COTTON HARVEST MANAGEMENT:
Use and Influence of Harvest Aids

The Cotton Foundation
THE COTTON FOUNDATION

Reference Book Series

The Cotton Foundation is dedicated to the advancement and economic viability of the cotton industry. Created in 1955 to foster innovative research and education, the Foundation is supported by membership dues and special grants from commercial agriculture. Members include many of North America’s finest manufacturers and suppliers of machinery, crop protection products, seed, diagnostic equipment, consulting and financial services, trade media, processing materials, and other inputs used to enhance cotton production, processing, and marketing.

The Foundation plays an integral role in focusing the industry on high-priority needs. We bring commercial agriculture and the cotton industry together in an alliance to reach common goals: enhanced markets and profitability. Understanding that sales and services to cotton producers are closely linked to the vitality of the cotton industry, corporate suppliers are eager to participate in the Foundation. Membership dues, research grants, and other contributions go entirely to support research and educational programs.

In keeping with its mission, the Foundation is pleased to publish COTTON HARVEST MANAGEMENT: Use and Influence of Harvest Aids, the fifth publication in our series of cotton reference books, which now includes:

1. Cotton Physiology
2. Weeds of Cotton: Characterization and Control
3. Cotton Insects and Mites: Characterization and Management
4. Vegetable Oils and Agrichemicals
5. Cotton Harvest Management: Use and Influence of Harvest Aids

Andrew Jordan, Ph.D.
Executive Director
The Cotton Foundation
1918 North Parkway
Memphis, Tennessee 38112
ACKNOWLEDGEMENT

Publication of this book was made possible by a grant to The Cotton Foundation from Uniroyal Chemical, a business of Crompton Corporation, and by the efforts of the Cotton Defoliation Work Group (CDWG) and Cotton Incorporated. The book is the culmination of a five-year research effort by the CDWG, which was underwritten by Cotton Incorporated.

The CDWG, in 1992, implemented a research protocol guided by a single objective:

To develop effective, contemporary harvest-aid recommendations that contribute to harvest efficiency and high-quality fiber, by evaluating performance of standard defoliation treatments on a uniform basis and relating this performance to biotic and environmental factors.

In essence, the CDWG was striving to bring a higher level of science and technology to the art of defoliation. Over the following five years, the CDWG continued to refine and improve its research protocols. The knowledge gained from the effort annually has been applied on-farm and in the marketplace through state-by-state recommendations from the researchers and Extension specialists who participated in the CDWG. The group continues to operate as a self-sustaining entity, gaining funding from commercial companies for uniform testing of various harvest-aid materials and tank mixes.

Administration of the CDWG and budgets to facilitate annual meetings has been and continues to be underwritten by Uniroyal Chemical, a longtime supplier of crop protection products to the cotton industry. Uniroyal Chemical is a leading worldwide manufacturer of agricultural and specialty chemicals and polymers, serving customers in 120 countries. The company’s products are used in many markets, including agriculture, rubber processing, plastics, paints and coatings, petroleum, and construction.

Cotton producers will recognize Uniroyal Chemical products, which include Harvade®, growth regulator for weed control and defoliation, Leafless™, LintPlus™, Terraclor® and Terraclor Super X®, Dimilin®, and Comite®.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>List of Tables</td>
<td>xvii</td>
</tr>
<tr>
<td>List of Figures</td>
<td>xxiii</td>
</tr>
<tr>
<td>Foreword and Dedication</td>
<td>xxvii</td>
</tr>
<tr>
<td><strong>Preface: Evolution of Cotton Harvest Management</strong></td>
<td>xxxi</td>
</tr>
<tr>
<td>James R. Supak, Charles E. Snipes, J. C. Banks,</td>
<td></td>
</tr>
<tr>
<td>Michael G. Patterson, Bruce A. Roberts,</td>
<td></td>
</tr>
<tr>
<td>Thomas D. Valco, &amp; Jerry N. Duff</td>
<td></td>
</tr>
<tr>
<td>Unique Attributes of Cotton</td>
<td>xxxii</td>
</tr>
<tr>
<td>Earlier Harvest</td>
<td>xxxiii</td>
</tr>
<tr>
<td>Science Complements Art</td>
<td>xxxiv</td>
</tr>
<tr>
<td>Cotton Defoliation Work Group</td>
<td>xxxiv</td>
</tr>
<tr>
<td>Monograph Highlights</td>
<td>xxxv</td>
</tr>
<tr>
<td>Chapter 1 – A History of Cotton Harvest Aids</td>
<td>xxxvi</td>
</tr>
<tr>
<td>Chapter 2 – Physiology of Cotton Defoliation and Desiccation</td>
<td>xxxvi</td>
</tr>
<tr>
<td>Chapter 3 – Influence of Environment on Cotton Defoliation and Boll Opening</td>
<td>xxxvi</td>
</tr>
<tr>
<td>Chapter 4 – Influence of Crop Condition on Harvest-Aid Activity</td>
<td>xxxvi</td>
</tr>
<tr>
<td>Chapter 5 – Harvest-Aid Treatments: Products and Application Timing</td>
<td>xxxvii</td>
</tr>
<tr>
<td>Chapter 6 – Harvest-Aid Application Technology</td>
<td>xxxvii</td>
</tr>
<tr>
<td>Chapter 7 – Uniform Harvest-Aid Performance and Lint Quality Evaluation</td>
<td>xxxvii</td>
</tr>
<tr>
<td>Chapter 8 – Factors Influencing Net Returns to Cotton Harvest Aids</td>
<td>xxxvii</td>
</tr>
<tr>
<td>Chapter 9 – Overview of Regional Defoliation Practices</td>
<td>xxxviii</td>
</tr>
<tr>
<td>Chapter 10 – Public and Environmental Issues</td>
<td>xxxviii</td>
</tr>
<tr>
<td>Chapter 11 – Cotton Harvest Aids and Biotechnology: The Possibilities</td>
<td>xxxviii</td>
</tr>
<tr>
<td>Future Direction and Needs</td>
<td>xxxix</td>
</tr>
<tr>
<td>Monograph Editorial Committee, Cotton Defoliation Work Group</td>
<td>xl</td>
</tr>
<tr>
<td>Literature Cited</td>
<td>xli</td>
</tr>
</tbody>
</table>
Contributors ................................................................. xliii

