th>
<th>To obtain</th>
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</thead>
<tbody>
<tr>
<td>acre</td>
<td>$4.05 \times 10^1$</td>
<td>square meter, $m^2$</td>
</tr>
<tr>
<td>acre</td>
<td>0.405</td>
<td>hectare, ha ($10^4 m^2$)</td>
</tr>
<tr>
<td>acre</td>
<td>$4.05 \times 10^{-3}$</td>
<td>square kilometer, $km^2 (10^6 m^3)$</td>
</tr>
<tr>
<td>Angstrom unit</td>
<td>0.1</td>
<td>nanometer, nm ($10^{-6}$ m)</td>
</tr>
<tr>
<td>atmosphere</td>
<td>0.101</td>
<td>megapascal, MPa ($10^6$ Pa)</td>
</tr>
<tr>
<td>bar</td>
<td>0.1</td>
<td>megapascal, MPa ($10^6$ Pa)</td>
</tr>
<tr>
<td>British thermal unit</td>
<td>$1.05 \times 10^1$</td>
<td>joule, J</td>
</tr>
<tr>
<td>calorie</td>
<td>4.19</td>
<td>joule, J</td>
</tr>
<tr>
<td>calorie per square centimeter minute</td>
<td>698</td>
<td>watt per square meter, W $m^{-2}$</td>
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<tr>
<td>calorie per square centimeter (langley)</td>
<td>$4.19 \times 10^4$</td>
<td>joules per square meter, J $m^{-2}$</td>
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<tr>
<td>cubic feet</td>
<td>0.028</td>
<td>cubic meter, $m^3$</td>
</tr>
<tr>
<td>cubic feet</td>
<td>28.3</td>
<td>liter, L ($10^{-3}$ m$^3$)</td>
</tr>
<tr>
<td>cubic inch</td>
<td>$1.64 \times 10^3$</td>
<td>cubic meter, $m^3$</td>
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<tr>
<td>dyne</td>
<td>$3.7 \times 10^9$</td>
<td>bequerel, Bq</td>
</tr>
<tr>
<td>degrees (angle)</td>
<td>$1.75 \times 10^{-2}$</td>
<td>radian, rad</td>
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<tr>
<td>erg</td>
<td>$10^{-6}$</td>
<td>newton, N</td>
</tr>
<tr>
<td>foot</td>
<td>0.305</td>
<td>meter, m</td>
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<tr>
<td>foot-pound</td>
<td>1.36</td>
<td>joule, J</td>
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<tr>
<td>gallon</td>
<td>3.78</td>
<td>liter, L ($10^{-3}$ m$^3$)</td>
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<tr>
<td>gallon per acre</td>
<td>9.35</td>
<td>liter per hectare, L ha$^{-1}$</td>
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<tr>
<td>gram per cubic centimeter</td>
<td>1.00</td>
<td>megagram per cubic meter, Mg m$^{-3}$</td>
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<tr>
<td>gram per square decimeter hour</td>
<td>27.8</td>
<td>milligram per square meter</td>
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<tr>
<td>gram per square decimeter hour (transpiration)</td>
<td></td>
<td>second, mg m$^{-2}$ s$^{-1}$ (10$^{-3}$ g m$^{-2}$ s$^{-1}$)</td>
</tr>
<tr>
<td>inch</td>
<td>25.4</td>
<td>millimeter, mm ($10^{-3}$ m)</td>
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<tr>
<td>micromole (H$_2$O) per square centimeter</td>
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<td>milligram (H$_2$O) per square meter</td>
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<tr>
<td>(transpiration)</td>
<td>10000</td>
<td>second, mg m$^{-2}$ s$^{-1}$ (10$^{-3}$ g m$^{-2}$ s$^{-1}$)</td>
</tr>
<tr>
<td>micron</td>
<td>1.00</td>
<td>micrometer, $\mu$m ($10^{-6}$ m)</td>
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<tr>
<td>mile</td>
<td>1.61</td>
<td>kilometer, km ($10^{3}$ m)</td>
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<tr>
<td>mile per hour</td>
<td>0.477</td>
<td>meter per second, m s$^{-1}$</td>
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<tr>
