AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523

BIBLIOGRAPHIC INPUT SHEET

FOR AID USE ONLY
Batch 54

1. SUBJECT CLASSIFICATION

A. PRIMARY
Food production and nutrition

AS00-0000-G214

B. SECONDARY
Human nutrition--Nigeria

2. TITLE AND SUBTITLE
Efficient resource use for tropical nutrition: Nigeria

3. AUTHOR(S)
Smith,V.E.

4. DOCUMENT DATE	5. NUMBER OF PAGES	6. ARC NUMBER
1975	395p.	ARC

7. REFERENCE ORGANIZATION NAME AND ADDRESS
Mich.State

8. SUPPLEMENTARY NOTES (Sponsoring Organization, Publishers, Availability)
(In MSU int.business and economic studies)

9. ABSTRACT

Presents a method for organizing skills into a system that can be used to examine the efficiency of the agricultural sector in the production of nutrition. The capacity to provide adequate nutrition for the people of a country depends upon the resources available, the agricultural techniques in use, and the efficiency with which those resources are employed. For an efficient solution of the problems the goals of the nutritionist must be combined with the knowledge of the economist and the expert in agricultural development. This report describes a methematical programming model of the nutritional supply problem in Nigeria during the 1960's. It applies this model to answering questions that are important in planning for improved nutrition for the poor. It concludes that the nutrients which are costly to produce in quantities that meet specified allowances are riboflavin, calories, calcium, and Vitamin A. More nutritutional benefit can be gained by expanding certain of the food crops than any of the income crops. Expansion of the animal industries offers relatively little benefit.

10. CONTROL NUMBER
PN-AAD-425

11. PRICE OF DOCUMENT

12. DESCRIPTORS
Allocations
Factor analysis
Models
Nigeria
Resources
Tropics

13. PROJECT NUMBER

14. CONTRACT NUMBER
CSD-2826 211(d)

15. TYPE OF DOCUMENT

AID 590-1 (4-74)

Efficient Resource Use for Tropical Nutrition: Nigeria

Victor E. Smith

Professor of Economics
Michigan State University

1975
MSU International
Business and Economic Studies

Division of Research
Graduate School of Business Administration
Michigan State University
East Lansing

ISBN: 0-87744-126-X
Library of Congress Catalog Card Number: 74-620058

Copyright © 1975
By the Board of Trustees of Michigan State University
East Lansing, Michigan. All rights reserved

Printed in the United States of America

To David and Michael

Contents

List of Tables xi
List of Figures xv
Acknowledgments xvii
Introduction xxi
Part I: Adequate Nutrition Using 1963 Techniques
Chapter 1 : Summary Statement: Problem and Method 3
Producing the Nutrients Needed 5
The Model 6
Interpreting the Results 9
Chapter 2 : The Model as a Whole 10
An Interdisciplinary Approach 11
Problems 12
The Model 15
The Objective Function 17
The Areas 19
The Activities 22
The Restraints 27
The Data 33
Summary 41
Appendix 41
Chapter 3 : The Nutritional Model 43
The Protein Allowance 44
Protein Quality 45
Essential Amino Acids: Proportions 47
Essential and Nonessential Amino Acids: Proportions 47
A Fully Utilizable Protein 50
Other Factors 51
The Protein Model 52
The Complete Nutritional Model 56
Conclusion 60

Chapter 4 : The Costs of Individual Nutrients 61
Résumé of the Model 63
The Controlling Nutrients 63
Costs of Individual Nutrients 67
The Protein Problem 71
The Riboflavin Allowance 72
A Higher Protein Allowance 73
The Limiting Amino Acids 75
The Most Economical Foods 77
Summary 79
Chapter 5 : Geographical Specialization and Internal Trade 81
Aggregate Output of the Agricultural Sector 81
Revenue Producing Activities 83
Purchases from Outside Nigerian Agriculture 86
Internal Movements of Food 90
Chapter 6 : Production Activities in the Optimal Solution 97
Cash Crop Production 100
Efficient Food Crops 105
Surpluses Earned 109
Improved Techniques 116
The Animal Industries 117
Resource Earnings 129
Summary 135
Designing a Development Strategy 135
Chapter 7 : Conclusion 138
Part II: Adequate Nutrition Using Traditional Techniques in the Savanna
Chapter 8 : Introduction: Changes from the Previous Model 145
Chapter 9 : The Costs of Individual Nutrients: Traditional Techniques 158
Feasibility of the Allowances 158
Costs of Individual Nutrients 161
The Most Economical Foods 166
Effects of Improved Techniques 171
Conclusion 172
Chapter 10 : Geographical Specialization and Internal Trade: Traditional Techniques 174
Purchases from Outside Nigerian Agriculture 174
Food and Fertilizer 174
Transportation Services 178
Revenue Producing Activities 182
Internal Trade in Food 188
Effects of Improved Techniques 194
Conclusion 195
Chapter 11 : Production Activities in the Optimal Solution: Traditional Techniques 198
Cash Crop Production 199
Efficient Food Crops 202
Surpluses Earned 207
Effects of Improved Techniques 213
The Animal Industries 215
Resource Earnings 222
Efficient Nutrient Production 229

Chapter 12 : Efficient Nutrition with Traditional Techniques 234
Part III: Summary and Recommendations
Chapter 13 : Persistent Characteristics of the Nutritional Problem 241
The Model Using 1963 Techniques 242
Persistent Characteristics of the Nutritional Problem 244
Chapter 14 : The Effects of Technical Improvement 249
Nigerian Productive Capacity 250
Costs of Individual Nutrients 253
Internal Trade 254
Cash Crop Production 255
Efficient Food Production Activities 256
Resource Use 258
Summary 259
Chapter 15 : Policy Recommendations 261
Summary of Results 262
The Nutritional Problem 263
The Scarce Nutrients—and Protein 265
Calories 267
Riboflavin 270
Protein 275
Calcium 280
Vitamin A 280
More on Nutrition 280
Efficient Foods 280
Pigs 283
Hides and Skins 283
Nutritional Information for Planners 283
Selecting Production Activities 285
Food Production 285
Income Production 286
Trade 288
Within the Agricultural Sector 288
Outside the Agricultural Sector 289
The Role of Technical Change 289
Adapting to Change 291
Conclusion 294
Notes 297
Appendix A 323
Potential Improvements and the Capacity to Produce Nonfood Income 325
Appendix B 343
Nutritional Efficiencies of Potential Improvements 345
Bibliography 371

List of Tables

Table		Page
1	*Yield and May–June Labor Requirements per Acre*	36
2	*Population Estimates for Nigeria, November 1967, in Thousands*	39
3	*Daily per Capita Nutrient Allowances for Nigeria as a Whole*	39
4	*Milligrams of Specified Amino Acid per Gram of Total Essential Amino Acids in Egg Protein*	48
5	*The Amino Acid Composition of a Fully Utilizable Protein, in Grams*	51
6	*The 1957 FAO Provisional Pattern for Five Essential Amino Acids or Groups of Acids*	51
7	*The Complete Nutritional Model*	57
8	*Costs of Nutrient Elements in Average Daily per Capita Allowances, in Shillings*	68
9	*Potential Gains from Expanding or Contracting Those Consumption Activities Significantly Constrained by Their Maximum or Minimum Levels, in Shillings per Kilogram*	78
10	*Income Producing Activities, in Millions of Shillings*	84
11	*Expenditures on Food and Fertilizer*	85
12	*Payments for Transportation of Foods Produced by Nigerian Agriculture, in Millions of Shillings*	87
13	*Summary of Revenue Transactions*	89
14	*Quantities of Nigerian Foods Transported between Areas, Weight at Farm, in Millions of Pounds*	92
15	*Offsetting Purchases and Sales, in Millions of Pounds*	96
16	*Levels of Cash Crop Activities, in Thousands of Acres*	101
17	*Additions to Revenue Possible if a Single Cash Crop Activity Were Expanded, in Shillings per Acre per Year*	102
18	*Levels of Food Crop Activities, in Thousands of Acres*	106
19	*Additions to Revenue Possible if a Single Food Crop Activity Were Expanded, in Shillings per Acre per Year*	110
20	*The Twenty-Seven Field Crop Activities with the Largest Surpluses*	113

