



PRINCIPLES & PRACTICES FOR
**HARVESTING &
HANDLING
FRUITS & NUTS**

PRINCIPLES & PRACTICES FOR **HARVESTING & HANDLING FRUITS & NUTS**

EDITED BY

MICHAEL O'BRIEN, PH.D., P.E.

Agricultural Engineering Department
University of California, Davis, California

BURTON F. CARGILL, PH.D., P.E.

Agricultural Engineering Department
Michigan State University, East Lansing, Michigan

ROBERT B. FRIDLEY, PH.D., P.E.

Silvicultural Engineering
Weyerhaeuser Company, Tacoma, Washington



AVI PUBLISHING COMPANY, INC.
Westport, Connecticut

Copyright 1983 by
THE AVI PUBLISHING COMPANY, INC.
Westport, Connecticut

All rights reserved. No part of this work covered by the copy-right hereon may be reproduced or used in any form or by any means—graphic, electronic, or mechanical, including photocopying, recording, taping, or information storage or retrieval systems—without written permission of the publisher.

Library of Congress Cataloging in Publication Data

Main entry under title:

Principles & practices for harvesting &
handling fruits & nuts

Includes bibliographical references and index.

1. Fruit—Harvesting. 2. Nuts—Harvesting. 3. Fruit—Handling. 4. Nuts—Handling. I. O'Brien, Michael, 1918—. II. Cargill, Burton F. III. Fridley, Robert B. IV. Title: Principles and practices for harvesting and handling fruits and nuts. V. Title: Harvesting & handling fruits & nuts. VI. Title: Harvesting and handling fruits and nuts.

SB360.3P74 1983 634'.045 83-9952
ISBN 0-87055-413-1

Printed in the United States of America

PRINCIPLES & PRACTICES FOR
**HARVESTING &
HANDLING
FRUITS & NUTS**

Contributors

- ALDRED, WILLIAM H., Agricultural Engineering Department, Texas A & M University, College Station, TX 77801
- BERLAGE, ARNOLD G., USDA-ARS, Agricultural Engineering Department, Oregon State University, Corvallis, OR 97331
- BOOSTER, DEAN E., Agricultural Engineering Department, Oregon State University, Corvallis, OR 97331
- BROWN, GALEN K., USDA-ARS, Agricultural Engineering Department, Michigan State University, East Lansing, MI 48824
- CARGILL, BURTON F., Agricultural Engineering Department, Michigan State University, East Lansing, MI 48824
- CLARY, CARTER D., Department of Plant Science, Viticulture, California State University, Fresno, CA 93740
- CLAYPOOL, LAWRENCE L., Pomology Department, Emeritus, University of California, Davis, CA 95616
- COPPOCK, GLENN E., Agricultural Research and Education Center, Florida Department of Citrus, Lake Alfred, FL 33850
- DIENER, ROBERT G., Agricultural Engineering Department, West Virginia University, Morgantown, WV 26505
- FRIDLEY, ROBERT B., Silvicultural Engineering Department, Weyerhaeuser Company, Federal Way, WA 98003
- GAFFNEY, JEROME J., USDA-ARS, Agricultural Engineering Department, University of Florida, Gainesville, FL 32611
- HANSEN, CLARENCE M., Agricultural Engineering Department, Emeritus, Michigan State University, East Lansing, MI 48824
- KIRK, DALE E., Agricultural Engineering Department, Oregon State University, Corvallis, OR 97331
- LEPORI, WAYNE A., Agricultural Engineering Department, Texas A & M University, College Station, TX 77801
- LEVIN, JORDAN H., USDA-ARS, Retired, 545 Stoddard Avenue, East Lansing, MI 48823
- MONROE, GORDON, E., USDA-ARS, Coastal Plains Experiment Station, Tifton, GA 31794
- NORTON, JOHN S., Experiment Station, University of Massachusetts, East Wareham, MA 02538
- O'BRIEN, MICHAEL, Agricultural Engineering Department, University of California, Davis, CA 95616
- PETERSON, DONALD L., USDA-ARS, Appalachian Fruit Research Station, Kearneysville, WV 25430
- PETRUCCHI, VINCENT E., Department of Plant Science, Viticulture, California State University, Fresno, CA 93740
- REHKUGLER, GERALD E., Agricultural Engineering Department, Cornell University, Ithaca, NY 14850
- RICKS, DONALD J., Department of Agricultural Economics, Michigan State University, East Lansing, MI 48824
- RUFF, JAMES H., Engineering Department, John Deere Company, Cedar Falls, IA 50613