<td>milligram per square decimeter hour (apparent photosynthesis)</td>
<td>0.0278</td>
<td>milligram per square meter</td>
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<tr>
<td>milligram per square decimeter hour (transpiration)</td>
<td>10000</td>
<td>milligram per square meter</td>
</tr>
<tr>
<td>millimho per centimeter</td>
<td>0.1</td>
<td>siemen per meter, S $m^{-1}$</td>
</tr>
<tr>
<td>ounce</td>
<td>$28.4$</td>
<td>gram, g ($10^{-3}$ kg)</td>
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<tr>
<td>ounce (fluid)</td>
<td>$2.96 \times 10^{-3}$</td>
<td>liter, L ($10^{-3}$ m$^3$)</td>
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<tr>
<td>pint (liquid)</td>
<td>0.473</td>
<td>liter, L ($10^{-3}$ m$^3$)</td>
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<tr>
<td>pound</td>
<td>454</td>
<td>gram, g ($10^{-3}$ kg)</td>
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<tr>
<td>pound per acre</td>
<td>1.12</td>
<td>kilogram per hectare, kg ha$^{-1}$</td>
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<tr>
<td>pound per acre</td>
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<td>megagram per hectare, Mg ha$^{-1}$</td>
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<td>pound per bushel</td>
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<td>pound per cubic foot</td>
<td>16.02</td>
<td>kilogram per cubic meter, kg m$^{-3}$</td>
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<tr>
<td>pound per cubic inch</td>
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<td>kilogram per cubic meter, kg m$^{-3}$</td>
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<td>pound per square foot</td>
<td>47.9</td>
<td>pascal, Pa</td>
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<tr>
<td>pound per square inch</td>
<td>$6.90 \times 10^1$</td>
<td>pascal, Pa</td>
</tr>
<tr>
<td>quart (liquid)</td>
<td>0.946</td>
<td>liter, L ($10^{-3}$ m$^3$)</td>
</tr>
<tr>
<td>quintal (metric)</td>
<td>10$^2$</td>
<td>kilogram, kg</td>
</tr>
<tr>
<td>rad</td>
<td>1.00</td>
<td>0.01 Gy</td>
</tr>
<tr>
<td>roentgen</td>
<td>1.00</td>
<td>2.58 $ \times 10^{-4}$ (coulomb) kg$^{-1}$</td>
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<tr>
<td>square centimeter per gram</td>
<td>0.1</td>
<td>square meter per kilogram, m$^2$ kg$^{-1}$</td>
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<tr>
<td>square feet</td>
<td>$9.29 \times 10^{-3}$</td>
<td>square meter, m$^2$</td>
</tr>
<tr>
<td>square inch</td>
<td>645</td>
<td>square millimeter, mm$^2$ ($10^{-4}$ m$^2$)</td>
</tr>
<tr>
<td>square mile</td>
<td>2.59</td>
<td>square kilometer, km$^2$</td>
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<tr>
<td>square millimeter per gram</td>
<td>$10^{-3}$</td>
<td>square meter per kilogram, m$^2$ kg$^{-1}$</td>
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<tr>
<td>temperature ($^\circ$F - 32)</td>
<td>0.556</td>
<td>temperature, $^\circ$C</td>
</tr>
<tr>
<td>temperature ($^\circ$C + 273)</td>
<td>1</td>
<td>temperature, K</td>
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<tr>
<td>ton (metric)</td>
<td>10$^9$</td>
<td>kilogram, kg</td>
</tr>
<tr>
<td>ton (2000 lb)</td>
<td>907</td>
<td>kilogram, kg</td>
</tr>
<tr>
<td>ton (2000 lb) per acre</td>
<td>2.24</td>
<td>megagram per hectare, Mg ha$^{-1}$</td>
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