Table		Page
21	*Activities that May Represent Improved Practices: Estimates of Yields and Surpluses per Acre*	118
22	*Levels of the Animal Industries*	120
23	*Additions to Revenue Possible if a Single Animal Activity Were Expanded*	123
24	*Aggregate Value of Animal Industry Output in the Optimal Solution, in Thousands of Shillings*	128
25	*Revenue Obtainable from an Additional Unit of a Resource, in Shillings*	130
26	*Resources Available and Unused*	132
27	*Changes in the Quantitative Specifications of the Models*	148
28	*New Activities Included in Model Four*	151
29	*Changes in Data for the Production Activities, Areas I, II, and VI*	153
30	*Nutrient Costs at the Limit of Feasibility, Traditional Techniques, in Shillings*	159
31	*Costs of Nutrient Elements in Average Daily per Capita Allowances, Traditional Techniques, in Shillings*	161
32	*Potential Gains from Expanding or Contracting Those Consumption Activities Significantly Constrained by Their Maximum or Minimum Levels, Traditional Techniques, in Shillings per Kilogram*	167
33	*Comparison of the Costs of the Average Daily Allowances, in Shillings*	172
34	*Expenditures on Food Not Obtained from Nigerian Agriculture, Traditional Techniques, in Millions of Shillings*	175
35	*Expenditures on Fertilizer, Traditional Techniques, in Millions of Shillings*	178
36	*Payments for Transportation of Foods Produced by Nigerian Agriculture, Traditional Techniques, in Millions of Shillings*	180
37	*Income Producing Activities, Traditional Techniques, in Millions of Shillings*	184
38	*Summary of Revenue Transactions, Traditional Techniques*	186
39	*Quantities of Nigerian Foods Transported between Areas, Traditional Techniques, Weight at Farm, in Millions of Pounds*	190
40	*Offsetting Purchases and Sales, Traditional Techniques, in Millions of Pounds*	191
41	*Levels of Cash Crop Activities, Traditional Techniques, in Thousands of Acres*	200
42	*Additions to Revenue Possible if a Single Cash Crop Were Expanded, Traditional Techniques, in Shillings per Acre per Year*	202
43	*Levels of Food Crop Activities, Traditional Techniques, in Thousands of Acres*	204
44	*Additions to Revenue Possible if a Single Food Crop Activity Were Expanded, Traditional Techniques, in Shillings per Acre per Year*	208
45	*The Twenty-Seven Field Crop Activities with the Largest Surpluses, Traditional Techniques*	212
46	*Levels of the Animal Industries, Traditional Techniques Employed in Cropping Activities*	217

Table		Page
47	*Additions to Revenue Obtainable by Expanding a Single Animal Industry, Traditional Techniques Employed in Cropping Activities*	218
48	*Additions to Revenue Obtainable from an Additional Unit of a Resource, Traditional Techniques in the Savanna Areas*	219
49	*Resources Available and Unused, Traditional Techniques*	221
50	*Aggregate Cost of Food, in Millions of Shillings*	252

Appendix Tables

1A	*Yields at Four Technical Levels, in Pounds per Acre*	328
2A	*Potential Net Contribution of the Agricultural Sector to Nonfood Income, in Millions of Shillings*	332
1B	*Improvements Not Used, Recommended Practices Solution*	359
2B	*Efficient Improvements when Recommended Practices Are Employed*	360
3B	*Costs of Daily Nutrient Allowances, in Shillings per Capita*	363
4B	*Food Crops at Zero Level in the Recommended Practices Solution*	363
5B	*Efficient Food Crops Produced at Less than Maximal Levels in the Recommended Practices Solution*	364
6B	*Prospective Varieties*	367

List of Figures

Figure		Page
1	*Map of Ecological Areas*	20
2	*A Sketch of the Model*	23
3	*Acceptable Region for Variations in Protein Quality: The Intermediate Savanna*	55
4	*Linear Approximation to the Nonlinear Restraint*	59
5	*Maximum Riboflavin and Calcium Allowances Attainable*	65
6	*Major Food Movements*	91
7	*Major Food Movements, Traditional Techniques*	189

Appendix Figures

1B	*Acreages Available and Used: Major Crops*	348
2B	*Acreages Available and Used: Remaining Crops*	350

Acknowledgments

This study was conducted under the auspices of the Consortium for the Study of Nigerian Rural Development, a contractor for the United States Agency for International Development. The final stages of the work, including the preparation of this report, were financed partially by the Midwest Universities Consortium for International Activities, by the Rockefeller Foundation, and by a 211d grant from USAID to the Agricultural Economics Department of Michigan State University. Use of the Michigan State University computing facilities was made possible in part because of the support for those facilities from the National Science Foundation. None of the grantors bears any responsibility for either the analysis or the findings of this investigation.

Without the generous help of scientists and officials in several countries, the work would have been impossible. In Nigeria, in particular, invaluable assistance was provided by government officials; scientists at research stations (especially the Federal and State Moor Plantations and the Institute of Agricultural Research stations at Samaru and Kano); staff members at the University of Ibadan, Ahmadu Bello University, and the University of Ife; and members of the United States Agency for International Development. I cannot mention by name all who have helped, but I deeply appreciate the assistance of every one.

I must make special mention of the contributions of some. Dr. Glenn Johnson of Michigan State University first suggested the possi-

bility of a study such as this. His contributions to early discussions of the study and his continued support and assistance at all stages of the work have been invaluable.

At various points I have called upon Dr. Dena Cederquist and Dr. Cecilia Florencio of Michigan State University for assistance with nutritional aspects of the study. Dr. Isaac S. Dema of the University of Ibadan helped in important ways until he left Nigeria for an FAO assignment. I am particularly grateful to him for having suggested Mr. Ephraim Idusogie as a member of our staff. To Dr. Phillip R. Payne of the London School of Hygiene and Tropical Medicine I am deeply indebted for an explanation of the complicated problems of protein allowances and protein utilization. Dr. John M. Hunter, then of the University of Durham, provided wise counsel concerning the establishment of geographical units appropriate for the purposes of the study. Mr. Richard B. Woodroofe, Chief Agricultural Officer, Kano State Ministry of Agriculture, was an invaluable source of information and data for one of the models.

Major burdens were borne by the professional members of my staff, Mr. Ephraim Idusogie and Mr. John Whitney. Mr. Idusogie was the nutritionist for the study. In addition to providing information concerning Nigerian food habits and preferences, he was responsible for preparing our data on the nutrient composition of Nigerian foods, developing an estimate of the aggregate actual intake of each of 15 nutrient elements (by geographic area), preparing a scale of recommended nutrient allowances, obtaining data on the age and sex distribution of the population, and calculating the aggregate intake levels needed to meet our scale of recommended nutrient allowances for the population in each area. Both Mr. Idusogie and Mr. Whitney contributed to our estimates of food losses through wastage.