Related AVI Books

AGRICULTURAL ENERGETICS

Fluck and Baird

AGRICULTURAL PROCESS ENGINEERING, 3rd Edition

Henderson and Perry

AN INTRODUCTION TO AGRICULTURAL ENGINEERING

Roth, Crow and Mahoney

BASIC ENGINEERING PRINCIPLES, 2nd Edition

Merkel

COCONUTS, 2nd Edition

Woodroof

COMMERCIAL FRUIT PROCESSING

Woodroof and Luh

COMMERCIAL WINEMAKING

Vine

FUNDAMENTALS OF ELECTRICITY FOR AGRICULTURE

Gustafson

HANDLING, TRANSPORTATION AND STORAGE OF FRUITS AND
VEGETABLES

Vol. 1-Vegetables and Melons, 2nd Edition *Ryall and Lipton*

Vol. 2-Fruits and Tree Nuts, 2nd Edition *Ryall and Pentzer*

PRINCIPLES OF FARM MACHINERY, 3rd Edition

Kepner, Bainer and Barger

PROCESSING EQUIPMENT FOR AGRICULTURAL PRODUCTS,
2nd Edition *Hall and Davis*

RETAILING FARM AND LIGHT INDUSTRIAL EQUIPMENT, 2nd Edition

Mayeux

SMALL FRUIT CULTURE, 5th Edition

Shoemaker

TECHNOLOGY OF WINE MAKING, 4th Edition

Amerine, Berg, Kunkee, Ough, Singleton and Webb

TREE FRUIT PRODUCTION, 3rd Edition

Teskey and Shoemaker

TREE NUTS, 2nd Edition

Woodroof

Preface

Research and development of mechanized methods and systems for harvesting and handling fruits have been under way for the past few decades. Numerous articles have appeared in professional and scientific journals and trade magazines and parts of a few books deal with the subject. However, no publication is available that contains a complete and comprehensive description and analysis of the engineering principles and concepts used for mechanical harvest and handling of fruits.

This book is intended as a reference and supplementary textbook for individuals familiar with the production of fruits and nuts and/or the application of engineering to the production of agricultural commodities. An engineering approach has been used extensively, but an effort has been made to present material in a style and language accessible to the non-engineer as well. To this end, pictures have been used liberally. Persons not versed in engineering should find that a good understanding of the principles and practices for harvesting and handling fruits can be achieved by scanning the limited areas of the book which deal with in-depth analysis or theory of basic principles.

Section I deals with the broad aspects of fruit harvesting, planning for harvest, and the economics of the fruit industry. Cultural, social, and economic aspects are addressed.

Section II presents engineering principles which have been used for making harvest less labor intensive. Aids for manual harvest and removal and collection techniques for machine harvest are described.

Section III covers postharvest functions. Transport, preprocessing, sampling, and containerization are included.

Section IV presents the total harvest systems and describes how several principles and practices are integrated into a variety of workable systems, each matching the machine principles with the biological and economic constraints of particular crops. Several systems for bush, vine, and tree crops are described.

Appreciation is hereby expressed to the many people who made this book possible. Several individuals are recognized as authors of specific chapters. Many others reviewed chapters and provided meaningful input. It is the

hope and the intent of the authors that participation of many leaders in the field has provided the most up-to-date treatment of the subject possible.

We wish to give special recognition to the American Society of Agricultural Engineers Textbook Development Committee for sponsoring sessions on presentation and review of the subject matter included in the text.

Finally, we wish to thank A.M. Nelson, S.V. Mikelbank, T.K. Tremper and C.M. Zahner for their help with the preparation and organization of the text material, to K.B. Clawson for her untiring help in preparation and typing of the book, and to the many others who helped in so many ways.

M. O'Brien
B.F. Cargill
R.B. Fridley

Contents

Contributors	xi
Preface	xiii
PART I INTRODUCTION TO FRUIT MANAGEMENT	1
1 Evolution of Fruit Harvesting	3
<i>R.B. Fridley</i>	
Introduction	3
Elements of the Harvest Operation	6
The Harvest System	11
References	12
2 Biological and Cultural Aspects of Production and Marketing of Fruits	15
<i>L.L. Claypool</i>	
Introduction	15
Genetic Considerations	16
Planting Systems and Tree Training	18
Crop Control	24
Harvesting	29
Postharvest Handling of Fruits	39
References	42
3 Economic Aspects Related to the Food Industry	47
<i>D.J. Ricks and M. O'Brien</i>	
Introduction	47
Mechanically Harvested Crops and the Fruit Marketing System	48
A Grower's Economic Decision on Adoption of Mechanical Harvesting	51
Economic Impact of Mechanical Harvesting	60
Recent Social and Political Developments	64
Changes in Hand Harvesting Methods	68
References	70