Chapter 1. A History of Cotton Harvest Aids ......................... 1

Stephen H. Crawford, J. Tom Cothren, Donna E. Sohan,
& James R. Supak

Introduction ..................................................................... 1

Chemical Defoliation ....................................................... 3

Calcium Cyanamide ........................................................ 4

Aqueous Sprays .............................................................. 5

Tribufos and Sodium Cacodylate ...................................... 6

Thidiazuron and Dimethipin ............................................. 6

Ethephon ........................................................................ 7

Conditioners ................................................................. 8

Carfentrazone-Ethyl ......................................................... 8

Thidiazuron Mixtures ...................................................... 9

Glyphosate ....................................................................... 9

Enhanced Ethephons ....................................................... 10

Chemical Desiccation ..................................................... 10

Pentachlorophenol .......................................................... 12

Arsenic Acid .................................................................. 12

Ammonium Compounds ............................................... 13

Paraquat ........................................................................ 13

Sodium Chlorate ........................................................... 14

Summary .......................................................................... 14

Literature Cited ............................................................. 16

Additional References .................................................... 19

Chapter 2. Physiology of Cotton Defoliation and Desiccation .. 21

J. Tom Cothren, C. Owen Gwathmey, & Ron B. Ames

Introduction ..................................................................... 21

Senescence .................................................................... 22

Leaf Abscission .............................................................. 25

Hormones and Senescence ............................................. 29

Harvest-Aid Chemicals .................................................... 32

Boll Openers/Conditioners ............................................. 33

Defoliants ....................................................................... 33

Desiccants ...................................................................... 37

Regrowth Inhibitors ....................................................... 37

New and Experimental Compounds ................................ 39
Chapter 3. Influence of Environment on Cotton Defoliation and Boll Opening

C. Owen Gwathmey, J. Tom Cothren, Ken E. Legé, Joanne Logan, Bruce A. Roberts, & James R. Supak

Introduction ........................................... 52
Growing Season Conditions ......................... 52
  Moisture Effects on the Leaf Cuticle ............ 52
  Nitrogen Nutrition Effects ....................... 53
  Temperatures for Boll Maturation ............... 53
Environmental Conditions During Harvest-Aid Application ........ 54
  Temperature and Sunlight ......................... 54
  Relative Humidity .................................. 56
  Crop Water Stress .................................. 56
  Precipitation Shortly After Application ........ 57
Environmental Conditions After Application .......... 57
  Heat Unit Accumulation Effects .................. 57
  Q10 of Biological Activity ....................... 58
  Freezing Conditions ............................... 58
Uniform Harvest-Aid Evaluation ..................... 59
Regional Perspectives ............................... 61
  Southeast ......................................... 61
  Midsouth .......................................... 62
  Southwest ......................................... 64
  Far West ......................................... 66
Literature Cited ..................................... 68

Chapter 4. Influence of Crop Condition on Harvest-Aid Activity

Charles E. Snipes & Lisa P. Evans

Introduction ........................................... 73
Crop Conditions During the Season ................. 74
  Vegetative vs. Reproductive Growth .............. 74
  Varietal Differences ............................... 75
<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planting Density</td>
<td>76</td>
</tr>
<tr>
<td>Crop Stature and the Role of Plant Growth Regulators</td>
<td>77</td>
</tr>
<tr>
<td>Plant Stress Effects</td>
<td>77</td>
</tr>
<tr>
<td>Herbicide Injury</td>
<td>81</td>
</tr>
<tr>
<td>Crop Condition During Harvest-Aid Application</td>
<td>82</td>
</tr>
<tr>
<td>Maturity and Boll Load</td>
<td>82</td>
</tr>
<tr>
<td>Endogenous Hormone Activity and Natural Senescence</td>
<td>83</td>
</tr>
<tr>
<td>Plant Stress and Leaf Absorption Barriers</td>
<td>83</td>
</tr>
<tr>
<td>Changes in Crop Condition After Application</td>
<td>84</td>
</tr>
<tr>
<td>Carbohydrate Reserves and Regrowth</td>
<td>86</td>
</tr>
<tr>
<td>Summary</td>
<td>86</td>
</tr>
<tr>
<td>Literature Cited</td>
<td>87</td>
</tr>
</tbody>
</table>

**Photographic Plates** ........................................... 95

**Supplement to Chapter 4. Assessing Regrowth After Defoliation** . . 113

*Charles R. Stichler*

Literature Cited ............................................. 118

**Chapter 5. Harvest-Aid Treatments:**

*Products and Application Timing* .................................. 119

*Barry J. Brecke, J. C. Banks, & J. Tom Cothren*

Introduction .................................................. 119

Preparing Cotton for Harvest-Aid Application ........................ 120

Defoliation Timing ........................................... 121

Harvest-Aid Products ........................................ 127

Boll Openers ................................................................ 127

Enhanced Ethephons ........................................... 128

Defoliants .................................................................. 129

Desiccants .................................................................. 131

Products with Other Applications .................................. 131

Common Mixtures and Sequential Treatments .......................... 132
Beltwide Project ...................................... 171
Materials and Methods ............................ 171
Results and Discussion ............................... 174
Summary .............................................. 178
Literature Cited ..................................... 179

Chapter 8. Factors Influencing Net Returns to Cotton Harvest Aids ........................ 181
James A. Larson & Burton C. English

Introduction ........................................... 181
Harvest-Aid Cost and Return Considerations .......... 182
  Quality Price Differences ........................... 183
  Harvest Costs ..................................... 185
  Weather ........................................... 189
Analysis of Net Returns for Selected Treatments .... 190
  Yield Data ........................................ 190
  Price Data ....................................... 195
  Cost Data ....................................... 195
  Analysis of Lint Yields, Lint Prices, and Net Returns 196
Summary .............................................. 201
Literature Cited ..................................... 203

Chapter 9. Overview of Regional Defoliation Practices And Results of Regional Treatments Conducted by the Cotton Defoliation Work Group .......... 207

Introduction ........................................... 207
Southeast ............................................. 207
  Michael G. Patterson & Charles H. Burmester