Mr. Idusogie's knowledge of nutrition, his receptiveness to approaches that departed from those most customary in nutritional studies, and his intimate acquaintance with the Nigerian situation were invaluable.

Mr. Whitney was our agricultural economist. He was primarily responsible for identifying the important crops in each area, providing the necessary information concerning cultural practices, developing the data on acreages harvested, computing yields and input requirements per acre, and obtaining estimates from informed sources where other data were unsatisfactory or unavailable. He was also responsible for obtaining technical coefficients for the processing industries, prices

of crops sold for income, foreign exchange earnings data for such crops, information concerning marketing channels and transportation routes, and estimates of transportation costs over each route.

Mr. Whitney possessed an extraordinary talent for absorbing information about Nigerian agriculture from government officials, USAID representatives, the staff members of universities and experiment stations, businessmen, and knowledgeable people from all walks of life. He was able to use this information in interpreting the published data available and to obtain expert opinion in evaluating the data, or, when necessary, in supplementing it. Without his insight and understanding this study might have been impossible.

Mr. Hossein Yaghoobi was my assistant in the development and solution of the second of the models presented in this book. He worked with me in the formulation of the model and in the collection and processing of new Nigerian data, and he handled the computing. His efforts are much appreciated. Appendixes A and B are based upon material from his dissertation.

Portions of chapter 3 appeared in Victor E. Smith, "A Diet Model with Protein Quality Variable," *Management Science* 20 (February 1974): 971–80.

Introduction

The pressure of population against resources has created severe problems of malnutrition over much of the globe. Attempts to introduce low-cost, nutritious foods such as fish flour and incaparina generally have been disappointing. In some areas, such as India and Pakistan, the "green revolution" has given temporary relief, but the production of pulses has declined as wheat harvests have risen, and the improved cereals often contain less protein than the native varieties they replace. Even where the green revolution has helped, population continues to grow and malnutrition remains a major threat to the welfare of man. In the less developed countries as a whole, per capita food production is rising only slowly. In Africa, it has been falling since 1963.[1]

Countries burdened with undernutrition must make do with an undernourished labor force, too lacking in strength and energy to be fully productive.[2] Moreover, we are learning that malnutrition among children has long-run effects. It not only reduces learning during the school years, but also, among infants, can inhibit the full development of the brain, reducing the intellectual capacity of the labor force for decades to come. It even has been reported that protein deficiency leads baby monkeys to fear and avoid novel experiences. If the malnutrition of adults limits current productivity and if that of infants stunts the mind and reduces the capacity to adapt to change, what nation can afford to ignore it? As Pedro Belli has said: "Where malnutrition is common, a large percentage of the population may never be

able to achieve its full potential as human beings or as economic agents. It would be surprising to find high rates of growth in countries where malnutrition is widespread."[3] He adds that "the child of a poor family in a poor country is almost doomed from the moment of conception. . . . Regardless of the amount of capital and education that society makes available to him, he will not be able to achieve the levels of productivity that his genetic potential dictated."[4]

Given the gravity of the problem, we must begin to apply the principles of economic efficiency to providing the nutrients needed by the masses of our people. Planning to meet the needs of a growing population must include planning for nutritional needs. Simply creating a larger per capita income will not solve the problem. The Western economist traditionally assumes that people's choices will be optimal, but "optimal" to the economist has no reference to the physiological needs that concern the nutritionist. The nutritionist realizes that most people do not know what nutrients they need, or what foods contain them, and he is aware that even if they had such knowledge they might choose other consumption goods (transistor radios, bicycles, or more education for their children) instead of the food essential to the physical well-being of both parents and children.

Even if people did choose wisely, and if their nutritional well-being were as important to them as the nutritionist thinks it should be, we could not rely upon free markets to provide the foods needed for adequate nutrition in most countries. Free markets will provide the food that the well-to-do demand, but those whose incomes do not permit paying market prices will not find food available. The nutritional needs of the poor are not fully recorded in the market. Recognizing those needs requires going beyond market demands and current consumption levels for foods to statements of nutritional needs that are based upon physiological considerations, not upon quantities purchased. Market directed production research will not suffice when much of the problem stems from poverty. To feed *all* Nigerians adequately we must find ways of producing more of the essential nutrients than the market now provides.[5] Furthermore, we must find ways of producing them cheaply enough so that the poor can obtain what is now unavailable to them. If protein-calorie malnutrition is to be eliminated among the poor, sources of protein and calories must be found that they can afford. The present emphasis on increasing the production of animal protein in Nigeria cannot contribute much toward this objective.

In the absence of deliberate attention to its nutritional consequences, the course of economic development often leads to worse diets and degenerating nutritional levels. Jacques May has asserted that in Nigeria one of the two most important reasons for inadequate diets is the expansion of cash crops, particularly cocoa and palm oil. (The other is population growth.) Cocoa villages have too little food. Building a road to Bero-Okuta led to the sale of yams to the cocoa regions, which improved the supply there, but caused malnutrition in Bero-Okuta.[6] Ephraim Idusogie confirms this view with respect to southern Nigeria.[7] Cocoyams and cassava have expanded at the expense of yams, to release labor and land for the production of cocoa, rubber, and palm oil.[8] Because yams traditionally are grown with a mixture of other crops, such as upland rice, maize, beans, groundnuts, melon seeds, peppers, pumpkin, pineapples, and vegetables, lower yam production means less production of the accompanying crops, many of which are valuable sources of protein and vitamins.[9]

With appropriate planning, new sources of the crucial nutrients can be developed, the production costs of important foods can be reduced, and the consumer with limited income can be given a chance to improve his nutritional well-being as well as to extend his consumption into the new and attractive areas opened to him by the processes of development.

The nutritionist can tell us how the diet can be improved, but, usually, not how to do this in the most economical way. Neither can he predict the effects of dietary change on production, resource use, and income. The agricultural development expert can suggest improved production techniques, but how their adoption may affect the nutritional status of the country is a question outside his realm of competence. For an efficient solution of the problem the goals of the nutritionist must be combined with the knowledge of the economist and the expert in agricultural development. We must take into account the interdependence between food and income production so that gains in income do not come at the expense of nutrition, and so that nutritional gains are obtained at the least possible sacrifice of other goals (income). We must recognize that our capacity to provide adequate nutrition for the people of a country depends upon the resources available, the agricultural techniques in use, and the efficiency with which those resources are employed. We must realize that the proportions in which nutrients are needed by the population may not coincide with the proportions in which they can be produced conve-

niently, with the result that some nutrient objectives will be more difficult to attain than others. We will learn that employing resources efficiently means finding the most efficient sources of those nutrients that are relatively most difficult to obtain and that to do this we must examine the competition among crops, which simultaneously provide nutrients and use up resources.

This volume presents a method for organizing the knowledge of the nutritionist, the agriculturist, and the economist into a system that can be used to examine the efficiency of the agricultural sector in the production of nutrition. It describes a mathematical programming model of the nutritional supply problem as it existed in Nigeria during the 1960s,[10] and it applies this model to answering a number of questions that are important in planning for improved nutrition for the less well-to-do. The method is applicable to any country faced with the need to choose among alternative ways of increasing its food supplies. The results, of course, will have special relevance for those West African countries that share some of the ecological characteristics of Nigeria.

The study uses a mathematical programming model to find an agricultural production pattern that is efficient in nutritional terms (not simply in market terms), to discover which crops or which techniques of cultivation are most efficient nutritionally, and to identify changes in the production pattern that would lower the cost of obtaining adequate nutrition. A model of this type could be extended, of course, to compare the merits of a variety of alternative intervention strategies designed to improve nutrition in a developing country.