PART II HARVEST PRINCIPLES	73
4 Manual Harvesting of Fruits and Nuts and Use of Mechanical Aids	75
<i>M. O'Brien and A.G. Berlage</i>	
Introduction	75
People As the Major Fruit Harvesters	75
Hand Picking of Fruit Has Some Disadvantages	77
Pay Scales	80
Collection Problems and Containerization for Hand Harvesting	81
Improving Manual Harvesting	84
Harvest Aids	86
Comparison of Mechanical Aids and Hand Picking	91
Design Aspects for Mechanical Aids for Tree Fruits	94
The Ladder-Bag Harvesting Future	95
Mechanical Aids for Small Fruits	99
Feasibility Comparisons Between Single-Man Positioners and Hedgerow Platforms	100
Fillers on Harvesting Platforms	104
Positioners for the Harvest of Palm Dates	104
Harvesting Papaya	106
Harvesting Pineapple	106
Harvesting Coffee	109
Harvesting Grapes	111
Outlook on Manual Harvesting	112
References	114
5 Mechanical Detachment of Fruits by Direct Contact Devices	119
<i>B.F. Cargill and D.E. Kirk</i>	
Introduction	119
Lowbush Blueberry Harvesting	119
Cranberry Harvest Mechanization by Stripping, Combing, and Impacting	121
Strawberry Harvesting by the Combing and Cutting Concept	125
Mechanical Harvesting of Pineapple by the Bending Action	130
Grape Harvesting by Cutting	130
Cane and Bushberry Harvesting by the Impacting (Slapping) Concept	132
Citrus Harvesting by Combing, Pulling, Cutting and Twisting	137
Olive Harvesting by the Combing Concept	146
Apple Harvesting by Stripping and Impacting	146
Tree Fruit Harvesting from a Meadow Orchard Concept	151
References	153
6 Vibration and Vibratory Mechanisms for the Harvest of Tree Fruits	157
<i>R.B. Fridley</i>	
Introduction	157
Evolution of Vibratory Harvesting	158
Basics of Vibratory Harvesting	160
Analysis of Tree Vibration	167
Principles of Tree Shaker Design	172
Mechanical Shaking of Tree Foliage	180

Shaking Tree Fruits with an Oscillating Airblast	182
References	185
7 Vibrational Removal Techniques: High-Density: Applications	189
<i>B.F. Cargill and D.E. Booster</i>	
Introduction	189
Harvesting Grapes	191
Harvesting Berries	197
High Bush Blueberries	205
Harvesting Coffee Cherries	208
Harvesting High Density Orchards	209
References	217
8 Fruit and Nut Collection by Pickup	221
<i>J.H. Ruff and W.A. LePori</i>	
Introduction	221
Preharvest Operations	221
Harvest Operations	222
Ground Concentration Mechanisms	223
Pickup Mechanisms	229
Advantages and Disadvantages of Ground Pickup	238
Summary	242
References	242
9 Collection by Catching	245
<i>R.G. Diener and R.B. Fridley</i>	
Introduction	245
Conventional Catching Frames	245
Catching Surface Materials and Impact Problems	264
Tree Structure Modification to Reduce Bruising During Collection	274
Innovative Catching and Collecting Techniques	285
Summary	299
References	299
PART III POSTHARVEST OPERATIONS	305
10 Postharvest Functions	307
<i>G.E. Monroe and M. O'Brien</i>	
Introduction	307
Conveying	307
Removing Unwanted Material	316
Sorting Harvested Fruits or Nuts	322
Washing and Surface Drying	333
Treating for Appearance, Preservation, and Ripening	335
Cooling Fruits and Nuts	338
Major Postharvest Special Operations	354
Packaging for Fresh Market	360
Containers, Bulk Handling, and Storage	362
Certifying Quality	366
References	368