Overview ............................................. 208
Environmental Considerations ........................ 209
Standard and Recommended Practices ................... 211
Summary of Results ................................... 212
Five-Year Regional Averages .......................... 213
Two- and Three-Year Regional Averages ............... 215
Summary .............................................. 216
Literature Cited ..................................... 219
Midsouth .................................................. 221
Charles E. Snipes & Lisa P. Evans
Overview .............................................. 221
Use of Harvest Aids ............................... 223
Five-Year Summary ............................... 224
Regional Results and Discussion ............... 228
- Performance Index ............................. 228
- Defoliation ..................................... 230
- Desiccation ..................................... 230
- Boll Opening .................................. 230
- Regrowth ....................................... 231
- Treatments Protected Quality ............... 231
Summary ............................................ 234
Literature Cited .................................. 235

Southwest ............................................. 237
James R. Supak & J. C. Banks
Overview .............................................. 237
Environmental Considerations .................. 240
Crop Yield Potential ............................. 241
Harvest Methods ................................... 244
Common Harvest-Aid Practices .................. 244
- Stripper Harvest ............................... 245
- Picker Harvest ................................. 246
- Regrowth Control ............................. 246
Regional Trials ................................... 247
- Picker Trials .................................. 249
- Stripper Trials ................................ 250
Summary ............................................ 252
Literature Cited .................................. 253

Far West .............................................. 255
Bruce A. Roberts, Steven D. Wright, & Ron Vargas
Overview .............................................. 255
Environmental Considerations .................. 257
California Harvest-Aid Practices and Performance 258

xiii
Chapter 10. Public and Environmental Issues ............... 275

Phillip J. Wakelyn, James R. Supak, Frank Carter, & Bruce A. Roberts

Introduction ............................................... 275
  Mechanical Harvesters ................................... 276
  Consumer Concerns .................................... 277
Effect of Public Perception – A Case History ............ 278
  Arsenic Acid ........................................... 278
  Residues .................................................. 279
  Registration Voluntarily Canceled .................... 280
  Health and Environmental Concerns .................. 281
Additional Concerns/Environmental Issues ............... 281
  Trash .................................................... 284
  Air Quality .............................................. 284
Material Registration, Regulation, and Safe, Efficient Use ... 285
  Registration of Defoliant Products .................. 285
  Selecting Harvest Aids ................................ 288
Proactive Stewardship Programs and Safety Requirements ... 290
  Heavy-Metal Screening ................................ 290
  Proactive Programs and Communication ................ 291
State and Local Regulations Concerning Pesticide Application ... 292
LIST OF TABLES

Chapter 2. Physiology of Cotton Defoliation and Desiccation

1. Harvest-aid chemicals registered for use in cotton production as late as 2001. ........................................ 34

Chapter 3. Influence of Environment on Cotton Defoliation and Boll Opening

1. Minimum temperatures (T_{min}) for optimum performance of selected harvest aids. ................................. 55
2. Distributions of weather data by univariate analysis of weather variables recorded before, during, and after treatment application in the Uniform Harvest-Aid Evaluation conducted for five years at 16 locations. .......... 60

Chapter 6. Harvest-Aid Application Technology

1. Effect of droplet size on drift potential. ..................... 148
2. Basic droplet size guide. ...................................... 148
3. Effect of spray angle and various pressures on fan nozzle droplet sizes. ................................................. 150
4. Effect of nozzle type on droplet size. 
   Volume Median Diameter (D_{50}, microns). ................. 158
5. Droplet size distribution for various nozzles at 40 psi. Water in 115- to 120-mph airstream and parallel to airflow. ............................................. 160

Chapter 7. Uniform Harvest-Aid Performance and Lint Quality Evaluation

2. Influence of harvest-aid treatments on percent defoliation and selected HVI lint quality measurements at all test sites (1992-1996). ............................................ 174
3. Number of white specks observed in 40 square inches of dyed jersey knit fabric over a three-year period. 176
4. Influence of harvest-aid treatments on selected AFIS fiber quality measurements from selected 1994-1996 test locations. 177
5. Linear regression comparisons of selected quality measurements and harvest methods vs. percent defoliation at 14 DAT. 178

Chapter 8. Factors Influencing Net Returns to Cotton Harvest Aids

4. Cotton harvest equipment ownership and operating costs. 187
5. Estimated lint yield and revenue losses due to a delayed cotton harvest. 191
6. Rainfall probabilities for Jackson, Tennessee. 191
7. Treatment descriptions and costs for the cotton harvest-aid analysis. 194
8. Average lint yields for alternative cotton harvest-aid treatments for the Midsouth region, 1992-1996. 197
10. Lint prices for alternative cotton harvest-aid treatments for the Midsouth region, using 1996-1997 season average prices. 199
11. Lint prices for alternative cotton harvest-aid treatments for the Southeast region, using 1996-1997 season average prices. 199
Chapter 9. Overview of Regional Defoliation Practices
And Results of Regional Treatments Conducted
by the Cotton Defoliation Work Group

Southeast

2. Thirty-year (1961-1990) average temperatures and precipitation for selected locations in the southeastern United States. 210
3. Southeast regional harvest-aid treatments. 213
5. Influence of harvest-aid treatments on percent open bolls, terminal regrowth, and basal regrowth at Southeast test sites (1992-1996). 216
8. Influence of additional regional harvest-aid treatments on percent open bolls, terminal regrowth, and basal regrowth at Southeast test sites (1992-1996). 218

Midsouth

1. Cotton variety, soil type, and percent open bolls at application for Midsouth locations. 225
3. Heat units (DD60) from treatment application to first harvest for each Midsouth location. 226
5. Harvest-aid data collected, 1992-1996. 228

Southwest

1. Defoliation and regrowth suppression obtained in 1995 with core treatments at College Station, Texas. .................. 242
2. Defoliation, desiccation, and regrowth suppression obtained in 1995 with core treatments at Prosper, Texas. ........ 242
3. Defoliation and regrowth suppression obtained in 1995 with “best” core treatment and with Ginstar®. ................. 243
4. Harvest-aid chemical and application costs per pound of lint produced for five yield levels. ............................. 243
5. Core and regional harvest-aid treatments used in the stripper-harvested trials in the Southwest region, 1992-1996. 248