Among other things, the present study asks whether the techniques employed in 1963 could have been adequate to meet the nutritional needs of the 1967 population (had there been no war), whether the 1963 production pattern would have been nutritionally efficient for the needs of the 1967 population, and what the situation would have been in the absence of various technical advances that already had come into use by 1963.

Work began in fall 1966 as an experiment to determine whether the data available in Nigeria were sufficient to permit building a useful model that would describe the interrelations between the nutrient needs of the population, the foods produced in the country, the resources required for the production of food crops, and the competing demands for those resources from crops grown for income. We wished also to take account of the differing productive capacities of

the various parts of Nigeria and of the possibilities for trade within the country. It was our hope to use this model to determine patterns of production, trade, and consumption that would provide for the nutritional needs of the Nigerian population in an efficient way. Efficient production of nutrients means that the poor can meet their needs as economically as possible and that national nutritional needs will interfere as little as possible with expanding the income to be earned by the production of export crops. Naturally, the data were not all that one could wish, but they turned out to be sufficient to provide useful results, plus insights into the nature of the Nigerian nutritional problems that previously had not been available.

Work proceeded through a series of four models, of which this volume discusses the third and fourth.[11] The first model contained limitations on the extent to which production could deviate from the 1963 pattern, but placed few restrictions on consumption levels. The diets that resulted contained embarrassingly large amounts of the cereal beers, red palm oil, groundnut oil, and dried freshwater fish with edible bones.

The second model imposed maximum limits on the consumption of each food and limited per capita consumption of alcoholic beverages to 1963 levels. Both of these first models used very high estimates of the meat output of the traditional animal industries and low estimates of milk production.

The third model revised those estimates. The result was reasonably descriptive of conditions within Nigeria and provided a generally satisfactory basis for policy formation. Model Three was not, however, without flaws. Therefore, when the opportunity arose in 1969 to obtain production data from a new source for a number of crops grown in the savanna area, the model was further revised before using the new information.

The new data, however, represented traditional methods, generally less advanced than those already in use by 1963. Therefore, the fourth model, while it has some advantages in form, is not as descriptive of recent conditions as is Model Three. The significance of Model Four lies not in its usefulness as a guide to policy, but in its ability to indicate the quantitative importance of the flaws that had been detected in Model Three, to permit a test of the stability of our results in the face of wide changes in the values of the production coefficients for several major crops, and to provide an estimate of the economic and nutritional importance of adopting improved agricultural techniques.

Model Four is also the basis of a separate study that evaluates nutritional efficiency for proposed improvements not yet available or in general use in 1966. Some results from that study are presented here in Appendices A and B.

Whichever model is used, the major features of the solution are the same. The nutrients that are costly to produce in quantities that meet the allowances specified are riboflavin, calories, calcium, and vitamin A in each case. (Protein, more specifically, the group of sulfur-containing amino acids, involves a small cost in the intermediate savanna in Model 1, but not in the other models.)

In each solution, more is to be gained by expanding certain food crops than by expanding any of the income crops, even though direct expansion of some cash crops could increase agricultural income appreciably without sacrificing desirable levels of nutrition. In each solution, expansion of the animal industries offers relatively little benefit, except, in some situations, for commercial cattle in the forest-savanna mosaic.

Part I:

Adequate Nutrition Using 1963 Techniques

1

Summary Statement: Problem and Method

The principal nutritional problems in Nigeria appear to be protein-calorie malnutrition, riboflavin deficiencies, anemia, low or borderline intakes of thiamine and calcium, and blindness from vitamin A deficiency. Jacques May, in his review of the nutritional literature concerning Nigeria, also reports evidence of low intakes of fat and ascorbic acid.[1]

The nutrition survey done in 1965 by a joint Nigerian-United States team reported cases of marasmus and kwashiorkor in young children in all hospitals, clinical evidence of severe protein-calorie malnutrition and marasmus in some areas, and mild and moderate degrees of protein-calorie malnutrition as the rule. Evidence from dietary survey studies showed low or borderline protein intake in a number of locations.[2] In the cocoa belt, deficiencies of methionine, cystine, and tryptophan have been found.[3] Ephraim Idusogie reports methionine and cystine as the limiting amino acids in diets from various parts of Nigeria.[4]

Throughout most of the country people are underweight, and "malnutrition bordering on starvation occurs in the north during the hun-

gry season of the pre-harvest months."[5] There is a seasonal element in protein intake also, for as the dry season ends and the rains begin, people turn to the poorer starchy foods such as plantain or manioc (cassava), which are inferior sources of protein.[6] Dr. J. M. Gurney, formerly of the Food Science and Applied Nutrition Unit, University of Ibadan, Nigeria, declares protein-calorie malnutrition the "main nutritional syndrome with an extraordinary high mortality and morbidity in Nigeria."[7]

There is agreement on the existence in the north of vitamin A deficiency and on the widespread incidence of anemia.[8]

May reports that signs of vitamin deficiencies are frequent, the most common relating to the B-vitamin complex.[9] The 1965 nutrition survey found the intake of thiamine (vitamin B_1) to be low or borderline in several locations, according to its dietary studies, and low or deficient in from 21 to 40 percent of the population, according to its biochemical studies.[10]

Signs of riboflavin (B_2) deficiency are seen in many parts of Africa.[11] In Nigeria the 1965 nutrition survey found riboflavin deficiency to be "severe and widespread" according to biochemical, dietary, and clinical evidence. Riboflavin intake was low in most locations, according to the dietary survey studies, and the biochemical investigation led to the conclusion that "the most pronounced nutritional problem as judged by biochemical criteria is low nutriture with respect to riboflavin."[12]

Gurney questions the conclusions regarding riboflavin, maintaining that the frequency of occurrence of clinical evidence is low and that dietary surveys and biochemical tests are unreliable means of assessing riboflavin deficiency. He adds, moreover, that a "lack of dietary riboflavin does not appear to be fatal or even to cause more than minor clinical change in humans."[13]

Calcium intake is inadequate in some places and in practically all children, according to May, and the milk of lactating mothers is low in calcium and phosphorus.[14] Dietary studies done during the 1965 nutritional survey found calcium intake low in several locations, but Gurney asserts that "dietary calcium deficiency is unknown."[15]

Perhaps these contradictions are explained by the following quotation: "In many areas of Africa, the intake of calcium is low when compared with estimated requirements. The African, however, appears to be well adapted to this level of intake. Conditions associated

with calcium deficiency such as osteomalacia are rarely observed. An appreciable incidence of postrachitic signs has, however, been found, particularly in the forest areas. The cause of these signs is doubtful."[16]

In sum, it is agreed that protein and calorie malnutrition are serious problems in Nigeria and that anemias and vitamin A deficiencies exist. While calcium intake may be low, there is little evidence that this constitutes a serious nutritional problem. Nutritionists differ concerning the seriousness of the riboflavin problem.

Producing the Nutrients Needed

As in other developing countries, the Nigerian nutritional problem has many facets. Nutritional goals by their nature are multiple and interrelated. It is common practice to try to reduce the problem to one or two nutrients, but such an oversimplification can lead to distorted emphasis or even error. A method is needed that is capable of dealing with multiple goals, with the whole set of nutrient requirements at once.

Adequate nutrition is the result of a complex system of many components, but this study concerns primarily the production component. A method of analyzing the agricultural capabilities of a developing country is necessary in order to determine whether such a country can provide the nutrients required by its people and, if so, how agricultural production must be organized to accomplish this without unnecessarily sacrificing the income-producing capacity of the agricultural sector.