11	Post-Collection Operations on the Harvester	377
	<i>B.F. Cargill and G.E. Rehkugler</i>	
	Introduction	377
	Conveying	379
	Lowerators	379
	Sizing	388
	Extraneous Material Removed by Air	389
	Removal of Inedible Portions of Fruits	392
	Deburring and Dehusking	399
	Grinding and Pureeing Fruit	400
	Sorting	403
	Cooling Fruit to Maintain On-Tree Quality	406
	References	410
12	Postharvest Handling and Transport Operations	413
	<i>M. O'Brien and J.J. Gaffney</i>	
	Introduction	413
	In-Field Operations Facilities	413
	Centralization of On-Farm Operations	418
	Containers for Postharvest Operations	420
	Handling from Harvest to Operation Area	425
	Handling at Intermediate Central Facilities Areas	431
	Handling Considerations for Quality Grading	434
	Field Hydrocooling	438
	Postharvest Handling Equipment	440
	Transportation and Damage of Fruits and Nuts	447
	Miscellaneous Preservation Operations	456
	Delivery for Processing	458
	Fresh Market Packing Operations and Containers	459
	References	467
PART IV	SYSTEMS FOR HARVESTING VARIOUS CROPS	471
13	Berry Harvesting: I. Cranberry Harvesting	473
	<i>J.S. Norton</i>	
	Introduction	473
	Harvesting	474
	Handling	481
	References	482
14	Berry Harvesting: II. Strawberry Production, Harvesting, and In-Plant Processing Systems	483
	<i>C.M. Hansen and D.E. Kirk</i>	
	Introduction	483
	Strawberry Varieties	483
	Cultural Practices	484
	Strawberry Harvesting Systems	485
	Decapping Strawberries and Utilization of Product	492
	References	500

15 Berry Harvesting: III. Cane and High Bush Berry Harvesting	503
<i>D.E. Booster</i>	
Introduction	503
Commercial Harvesters for Blackberries and Raspberries	505
Cultural Practices for Mechanical Harvesting of Blackberries and Raspberries	516
Mechanical Harvesting of High Bush Blueberries	519
Cultural Practice for Mechanical Harvesting of High Bush Blueberries	522
Summary	522
References	523
16 Grape Harvesting Systems	525
<i>V.E. Petrucci, C.D. Clary, and M. O'Brien</i>	
Introduction	525
Viticultural Aspects	529
Raisin Grapes	539
Review of the History of Mechanical Wine Grape Harvesting	552
Development of the Systems Approach to Mechanical Harvesting of Wine Grapes	561
Conclusion	570
References	571
17 Tree Fruit Harvesting Systems: I. Individual Trees	575
<i>G.K. Brown, D.L. Peterson, and J.H. Levin</i>	
Introduction	575
Status of Tree Fruit Mechanical Harvest Systems	576
Manufacturers	584
Research	584
References	586
18 Tree Fruit Harvesting Systems: II. Intensive Fruit Tree Orchard Systems	589
<i>B.F. Cargill</i>	
Introduction	589
General Concerns	589
Intensification	590
References	595
19 System for Harvesting Nuts	597
<i>W.H. Aldred and W.A. LePori</i>	
Introduction	597
Almonds	605

Walnuts	606
Pecans	607
Filberts	609
Macadamia Nuts	610
Pistachios	611
References	611

20 Citrus, Tropical and Subtropical Fruit Harvesting

613

G.E. Coppock and G.K. Brown

Introduction	613
Citrus	613
Fruit Detachment	616
Citrus Collection and Handling	617
Citrus Harvest Systems	618
Avocado	618
Dates	619
Coffee	619
Figs	620
Olives	620
Pineapple and Other Fruits	621
References	622

Appendix

627

Part I

Introduction to Fruit Management

Evolution of Fruit Harvesting

R.B. Fridley

INTRODUCTION

Mechanization of the harvest and handling of fruits and nuts is the result of an interdisciplinary research effort involving engineers, plant scientists, food scientists, physiologists, and economists. Successful implementation of mechanization has demanded and received meaningful inputs from these and other disciplines (Cargill and Rossmiller 1969A). Cultural operations have been changed, new practices devised, and management practices altered. Special training and trellising practices have been developed for grapes and bushberries; pruning and training practices have been revised for some tree fruits; and chemicals have been introduced that induce abscission and loosen some fruits and tighten other fruits. A systems approach involving modification of preharvest, harvest, and postharvest operations has created efficient mechanized operations that are practical and economic.

Although mechanization has progressed rapidly and been adopted for harvest of many crops, new methods and machines will continue to evolve. Few if any fruits are harvested mechanically for the fresh market because of the risk of excessive physical damage during detachment, collection, and containerization. Mechanization will continue to be limited to fruits that are to be processed until improved production and harvest systems are developed. Improved machine systems will incorporate new production systems with new orchard designs, new tree structures, new training methods, and new hardware. Rapid automatic flaw detection and sorting, when developed, could change the economic feasibility of mechanically harvesting fruits for the fresh market. Economic feasibility will be affected also by the cost and availability of labor within the geographical area of production.

Harvest mechanization was given its first major thrust during World War II, when the need for people in the armed services brought about a shortage of laborers for the harvest of agricultural crops (Thor and Mamer 1969). The objective at that time was to develop the capability to harvest