Far West

1. Defoliation comparison for Acala® varieties – 1992. ............ 258
2. California planting, treatment, and harvest dates, and percent open bolls at treatment, 1993-1996. ....................... 260
3. Percent defoliation at 14 days after treatment – California. 261
4. Percent desiccation at 14 days after treatment – California. 262
5. Percent Open Bolls at 14 days after treatment – California. 263
6. Percent terminal regrowth at 21 to 28 days after treatment – California. ......................................................... 264
7. Percent basal regrowth at 21 to 28 days after treatment – California. ......................................................... 265
8. Total lint yield (lb per acre) – California. .......................... 266
9. Fiber length (in) – California. ........................................ 267
10. Fiber strength (g/tex) – California. ................................ 267
11. Micronaire – California. ............................................. 268
12. Color grade – reflectance (Rd) – California. .................... 268
13. Color grade – yellowness (+b) – California. .................... 269
14. Percent trash – California. .......................................... 269
15. Fiber length uniformity – California. .............................. 270
Appendix 1. Standard harvest-aid treatments. .................. 274
Appendix 2. Harvest-aid performance data collected each year. 274

Chapter 10. Public and Environmental Issues

1. Concentration of arsenic in nature. ................................. 279
2. Laws and regulations for chemical residues on plant materials, in air emissions, and in water. ........................ 282
3. Summary of residue data, tribufos (Folex®/Def®). ............... 285
4. Summary of residue data, arsenic (As.). ............................ 286
### LIST OF FIGURES

<table>
<thead>
<tr>
<th>Preface: Evolution of Cotton Harvest Management</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Chapter 2. Physiology of Cotton Defoliation and Desiccation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Mechanisms of senescence.</td>
</tr>
<tr>
<td>2. Abscission layer found within a leaf petiole.</td>
</tr>
<tr>
<td>3. Three distinct sequential phases of the hormonal control of leaf abscission.</td>
</tr>
<tr>
<td>4. Proposed model for hormone-signal transduction in plant cells.</td>
</tr>
<tr>
<td>5. Z-scheme with location of diuron and paraquat action sites.</td>
</tr>
<tr>
<td>6. Glyphosate blocks production of an enzymatic step in the shikimic acid pathway.</td>
</tr>
<tr>
<td>7. Effect of adjuvants on Action™ activity in tank mixes.</td>
</tr>
<tr>
<td>8. Effect of adjuvants on thidiazuron absorption in combinations.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Supplement to Chapter 4. Assessing Regrowth After Defoliation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Stages T-0 and B-0: No terminal or basal regrowth.</td>
</tr>
<tr>
<td>2. Stages T-1 and B-1: New leaves less than or equal to ( \frac{1}{4} ) inch in length in terminals; no basal regrowth.</td>
</tr>
<tr>
<td>3. Stages T-2 and B-2: Leaves in terminal unfurling and typically less than ( \frac{1}{2} ) inch in size; new leaves (less than ( \frac{1}{4} ) inch) forming at basal buds.</td>
</tr>
<tr>
<td>4. Stages T-3 and B-3: Terminal leaves ( \frac{1}{2} ) to 1 inch in diameter and expanding rapidly; leaves and stems forming at basal nodes.</td>
</tr>
<tr>
<td>5. Stages T-4 and B-4: Terminal leaves 1 to 2 inches in diameter; stems with leaves attached at basal buds.</td>
</tr>
<tr>
<td>6. Stages T-5 and B-5: Full canopy of leaves, some more than 3 inches in diameter.</td>
</tr>
</tbody>
</table>
Chapter 5. Harvest-Aid Treatments: Products and Application Timing

1. Effect of defoliation on boll size. ............................................. 125
2. Effect of defoliation on micronaire. ........................................... 125

Chapter 6. Harvest-Aid Application Technology

1. Effect of wind and droplet size on drift in a 10-foot fall
   at 3 mph wind speed. ............................................................. 149
2. Effect of wind speed on drift in a 10-foot fall. .......................... 157
3. Smoke rising with wind velocity of less than 5 mph. .................... 152
4. Overhead view of flat-fan nozzles angled 5 degrees from
   the boom, to illustrate spray patterns. Patterns overlap, but do
   not intersect. ........................................................................... 153
5. Spray pattern overlaps 40 to 50 percent
   for flat-fan nozzles. ................................................................. 154
6. Turbo TeeJet® flat-fan nozzle. ................................................... 155
7. Air-assist nozzle. ..................................................................... 156
8. Hollow-cone nozzles: nozzle body and disc-core. ....................... 157
9. Uniform droplets can be attained by lowering
   the nozzle into cleaner air. ....................................................... 161

Chapter 8. Factors Influencing Net Returns to Cotton Harvest Aids

1. U.S. upland cotton planted acreage and spot
   market lint prices, 1970-2000. ............................................... 182
2. Relationship between acres harvested per hour
   and harvest cost per acre. ......................................................... 188
3. Midsouth cotton harvest-aid study locations. ............................ 193
4. Southeast cotton harvest-aid study locations. ............................ 193

Chapter 9. Overview of Regional Defoliation Practices
   And Results of Regional Treatments Conducted
   by the Cotton Defoliation Work Group

Southeast

1. Southeast cotton harvest-aid study locations. .......................... 208
Midsouth

1. Midsouth cotton harvest-aid study locations. ... 222

Southwest

1. Acres of upland cotton harvested by county in Texas and Oklahoma during 2000. ... 238
2. Cotton production and ginning trends in Texas, 1972-1993. ... 239
3. Southwest cotton harvest-aid study locations. ... 247

Far West

1. Far West cotton harvest-aid study location. ... 256
The production of cotton has fascinated and intrigued many for generations. The more effort put into controlling the growth and production of this perennial plant, typically grown as an annual, the more it seems in control.

Man often humanizes inanimate objects. We do this for the cotton plant, either affectionately or with disgust: We commonly refer to cotton as "King Cotton" – does this indicate its upper hand in our motivations?

At one point in history, it could have been said that cotton had us Southerners thinking we could go it alone – without the North. Our struggle to perfect the production of cotton often has left us confounded, except to say that the very nature of cotton production is "to beat it before it beats you."