Such a method will be developed for the Nigerian situation by preparing a mathematical programming model of Nigerian agricultural activities designed to answer the following question: What organization of agricultural activities will provide nutrients adequate for a population of 61 million while maximizing the revenue obtainable from the sale of the remaining products of the agricultural sector?[17] If the problem is feasible (if a solution exists), we know that Nigeria can provide the set of nutrients specified. Nonfood income is to be maximized, but subject to the constraint that the nutrients available shall not fall below specified levels.[18] The optimal solution will define a set of activities that provides the specified quantities of nutrients with the least sacrifice of revenue that could have been earned by using the resources for other purposes.

The Model

The model regards any agricultural product as providing either nutrients or cash income, but not both at once. Crops yielding produce not used for food within Nigeria will be called *revenue* or *cash crops*. The income from their sale is what we wish to maximize.[10] If the produce is used for food within Nigeria, the crop is regarded as a source of nutrients, but not as a source of the monetary income which we are attempting to maximize. Some crops (groundnuts, soybeans, and oil palm) may provide either food for Nigerians or income from sales outside Nigeria or for nonfood purposes. With such crops, the portion that is used as food within Nigeria is credited with the nutrients it provides. The remaining portion is credited with the cash income earned from the sale.

Because production possibilities and food consumption patterns differ widely from one part of Nigeria to another, the country has been divided into six ecological areas. The nutrients to be provided for the population in any area may be obtained by production within that area, by purchases of food from other areas, or by imports of food from outside Nigeria.

The quantities of nutrients to be made available within each area are determined by applying a scale of nutrient allowances, specified by age and sex, to the population data for each area. Because distribution of the population by age and sex differs from area to area, the proportions among the allowances for the several nutrients vary somewhat from one area to another.

It is assumed that production is carried on with the agricultural techniques generally in use on Nigerian farms in 1963, plus a few instances of modern techniques, namely, in tobacco production and what will be called the "commercial" production of maize, beef, pork, and chickens. For six other products the yield figures are high enough in one or more of the activities or areas involved to represent the use of improved practices. All told, 22 of the cropping activities may be regarded as reflecting the use of improved agricultural techniques.

A population of 61 million, essentially that of 1967, must be provided for. This is 9.5 percent above the 1963 population. It is assumed that agricultural manpower and the quantity of arable land available have increased from their 1963 levels in the same proportion. It also is assumed that yields per acre are the same as in 1963, except in the eastern moist forest area. There for some time the bush fallow period

has been shorter than in the other moist forest areas because of the increasing scarcity of land, so the model provides that any increase beyond 1963 levels in the quantity of arable land in use will be accompanied by a decrease in average yields per acre. If all the permissible 9.5 percent increase in arable land is put into use, this reduction in average yields will amount to 5 percent.

The quantity of bush pasture available is held at 1963 levels, except in the dry savanna, where the amount of the expansion in arable land is subtracted from the amount of bush pasture available in 1963. That the quantity of bush pasture in the dry savanna area is, in fact, limited, is made clear by the signs of overgrazing that have appeared there. Moreover, there has been a long-run expansion in the quantity of land under cultivation in that area at the expense of the quantity of bush pasture available.

It is assumed that the quantity of food obtained by gathering and collecting activities, or that grown in the compound, has not increased since 1963 in proportion to the population, but by only 6.33 percent.

The prices used in calculating the revenues obtainable from the sale of produce not to be used for food within Nigeria are representative of normal levels at or about 1963. They represent income earned for Nigeria rather than the return to the individual farmer. In most cases, this is the export value of the crop, suitably adjusted for transportation costs. (The marketing boards characteristically paid the farmer considerably less than the value of his produce to Nigeria.) We wish to determine what production is socially advantageous, so prices will be used that measure the social rather than the individual return, prices consistent with maximizing the contribution of agriculture to the income of Nigeria.

The technical coefficients used in the model represent average production practice, average soil, and average yield. If manpower, the land available, and the level of each production activity expand proportionately, one might suppose that these technical coefficients would remain reasonably representative at the new levels of output. If, however, some activities expand while others contract, a reallocation of resources among crops would be required which eventually might alter the technical coefficients. In order that no production activity should expand to the point at which our technical data no longer provide reasonably accurate summaries of production possibilities, each such activity has been limited to a maximum some 20 per-

cent greater than the 1963 level (except for a few of the newer activities, nonexistent in 1963).

In most areas, the expansion in manpower and arable land available allows each activity to expand by 9.5 percent without drawing resources from another activity. Further expansion must be at the expense of some other activity because of the limited quantities of land and labor available. Our solution will identify the activities that compete most effectively for limited quantities of land and/or labor. Except in the dry savanna, however, this competition for resources will not occur in the traditional animal industries. For them the only potentially limiting input requirement for which we have data is pasture. Outside the dry savanna, more of this is available than is used.

For different reasons, restrictions have been imposed upon the maximum levels of the consumption activities in the model. First, the consumption of alcoholic beverages is limited to the estimated per capita levels of 1963. (There is reason to doubt that a solution to Nigerian nutritional problems which depends upon large increases in the consumption of alcoholic beverages would represent a net gain either for Nigerian health or Nigerian productivity.) Second, for other foods, aggregate consumption is limited to four times the level of our estimate of customary aggregate consumption levels in 1963. This allows the computer to select those foods which are the most economical sources of nutrients and to indicate the composition of diets which use these foods in greater proportion than is now the case. At the same time, the computer is restrained from developing diets that differ so markedly from customary consumption patterns that they are of little use as practical guides to more nutritious or more economical patterns of consumption.

Our model, then, seeks to determine a set of production and consumption activities that will provide for specified levels of nutrient availability in each of six areas, where production activities generally are limited to some 120 percent of their 1963 levels and consumption activities cannot expand beyond four times their estimated 1963 levels. It seeks to provide these nutrients in such a way as to maximize the cash crop revenue that can be earned by the use of the resources left over after the nutrient allowances have been attained, whether by production or exchange.

Interpreting the Results

The solution that maximizes cash crop revenue will call for expanding certain production activities to their limit, for carrying on other activities at levels somewhat below the maxima allowed, and for reducing still other activities to zero. Every activity worth carrying on at a level greater than zero will be earning enough, directly or indirectly, to justify the use of the resources it requires for this activity rather than for some other. That is, every activity that is in the solution at a nonzero level earns enough to pay for the resources that it uses, at rates that represent what each of those resources could earn if devoted to some other activity permitted by the model. Activities not in the optimal solution will not produce as much value as the resources they employ could produce if they were used by some other activity.

If an activity is in the optimal solution at the maximum level permitted by the model, it often will be earning more than the resources it employs could earn if devoted to another activity. In such a case, the amount of the excess the activity earns above the opportunity-cost value of the resources it employs is a measure of the gain that would be attainable if this activity were allowed to expand beyond the maximum. That is, transferring resources from other activities to this one could increase the agricultural income of Nigeria. Beyond a certain point, of course, the gains from expanding any given activity will diminish. If the cost to the developmental agencies is no greater for promoting the expansion of one crop than for another, the greatest benefit to Nigeria will occur if developmental efforts are concentrated on those activities that produce the greatest surpluses in excess of the opportunity-cost values of the production resources they require.

2

The Model as a Whole

Although the Nigerian nutritional problem is moderate in comparison with that of many other countries, inadequate nutrition remains a serious problem. Deficiencies of protein, calories, and riboflavin are widespread. In all parts of the country, protein-calorie malnutrition frequently is observed among children between the ages of two and five. Protein deficiencies are most frequent in the rain forest zone.