This certainly is the case during the production phase commonly referred to as defoliation. More appropriately termed crop termination, defoliation is the procedure in which a chemical product, or harvest aid, is applied to cotton at an appropriate physiological stage to remove or desiccate leaves and immature fruiting structures to avoid their interference with harvesting and ginning procedures. As late as the mid 1980s, chemical crop termination using various harvest aids largely was considered an art.

The practice of crop termination came into vogue with the advent of the mechanical harvester during the 1950s. The nature of this practice required the reduction or desiccation of leaf material and foreign matter prior to the harvesting process to minimize negative effects on quality of the finished commodity.

As harvesting practices improved with larger and faster machines, the need for harvest aids intensified. Along with improvements in harvesting, ginning procedures were developed that also emphasized the need for proper preparation of the crop prior to harvest. Today, with earlier-maturing varieties, even faster harvesting and ginning procedures, modules for storage, escalating production costs, and increased scrutiny in the consumer market,
emphasis on crop termination has made it one of the most perplexing and difficult decisions a grower faces.

"Defoliation" has become a practice used to capture crop yield and quality produced during the growing season and to ensure timely harvest. The practice is part of an overall effort to meet the demands of a marketplace that requires ever-increasing standards in order to maintain a competitive edge in a global marketplace.

The nature of the cotton plant and the environment in which it is grown often makes the process of crop termination unreliable; it is difficult to predict the effectiveness or outcome of a chemical harvest-aid application.

In the mid to late 1980s, research in the area of chemical termination often was secondary to other factors and relied more on "hearsay" than on actual research results. The wide range of environmental conditions across the Cotton Belt resulted in inconsistent conclusions about similar practices. The "Art and Science of Defoliation" largely was art, with little science. The limited number of products available for the practice with various limitations for effective chemical termination contributed further to the indecisive nature of crop termination.

Concerns about the imperfect nature of the chemical crop termination process were confounded further with the introduction of High-Volume Instrumentation (HVI) for fiber-quality analysis. Such analyses heightened awareness of the need for more reliable information concerning the effects of harvest aids on fiber quality.

At an informal meeting on defoliation and crop termination early in 1991, a group of cotton specialists and researchers voiced a concern over the inexact nature of defoliation. The need for a uniform assessment of defoliation practices was recognized. This need fostered what has become known as the Cotton Defoliation Work Group (CDWG). The Group's well-planned, uniform approach over a five-year period has provided a benchmark for harvest-aid assessment.

This monograph, COTTON HARVEST MANAGEMENT: Use and Influence of Harvest Aids, is, in part, the culmination of the CDWG's original effort in a form that will be useful to the entire cotton industry. It is intended to be a resource guide for growers, consultants, and industry professionals, as well as a comprehensive resource for academic institutions.
Many people made significant contributions to this effort; they are to be commended for their hard work. However, it was through the commitment of Dr. James Supak of Texas A&M University that this Monograph became reality. His leadership of and mentorship to a diverse group of cotton researchers and Extension professionals was the common thread that bound the group. It is with deep appreciation and fond affection that the CDWG dedicates this work to Dr. Supak on the occasion of his retirement after 31 years of devoted service to the cotton industry.

Charles E. Snipes, Ph.D
Plant Physiologist and Northwest
District Cotton Specialist
Delta Research and Extension Center
Mississippi State University
Stoneville, Mississippi
PREFACE

EVOLUTION

OF COTTON HARVEST MANAGEMENT

For thousands of years, cotton has been grown widely for use in the manufacturing of domestic textiles. Over time, cotton culture evolved from gathering of the lint and seed from wild plants by indigenous people to the domestication and cultivation of selected species to provide textiles for people in organized agricultural societies. Innovations and improvements in textile manufacture led to increased demand for cotton fiber; as a result, acreage expanded and much progress was made in cotton culture. Presently, cotton is the primary cash crop for many farming operations throughout the world. It is among the most important agricultural commodities produced in the United States, with a recent high of 16.7 million planted acres in 1995 (Figure 1).

Figure 1. U.S. upland cotton planted acreage by region, 1970-2000.
Cotton often is viewed as a labor-intensive, high-input crop with harvesting usually regarded as the single most expensive and labor-intensive operation associated with its production. Indeed, even today, about 75 percent of the cotton produced in the world is harvested by hand, one boll at a time. For more than 50 years, mechanical cotton pickers and strippers have provided viable alternatives to hand harvesting. Their rapid acceptance in the United States and elsewhere is attributable in part to the development of harvest-aid materials, which condition and prepare cotton for mechanical harvesting. The purpose of this monograph is to review the biological, environmental, economic, cultural, and societal factors that affect the art and science of cotton defoliation.

**UNIQUE ATTRIBUTES OF COTTON**

Botanically, cotton is a perennial shrub that originated in the relatively arid tropical and subtropical regions of Africa, the Americas, Australia, the Middle East, and elsewhere (Lewis and Richmond, 1968). Presently, it is grown mostly as an annual crop in environments that range from arid to tropical, with relatively long to very short growing seasons. Cotton typically requires a growing season of more than 160 days when minimum temperatures are above 60 F (15 C) (Waddle, 1984) to produce economically acceptable yields of lint and seed.

In the U.S. Cotton Belt, environments range from the arid West to the Rain Belt of the Midsouth and Southeast. Connecting the two extremes are the subtropical production area of South Texas and the relatively dry, short production seasons of the Southern Plains in Texas and Oklahoma. Growers on the northern fringes of the Cotton Belt, including Kansas and Virginia, also are challenged by short growing seasons.

Cotton is grown as an annual crop, leading to challenges in production management, especially harvest-aid management. Because of cotton's indeterminate growth habit, fruit and leaves do not mature uniformly. Consequently, uniform defoliation and boll opening depend on many factors, including crop and environmental conditions, timing of treatment applications, and the harvest-aid materials used.

The adoption of mechanical harvesting in the United States had a tremendous impact on the need for chemical defoliation. In 1947, 98 percent
of the U.S. crop was handpicked or hand-snapped (Fortenberry, 1956). In 1957, only 68 percent was hand-harvested; and, by 1970, 98 percent of the crop was machine-harvested (Ghetti and Looney, 1972). The development of harvest aids in the 1940s and 1950s largely enabled this rapid transition from hand to mechanical harvesting (see Chapter 1).

EARLIER HARVEST

The ultimate goal of harvest-aid use is to protect the quality of the fiber and seed by enabling earlier harvest, in order to reduce field weathering losses, minimize trash content and staining of the lint, and allow for safe storage of seed cotton in trailers and modules. Harvest aids accelerate the physiological processes that induce or contribute to one or more of the following:

- Boll opening
- Removal of mature leaves
- Removal of immature leaves
- Regrowth suppression or inhibition
- Leaf desiccation (required for stripper harvest)
- Desiccation of weeds

Timely harvest of the most valuable fruit (generally the bolls on the lower one-half to two-thirds of the plants) allows the grower to capture much of the yield and quality potential of the crop. Economic value of the fiber is determined by its color, foreign matter content (trash), fiber length, strength, micronaire, and, possibly in the future, other traits, including fiber uniformity and maturity. The proper use of harvest aids primarily affects color and foreign-matter content.

Harvest aids also enable growers to better manage harvesting operations. Individual fields can be prepared and scheduled for harvest to accommodate equipment (farmer-owned or custom-operated) and manpower capacity and availability. Movement of equipment can be minimized by ensuring entire fields uniformly are ready for harvest. Seed cotton can be stored safely in modules, making harvesting operations independent of gin capacities.
Since the introduction of harvest aids, their successful use has been dependent in part on "art" and in part on science. Like the rest of the crop-protection industry, harvest-aid chemistry has changed dramatically in the last 50 years; today, producers have a relatively small, but effective, assortment of products to select from. The use of desiccants and defoliants has been explored and tested since the 1930s (Smith, 1950; Cathey, 1986; Walhood and Addicott, 1968), and harvest-aid management continues to be improved through application of scientific findings. Seasonal assessments of crop and environmental conditions, which constitute essential components of successful cotton harvest-aid programs, still are based largely on human judgement. However, computer-driven models and other techniques based on crop development now are available to assist growers with crop termination decisions.

The application of harvest-aid materials helps to terminate the crop and facilitate harvest scheduling. Improper choice or use of harvest-aid materials — or harvest-aid failures — can reduce quality and, ultimately, the economic value of the crop. Failures also increase costs, because of the need for re-treatment once an initial application has been deemed unacceptable. Ideally, for picker harvest, the harvest-aid treatment selected will promote boll opening and defoliate the entire plant with minimal drying or desiccation. For stripper harvest, high levels of boll opening and defoliation also are desirable, but complete desiccation of remaining green leaves is essential.

Successful harvest-aid performance depends on weather conditions, crop condition, and inherent properties of the materials used. Certain harvest aids have weaknesses that preclude their use under some conditions (e.g., cool temperatures). It has been determined that combinations of two or more harvest aids often provide a suitable hedge against the fallibility of single-product applications.

COTTON DEFOLIATION WORK GROUP

In 1992, a process was developed to uniformly assess harvest-aid performance under a wide range of cultural and environmental conditions. Initially formed as an ad hoc assembly of scientists interested in improving the predictability of harvest-aid practices, these cooperators agreed to form the Cotton Defoliation Work Group (CDWG), which planned, directed, and conducted an active, structured research effort. During the following five years,
the CDWG developed a significant database of harvest-aid performance across the U.S. Cotton Belt. The National Cotton Council funded this multistate effort the first year; Cotton Incorporated continued funding in subsequent years. Operations of the CDWG were facilitated with support from Uniroyal Chemical.

The CDWG recognized that standardized practices and protocols were required in order to attain clearer understanding of boll opening, defoliation, and desiccation processes and to further complement the “art of defoliation” with science. The knowledge gained and the database generated during the course of the five-year project was used by CDWG members and others to develop or update numerous state and local harvest-aid guides for use by producers, consultants, certified applicators, and others. In addition to the crop production aspects of the research, the CDWG’s efforts also documented that the proper use of harvest-aid materials has no adverse effects on fiber quality (Chapter 7; Anonymous, 1999).

There is a continuing need to evaluate new products and alternatives to current defoliation programs to ensure optimum harvest-aid performance and minimal impact on fiber quality. Procedures developed by the CDWG provide a proven format for conducting such evaluations at multiple locations across the entire U.S. Cotton Belt. In addition to product performance, findings from these trials also address concerns by cotton processors about possible detrimental effects of harvest aids on fiber quality (Anonymous, 1999).

The CDWG continues to operate as a self-sustaining, industry-supported entity; it comprises cooperators who are affiliated with state land grant institutions to ensure integrity of the research. The stated research objective of the CDWG is:

To develop effective, contemporary harvest-aid recommendations that contribute to harvest efficiency and high-quality fiber, by evaluating performance of standard defoliation treatments on a uniform basis and relating this performance to biotic and environmental factors.

MONOGRAPH HIGHLIGHTS

The content appearing in the chapters of this Monograph was developed or supervised by members of the CDWG. Topics range from a history of cotton harvest aids to the economic impact of cotton defoliation to public and environmental issues.
CHAPTER 1 - A HISTORY OF COTTON HARVEST AIDS

Mechanical harvesting of cotton is a relatively new concept. The scarcity of labor during World War II played a large role in the transition from handpicking to machine harvesting. Mechanical harvesting also required chemical defoliation, with the 1938 commercial introduction of calcium cyanamide leading the way. Within 25 years, the transition from hand to mechanical harvest essentially was complete in the United States and other developed countries.

CHAPTER 2 - PHYSIOLOGY OF COTTON DEFOILIATION AND DESICCATION

An understanding of cotton growth and development is necessary to fully appreciate the physiological mechanism of defoliation. Perhaps the greatest challenge in dealing with cotton is its growth habit. Cotton is an indeterminate, deciduous perennial grown as an annual. The plant has a natural mechanism to shed mature leaves, although shedding is not necessarily synchronized with the most appropriate time to harvest lint. Hence, the need exists for harvest-aid technology for timely and efficient harvest, field storage, and ginning.

CHAPTER 3 - INFLUENCE OF ENVIRONMENT ON COTTON DEFOILIATION AND BOLL OPENING

The results obtained from the use of harvest aids on cotton are among the least predictable of the operations a farmer may perform (Cathey and Hacsklaylo, 1971). Factors influencing harvest-aid performance include weather conditions, spray coverage, and absorption and translocation of the materials, all of which are influenced by the environment. The chapter summarizes knowledge about environmental effects on harvest-aid performance and provides perspectives from different regions of the U.S. Cotton Belt.