This study asks the question: What set of agricultural activities in Nigeria will provide acceptable levels of all the principal nutrients in an economical way? One must look at all the major nutrients, partly because it is impossible to be truly economical if one looks at only a few of them, and partly because looking at only a part of the problem may lead to measures that themselves create new problems. For example, if the protein problem alone is dealt with, the calorie problem may be intensified. Some of the animal industries now being developed in Nigeria convert cereal grains into meat, but in a country where both calories and protein are deficient for many people, can one afford to use the cereal grains as feed for animals rather than food for humans?[1]

One must seek not only a solution for the nutritional problem as a whole, but also an economical solution. If our proposals are not eco-

nomical, the nutrients will not be available to the poor, yet the poor suffer most from malnutrition.

To find an economical solution, the nutritional problem must be viewed in relation to the whole pattern of Nigerian agriculture, in particular, in relation to the nonfood-producing portion. To be economical is to conserve resources, to produce nutrition in such a way that the resources available for the production of income in other forms than food will yield as much income as possible. Consequently, an optimal balance must be sought not only between the animal industries and the direct production of food crops, but also between production for consumption as food and production for export, between production for export and the importation of food from abroad, between local production and the transportation of food within Nigeria, and, at more detailed levels, between root crops and cereal crops and between one cereal and another, or one root crop and another.

An Interdisciplinary Approach

To solve such a problem requires the integrated use of information from several disciplines, each of which usually deals with only one aspect. The agriculturist is knowledgeable about input requirements and outputs per acre, but he usually is not equipped to choose among various crops in terms of their nutritional significance. The nutritionist knows that protein and riboflavin are scarce, and that certain foods are rich sources of these nutrients, but he cannot, in general, explain how increasing the production of protein-rich foods would affect the costs of other foods or the scarcity of other nutrients in the diet. The economist is aware of the effects of expanding export production on incomes earned in agriculture, but usually he cannot predict how expanded export production might alter the quantities of nutrients available within Nigeria.

The present model combines information about nutrient needs, the nutrient composition of foods, production requirements, import possibilities, transportation services, and the income potential of production for export or other nonfood purposes. It seeks to determine what combinations of production and exchange activities would (1) provide specified quantities of nutrients in each part of Nigeria and (2) do so in such a way as to maximize the income that can be earned while attaining these nutritional objectives.

Implicit is the possibility of conflict between the goal of producing specified quantities of nutrients and the goal of increasing agricultural income. The income earned by agriculture might be larger if the resources of agriculture were devoted exclusively to the production of crops providing the greatest farmer income, rather than to those crops that provide the nutrients most needed by the population. Nigerians may not be willing to pay as much for nutrition as they would for other products of the land or for imported goods obtained in exchange for exported crops. Conversely, it might be possible to provide more adequate supplies of food for Nigerians if land were diverted to food production at the expense of the production of income via production for export.

Priorities have been set regarding these alternatives. It is asserted that the first obligation of agriculture is to provide, directly or indirectly, by production or by trade, the food that Nigerians need. It is the second obligation of the Nigerian agricultural sector to make as large a contribution as possible to the nonfood income of the country. Therefore, the problem is to provide specified quantities of various nutrients in such a way as to maximize income from those agricultural resources that are not employed, directly or indirectly, in providing for Nigerians' food needs. This formulation enables recognition and measurement of the competition that exists between improved levels of nutritional well-being and increased income from the sale of agricultural produce not to be consumed as food within Nigeria.

This approach can predict what amount of income would need to be sacrificed if the levels of nutritional intake were to be increased by specified amounts. Conversely, the approach can be used to determine what sacrifices in nutritional intake would be necessary in order to increase the income earned by the application of agriculture to purposes other than the provision of food for Nigeria.

Problems

The construction of a model for the purpose of making calculations of this kind presents a number of problems. First, Nigerian agriculture is mainly for subsistence, although a large and significant sector is engaged in the production of crops for sale, primarily export crops. The major portion of the agricultural labor force is engaged in the production of food to be consumed by the family that produces it.

Much of the food consumed in Nigeria does not pass through markets at all. While a considerable volume passes through local markets, no prices are recorded for such transactions. Even for that food which passes through large urban markets the data are limited and of dubious quality.

The second problem is that the model must give adequate representation to the tremendous variety to be found within Nigeria. There are marked changes in crops and technology as one moves from the rain forest area of the south to the dry savanna in the north. Nutritional deficiencies differ in kind and degree from one part of the country to another, as do the quantities and kinds of foods available. Food preferences and taboos have regional patterns.

There is also a great variety of agricultural activities within each area and of foods in the diet. The absence of greater specialization in production results from a number of conditions that are not represented explicitly in the model. The model must recognize the importance of these conditions and guard against a solution that calls for excessive specialization as a consequence of the oversimplification that is inevitable if the model is to be kept to manageable size. It also is desirable to preserve a reasonable amount of variety in the diets represented in the solutions of the model.

A third problem is that of specifying the nutritional needs of the nation. Individual requirements depend on age, sex, weight, degree of physical activity, and the climatic situation in which people live. For the most part, the nutritionist can provide a reasonably sound estimate of the nutrients needed by an average person and another estimate of the amount by which these figures should be adjusted in order to take into account the considerable range of variation among individuals. It is not possible, however, to make a simple statement as to the amount of protein that an individual requires. In addition to such factors as these, the protein requirement depends upon the level of the caloric intake and the concentration and quality of the protein in the diet. The nutritional portion of the model must represent these relationships accurately, which previous computer diet models have failed to do.

Other difficulties arise when setting allowances for the nation. Income inequality means an unequal distribution of foods, although this problem may be less serious in a subsistence economy, where most food is raised by the family that consumes it, than in a market

economy. There is appreciable loss of some nutrients in cooking, but few data with which to estimate the quantitative magnitude. Disease and parasitic infestation increase nutritional needs significantly, but not equally for all nutrients. Again, quantitative information is scarce or nonexistent. The child under five has special food requirements because his digestive tract cannot process enough of the bulkier foods to provide the protein he needs. Last, there are strong seasonal patterns in the availability of certain foods and, at least in the subsistence farming areas, in the availability of food as a whole.

A fourth problem is that the diets contained in the solution of the model must be reasonably palatable by Nigerian standards. The foods must be familiar. The diets must contain reasonable amounts of certain foods for which there are strong preferences, even though the nutritional contributions of these foods are negligible. Finally, taboos must not be violated, and there must be a moderate degree of variety.

The fifth difficulty is that data from the existing pattern of production must be used to predict the consequences of changing that pattern. No matter how descriptive the data might be of present production relationships, if the acreage devoted to a particular crop in any section of the country were to change markedly, one would expect that input-output relationships from the new acreage would differ from current relationships. New problems of disease, weed, and pest control would appear, and technically inferior resources might have to be used. The model needs to show in what directions production patterns might be changed, but it should not call for such a startling departure from existing experience that the new production relationships would be markedly different from those represented by the data in the model.

A sixth problem is that, to a large extent, the data either are insufficient or unreliable. This is particularly true on the production side of the problem. Data on manpower requirements, land requirements, and yields do exist, but satisfactory farm management studies of input-output relationships are limited. In 1967 various data were available from the Federal Office of Statistics and the Ministry of Agriculture of the Northern Region, but they were not very reliable. Other data could be obtained from the advisors and production experts located in government offices, universities, and research stations scattered about the country, but production data were simply nonexistent for a number of important foods. Conspicuous in this category

are fruits, vegetables, and the numerous animal and insect foods that are gathered, trapped, or caught in the bush.