CHAPTER 4 - INFLUENCE OF CROP CONDITION ON HARVEST-AID ACTIVITY

Although environmental factors have a significant impact on crop termination, crop condition can influence the success or failure of a harvest-aid decision. By applying sound management decisions throughout the growing season, growers can improve the likelihood of successful crop termination in the fall. This chapter explores how the efficacy of harvest aids is influenced by growth
habits of the cotton plant and the agronomic practices and decisions made during the growing season.

Assessing Regrowth After Defoliation – A supplement to the chapter offers assessment criteria for rating cotton regrowth after application of harvest aids.

CHAPTER 5 - HARVEST-AID TREATMENTS:

PRODUCTS AND APPLICATION TIMING

Harvest aids are applied to enhance boll opening, facilitate leaf removal, or desiccate the crop prior to mechanical harvest. Benefits of this process include a more efficient harvest of a mature crop and a preservation of yield and fiber quality. When cotton is properly treated, ginning efficiency also is enhanced. This chapter discusses different types of harvest aids and their applications and advantages.

CHAPTER 6 - HARVEST-AID APPLICATION TECHNOLOGY

Regardless of harvest-aid type, accurate application to the plant for uptake through the stomates and by penetrating the leaf cuticle is critical to success of the operation. Application decisions largely are based on crop maturity, crop condition, weather conditions, desired harvest schedule, and harvest-aid choices and rates. In addition, adjuvant usage, spray volume and pressure, physical drift, and application equipment are critical aspects that must be considered prior to use of cotton harvest aids.

CHAPTER 7 - UNIFORM HARVEST-AID PERFORMANCE AND LINT QUALITY EVALUATION

Successful cotton production largely depends on the proper use of harvest-aid products designed to defoliate plant leaves, accelerate boll opening, enhance seed cotton drying in the field, and, in some cases, desiccate green plant material. Harvest aids are needed to maintain the highest fiber quality possible by facilitating timely harvest and reducing plant trash created by mechanical harvesting procedures. This chapter provides an analysis and discussion of lint quality (foreign matter, color, strength, maturity, and neps) related to the harvest-aid treatments from the five-year study conducted by the CDWG.

CHAPTER 8 - FACTORS INFLUENCING NET RETURNS TO COTTON HARVEST AIDS

Because of frequent fluctuations in prices and profitability, producers are concerned about reducing the cost of production (Anonymous, 1998). One input that may improve net returns for cotton farmers is applying a harvest aid, at the correct
timing, prior to harvest. The purpose of this chapter is twofold: 1) to identify some of the factors that may influence the costs and returns to alternative harvest aids, and 2) to analyze the costs and returns for selected harvest-aid treatments from the five-year field study conducted by the CDWG.

CHAPTER 9 - OVERVIEW OF REGIONAL DEFOILIATION PRACTICES

Cotton production and management practices, such as defoliation, vary significantly across the U.S. Cotton Belt. The five-year study conducted by the CDWG applied a standardized protocol to field research, which recognized and evaluated regional variations in environmental and crop growing conditions. These variances and a summary of the standard and regionally specific treatments evaluated by the CDWG are presented in four segments of this chapter. The regions include the Southeast, Midsouth, Southwest, and Far West. The chapter segments also address variances in harvest-aid use within regions – particularly northern versus southern locales.

CHAPTER 10 - PUBLIC AND ENVIRONMENTAL ISSUES

Many individuals and groups in the United States have developed strong concerns about the potential social, economic, and environmental issues modern U.S. agriculture can raise that relate to food safety, air and water quality, and solid waste. These concerns have resulted in passage of numerous state and federal regulations that affect crop protection, including product use and availability, emissions from processing facilities, and disposal of wastes. Additional issues currently are emerging; others undoubtedly will surface in the future. These issues have affected – and will continue to affect – U.S. farmers and farm economies, as well as those of allied industries. Producers must be knowledgeable of potential problems and concerns and must work to minimize downstream effects. Inappropriate practices, or even inattention, could hurt the availability of agricultural products – including harvest aids – and the U.S. cotton industry as a whole.

CHAPTER 11 - COTTON HARVEST AIDS AND BIOTECHNOLOGY: THE POSSIBILITIES

Use of genetically modified crops has grown dramatically over the past five years; they have revolutionized crop production. Recent advancements in cotton biotechnology predominately have been in the area of transgenic varieties possessing such characteristics as herbicide and insect resistance. Little
biotechnological advancement has occurred in the area of cotton harvesting; however, many plant processes lend themselves to genetic modification for the improved efficiency of cotton harvest aids. This chapter discusses how biotechnology can be used to modify plant processes and the potential role of biotechnology in cotton harvesting in years to come.

FUTURE DIRECTION AND NEEDS

The successful development and introduction of new products and technologies for cotton production have advanced the industry in the past and will continue to do so in the future. Challenges to this effort, however, will be significant. Meeting the research and development needs of a vibrant, output-oriented cotton industry will be complicated compared to the previous three or four decades.

Capitalizing public and even private research will become an even bigger issue in the future than it is today. Therefore, it is incumbent on growers, consultants, manufacturers, and others in production agriculture to become better stewards of the products currently available. The industry must keep the present products in the marketplace for the indeterminate future, because higher costs of development and registration, resulting from increased and more restrictive government regulations, have narrowed the pipeline for new products considerably.

New technologies, especially biotechnology, are essential for agriculture to prosper and for the industry to meet the needs of a rapidly growing global population. From the U.S. perspective, bringing these new technologies into production agriculture must add value by decreasing production costs, increasing production, enhancing fiber qualities, and contributing to a safer environment and workplace.