Even if the data were of the best quality, one still would be faced by the need to use a single figure as an average to represent a wide range of production conditions. The model, in short, assumes a degree of homogeneity among input-output relationships that simply does not exist. There is wide individual variability from farm to farm, but this is not expressed in the model.

A seventh problem arises from the extensive use of mixed or intercropping. There are undoubtedly good and sufficient reasons why intercropping should be practiced, but scientists who collect production data generally come from countries where intercropping essentially has disappeared. Consequently, the phenomenon tends to be neglected, and information about production relationships is especially scarce and unreliable.

The last problem is the significance of wastage in determining the amount of nutrition available to the people. Because storage, processing, and marketing facilities are relatively undeveloped, an extremely large fraction of the nutrients in the food at the time of harvest disappears by the time the crop has reached the hands of the woman preparing the meal. It is necessary that the model take account of this fact and be constructed in such a way as to allow a study of the consequences of improved processing or storage.

The Model

Work began as an experiment to determine whether a model could be built from existing data that would provide useful information and new insights into the nature of the Nigerian nutritional problem—to the extent that the nutritional situation depended upon production conditions. Inadequate as the data might be, they were the basis upon which decisions about agricultural policy were being made. Since the attack on the nutritional problem cannot wait until that unknown future time when scientists will be satisfied with the data available, it seemed wise to see whether an integration of existing information into a systematic model of the agricultural sector could provide insight into the nutritional implications of agricultural production decisions.

The model was designed to make the most effective use possible of the information available. As will be seen, several features protect against distortions that might be caused by data error. Moreover,

by examining the consequences of various changes in the data, the sensitivity of the solutions to certain types of data errors has been tested.

Perhaps the two most difficult problems to be solved in formulating the model were: (1) How does one minimize the economic cost of adequate nutrition in a country where representative market prices for food are not available (or in any country where a major portion of the food consumed is produced by subsistence agriculture)? (2) How does one design a model that would be simple enough to be readily computable, yet still would represent accurately the complicated relationships between protein quality, protein quantity, the concentration of protein in the diet, and the total level of food energy (calorie) consumption?

The latter problem is discussed in chapter 3. As for the former, it turns out that the solution of the problem of subsistence agriculture follows naturally from the definition of the provision of subsistence needs as a major purpose of the model.

A programming model was used that permits resources to be shifted between the production of nutrients and the production of income. The model requires the agricultural sector to produce the greatest value product attainable with given resources and techniques, subject to the proviso that specified nutritional goals be met first. The monetary value of the food required to meet these nutritional goals is not included in the value product to be maximized. Food is regarded as a source of nutrients rather than of revenue.

In linear form the basic model is as follows:

$\text{Max } z = \sum_{\text{all } j} r_j x_j$, where		Revenue	(1)
$x_j \geqq 0$ and			
$\sum_{\text{all } j} a_{ij} x_j \geqq 0,$	$i \epsilon F$	Foreign Exchange	(2a)
$\sum_{j \epsilon C} a_{ij} x_j \geqq b_i,$	$i \epsilon N$	Nutrition[2]	(2b)
$\sum_{j \epsilon C} a_{ij} x_j \geqq b_i,$	$i \epsilon H$	Habit	(2c)
$\sum_{\text{all } j} a_{ij} x_j \geqq 0,$	$i \epsilon A$	Commodity	(2d)
$\sum_{\text{all } j} a_{ij} x_j \leqq b_i,$	$i \epsilon R$	Resource Use	(2e)
$\sum_{\text{all } j} a_{ij} x_j \leqq b_i,$	$i \epsilon M$	Maximum Limit	(2f)

Let z be the net contribution of the agricultural sector to the nonfood income of Nigeria and r_j the monetary revenue or expense associated with one unit of activity x_j. (Only activities providing nonfood income can have $r_j > 0$.) Each a_{ij} is either the contribution of one unit of the jth activity to meeting the ith requirement or the amount of the ith resources or commodity used up by one unit of x_j. The b_i either are requirements to be fulfilled or limits on the quantities of resources used or the levels of activities engaged in.

Consumption activities ($j \epsilon C$) normally do not enter the objective function. That is, $r_j = 0$. They satisfy the restraints for nutrition ($i \epsilon N$) and habitual consumption ($i \epsilon H$). If, however, the activity represents the consumption of a food obtained from a nonagricultural sector or purchased from abroad, r_j will be negative. Rather than include a separate importing or purchasing activity in the model, the necessary payment for the food is reported as one of the elements of the consumption activity.

Any of the other activities may be components of z. Selling or exporting activities ($j \epsilon E$) provide income ($r > 0$); buying (transportation) activities ($j \epsilon B$) use up income ($r_j < 0$); production or processing activities ($j \epsilon P$) may have $r_j < 0$ if they involve expenditures for fertilizers or other production expenses, or $r_j > 0$ if some product of the activity is invariably sold for income (and not used for food within Nigeria).[3] Buying activities transfer food from one area within Nigeria to another. The transportation and marketing margins associated with buying and selling activities are not included as income for the agricultural sector.

The restraints, to be discussed later in more detail, can be classified into six groups. The subject of each set of restraints is indicated in the descriptive labels accompanying the model.

The Objective Function

The model requires Nigerian agriculture to provide two things: food and income. *Income* is defined as the net product of agriculture after nutrient goals have been met. The sector must provide the food needed for the nutrition of all Nigerians, whether they are in the agricultural or the nonagricultural sector. It may do so either by producing food directly or by producing products of value to exchange for food produced by other countries or by nonagricultural sectors within Nigeria (fisheries or the brewing industry). Food obtained from outside the Nigerian agricultural sector is regarded as

having been obtained in exchange for Nigerian agricultural products. The value-product thus "exchanged" for food is regarded as a part of the value of the food provided by the agricultural sector. It is not included in z, the value of the nonfood income that the sector produces. According to the definitions used in this model, *revenue* (income) does not include the value of the food that is consumed within Nigeria. What is consumed as food does not contribute to the revenue produced by agriculture.

Alternatively, it can be said that Nigerian agriculture provides two sorts of income, income in kind (in the form of food or the nutrients that food provides) and income in money. The former (some of which may have been obtained through exchange) provides for the subsistence needs of the country; the latter may be exchanged for whatever nonfood items are desired.

In sum, the model requires Nigerian agriculture, by production or exchange, to provide specified quantities of nutrients for the population and to do so in such a way as to maximize the revenue to be earned by agriculture from the sale of the remaining produce—that produce which is neither consumed as food within Nigeria nor exchanged for food from abroad or from another sector. That is, agricultural production activities contribute to the purposes of the model if they provide (1) nutrients or (2) revenue. No activity is credited with revenue because it provides nutrients for the inhabitants of Nigeria. Revenue is provided only by those activities that result in sales for export outside the country, or in sales for nonfood purposes within Nigeria. From the revenue thus earned are subtracted any payments made for foods obtained from abroad or from nonagricultural sectors within Nigeria.

With this approach there is no need for prices for foodstuffs consumed in Nigeria. Thus the model applies equally well to a subsistence economy, a market economy, or a mixture of the two. Foods are valued for the nutrients they contain, not as sources of income to Nigerian agriculture. Agriculture must provide these foods before it is free to provide income in the sense in which that term is used in this model. No effort is made to determine what valuation the market actually would place on the food provided for the people of Nigeria. The nutritional portion of the problem is regarded as a technological, not a market, problem.