The information age created by a proliferation of the Internet technology platform throughout everyday life provides a conduit for educating and training all audiences, from growers to consumers. It is incumbent on the research and Extension communities, and on the private sector, to educate and train all audiences as advances in agricultural technologies are transferred to the marketplace. The CDWG will participate actively in meeting research-based information needs. This Monograph underscores that commitment.
MONOGRAPH EDITORIAL COMMITTEE,
COTTON DEFOLIATION WORK GROUP

James R. Supak, Ph.D.
Department of Soil and Crop Sciences
Texas A&M University System
College Station, Texas

Charles E. Snipes, Ph.D.
Delta Research and Extension Center
Mississippi State University
Stoneville, Mississippi

J. C. Banks, Ph.D.
Department of Plant and Soil Sciences
Oklahoma Cooperative Extension Service
Altus, Oklahoma

Michael G. Patterson, Ph.D.
Department of Agronomy and Soils
Auburn University
Auburn University, Alabama

Bruce A. Roberts
Cooperative Extension Service
University of California
Hanford, California

Thomas D. Valco, Ph.D., P.E.
Agricultural Research
Cotton Incorporated
Cary, North Carolina

Jerry N. Duff
The Duff Company
Kansas City, Missouri
LITERATURE CITED


CONTRIBUTORS

Ron B. Ames
Technical Manager, Herbicides and PGRs
Crop Protection Research and Development
Uniroyal Chemical
199 Benson Road
Middlebury, Connecticut 06749

Michael J. Bader, Ph.D.
Associate Professor/Extension Engineer
Biological and Agricultural Engineering Department
University of Georgia
P.O. Box 1209
Tifton, Georgia 31793

J. C. Banks, Ph.D.
Extension Cotton Specialist
Department of Plant and Soil Sciences
Cooperative Extension Service
Oklahoma State University
Route 1, Box 15
Altus, Oklahoma 73521

Barry J. Brecke, Ph.D.
Weed Scientist
Agronomy Department
University of Florida
West Florida Research and Education Center
4253 Experiment Drive
Jay, Florida 32565

(Retired)
Charles H. Burmester  
Extension Agronomist  
Department of Agronomy and Soils  
Auburn University  
Tennessee Valley Substation  
P.O. Box 159  
Belle Mina, Alabama 35615

Frank Carter, Ph.D.  
Manager, Pest Management and Regulatory Issues  
Technical Services  
National Cotton Council  
1918 North Parkway  
Memphis, Tennessee 38112

J. Tom Cothren, Ph.D.  
Professor  
Department of Soil and Crop Sciences  
Texas A&M University System  
Mail Stop 2474  
College Station, Texas 77843-2474

Stephen H. Crawford  
Professor Emeritus  
Louisiana State University Agricultural Center  
Northeast Research Station  
P.O. Box 438  
St. Joseph, Louisiana 71366

Crawford Agricultural Services (Currently)  
Rt. 2, Box 31  
St. Joseph, Louisiana 71366
A. Stanley Culpepper, Ph.D.
Assistant Professor/Extension Agronomist
Crop and Soil Sciences Department
University of Georgia
P.O. Box 1209
Tifton, Georgia 31793

Jerry N. Duff
President
The Duff Company
11125 N. Ambassador Drive, Suite 200
Kansas City, Missouri 64153-2014

Burton C. English, Ph.D.
Professor
Department of Agricultural Economics
University of Tennessee
P.O. Box 1071
Knoxville, Tennessee 37901-1071

Lisa P. Evans
Research Assistant
Delta Research and Extension Center
Mississippi State University
P.O. Box 197
Stoneville, Mississippi 38776

C. Owen Gwathmey, Ph.D.
Associate Professor
Department of Plant and Soil Sciences
University of Tennessee
605 Airways Blvd.
Jackson, Tennessee 38301-3200
Richard L. Jasoni, Ph.D.
Plant Physiologist
Department of Chemistry and Biochemistry
Texas Tech University
Box 41061
Lubbock, Texas 79409-1061

James A. Larson, Ph.D.
Associate Professor
Department of Agricultural Economics
University of Tennessee
P.O. Box 1071
Knoxville, Tennessee 37901-1071

Ken E. Legé, Ph.D.
Director of Technical Services, Eastern Region
Delta and Pine Land Co.
7265 Hwy. 9 South
Centre, Alabama 35960

Joanne Logan, Ph.D.
Associate Professor
Department of Plant and Soil Sciences
University of Tennessee
P.O. Box 1071
Knoxville, Tennessee 37901-1071

Michael G. Patterson, Ph.D.
Weed Scientist
Department of Agronomy and Soils
Auburn University
108 Extension Hall
Auburn University, Alabama 36849
Bruce A. Roberts  
County Director and Farm Advisor, Kings County  
University of California Cooperative Extension  
680 N. Campus Drive, Suite A  
Hanford, California 93230

Charles E. Snipes, Ph.D.  
Plant Physiologist and Northwest District Cotton Specialist  
Delta Research and Extension Center  
Mississippi State University  
P.O. Box 197  
Stoneville, Mississippi 38776

Donna E. Sohan, Ph.D.  
Lecturer  
Department of Letters, Arts, and Sciences  
University of Colorado  
Colorado Springs, Colorado 80933

Charles R. Stichler  
Professor and Extension Agronomist  
Texas Cooperative Extension  
Texas A&M University System  
P.O. Box 1849  
Uvalde, Texas 78802-1849

Paul E. Sumner  
Senior Public Service Associate/Extension Engineer  
Biological and Agricultural Engineering Department  
University of Georgia  
P.O. Box 1209  
Tifton, Georgia 31793
James R. Supak, Ph.D.
Professor, Associate Department Head,
and Extension Program Leader
Department of Soil and Crop Sciences
Texas Cooperative Extension
Texas A&M University System
Mail Stop 2474
College Station, Texas 77843-2474

Professor Emeritus and Extension Specialist (Currently)
5720 Chelsea Circle
Bryan, Texas 77802

Thomas D. Valco, Ph.D., P.E.
Director, Agricultural Research
Cotton Incorporated
6399 Weston Parkway
Cary, North Carolina 27513

Ron Vargas
County Director and Farm Advisor, Madera County
University of California Cooperative Extension
328 Madera Ave.
Madera, California 93637

Phillip J. Wakelyn, Ph.D.
Senior Scientist, Environmental Health and Safety
Technical Services
National Cotton Council
1521 New Hampshire, N.W.
Washington, D.C. 20036

Steven D. Wright
Farm Advisor, Tulare County
University of California Cooperative Extension
2500 W. Burrel Avenue
Visalia, California 93291-4584