It is not the purpose of this model to determine what food products it would be profitable for an individual farmer to produce, given the

alternative of production of revenue crops not to be used for food. If this were the case, market prices would be needed for at least that part of food production which is to be sold for use as food within Nigeria. Instead, the concern is with the worth of the various food products as means of meeting the nutritional goals set. The production pattern to be selected responds to the opportunity-cost values of the nutrients contained in the several foods, values not expected to be accurately reflected in actual market prices.

The model is essentially concerned with needs for subsistence—nutritional needs measured by physiological criteria. The criteria are not entirely physiological, for account has been taken of food preferences, customs, and taboos. The emphasis, however, is much more heavily upon physiological needs than upon satisfying the taste preferences of the people. The model does not attempt to provide the foods *desired* by Nigerians. In particular, it does not attempt to provide the types and varieties of foods desired by the more prosperous residents of the country. This could be done, but the resulting model would be less useful than this one for studying the crucial nutritional problem. The question is what changes in production conditions would make the especially nutritious foods more abundant and thereby make food prices more conducive to optimal nutrition for the low-income Nigerian, not what changes would lower prices for the Nigerian who already is able to buy a tasty and nourishing diet.

The Areas

In order to deal with the wide range of agricultural conditions and food customs found within the country, the model divides Nigeria into six areas. The basic model is applied in each area, except for the foreign exchange restriction, which applies to the country as a whole. Activities that ship goods from one area to another ($j \epsilon B$) link the several areas to each other.

The areas chosen possess reasonably homogeneous agricultural conditions. Type of farming data, of course, are not available for Nigeria, but fortunately we had access to the results of careful ecological studies of the country, so the areas are based upon ecological zones.[4]

The six areas are the dry savanna in the north; the intermediate savanna; three moist forest areas (the western, central, and eastern); and the forest-savanna mosaic, a transitional area that lies between the moist forest zone in the south and the intermediate savanna.[5]

The data were available by political subdivisions, not by ecological zones, so ecological zones were approximated by combining provinces and divisions of provinces in such a way as to obtain political boundaries that correspond as well as may be expected to the natural boundaries of the ecological zones on the map. See Figure 1, which compares the areas as we have defined them with the ecological zones as defined by R.W.J. Keay.[6] The general pattern consists of three horizontal bands proceeding from east to west across the country—the two savanna areas in the central and northern parts of Nigeria and the rain forest zone in the south.[7]

No area corresponds exactly to any one of the four principal political entities (regions) which existed at the end of 1963.[8] During

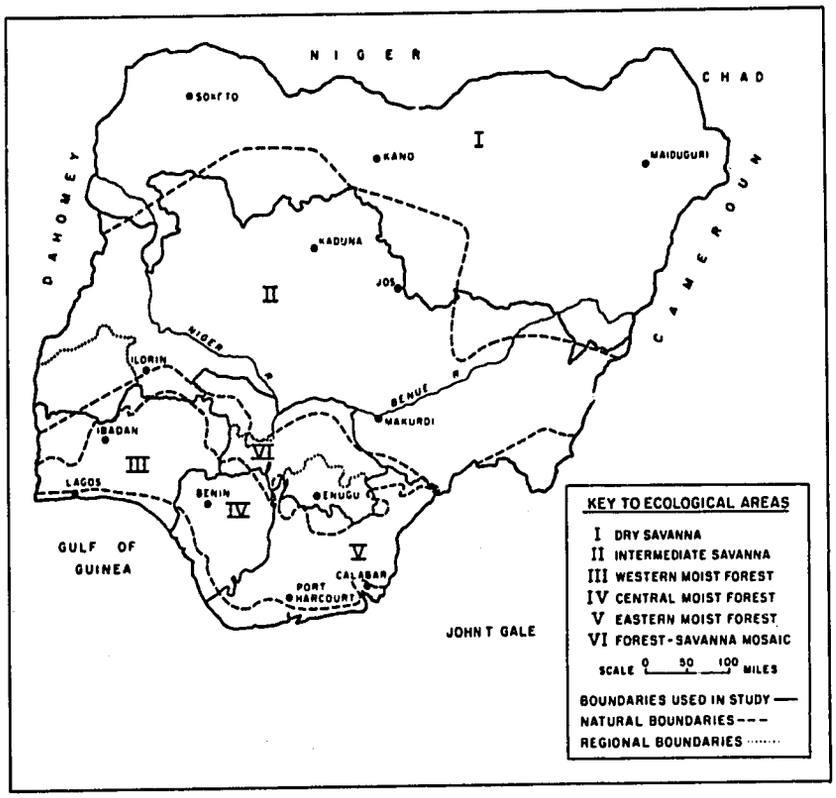


Figure 1. *Map of Ecological Areas*

the course of this study the four regions were replaced by twelve states.[9] As the data are based on the political subdivisions which existed prior to the formation of the new states, the map uses former regional boundaries rather than state boundaries as lines of reference.

Although type of farming data were unavailable, it has been gratifying that, as data were collected on agricultural patterns and input-output relationships, the areas have proved to be highly appropriate. In general, agricultural possibilities may be regarded as reasonably homogeneous within any one area.

Three of the areas consist of a partitioning of the moist forest zone. Thus distinction can be made between the cocoa producing areas of the western moist forest, the rubber producing areas of the central moist forest, and the oil palm producing areas of the eastern moist forest. Distinction also can be made among these three areas in terms of the customary foods consumed, the levels of urbanization and industrial activity, and the different ratios of land to labor (with their consequent effects upon the length of the rotation period and the technical coefficients of individual production activities).

Area VI, the forest-savanna mosaic, consists of eight provincial divisions that lie generally south of the confluence of the Benue and the Niger rivers. About two-thirds of the area lies east of the Niger, about one-third to the west. In this zone there is fairly rapid transition from the rain forest areas of the south, through the derived savanna that comprises this zone, to the intermediate savanna that comprises Area II. It is an area of diverse agricultural production, food habits, and population. A similar derived savanna area extends east and west across the country, but, except in Area VI, the corresponding ecological zone is relatively narrow from north to south. Therefore, the eastward and westward extensions of the forest-savanna mosaic are ignored, and that territory is combined with adjacent areas.

In each area the list of foods available for consumption consists of items commonly consumed by the inhabitants. The list of agricultural products differs in each area, as do the nutritional allowances to be provided. These latter depend upon the age and sex distribution of the population in the area, as reported by the 1963 census. The model is required to make physically available within each area sufficient food to provide the set of nutrient allowances specified for it.

This food can be made available either by production within the area itself, by transportation into this area from others within Nigeria,

or by transportation from outside the country. Consequently, the model contains transportation activities ($j \epsilon B$) which move agricultural produce from one area to another. These are termed *buying activities,* although from the standpoint of the producing area one might wish to regard them as selling activities.

While the model takes specific account of the cost of transportation for goods that move from area to area, it does not take into account transportation or marketing charges within a particular area. In other words, the model assumes that foods produced within the same area in which they are consumed are produced locally. Thus transportation and marketing costs may be ignored. Food produced within the area in which it is consumed is regarded as being produced under conditions of subsistence agriculture, that is, produced, for the most part, on the same farm or in the same village where it is being consumed. If a particular pattern of agricultural production is required in order to produce the nutrients allotted to a particular area, it is assumed that this pattern can be followed from east to west across the area.

The Activities

Figure 2 is a sketch of the model showing the relationships between the activities and the principal restraints in the model and how the several areas are connected to each other. Each row or column represents a group of rows or columns in the full model. An entry of x or —x at the intersection of a row and a column indicates that activities of that type are likely to have nonzero elements on rows corresponding to some of the restraints in that particular group. For example, the first column (Area I) shows that some consumption activities (using food purchased from abroad) provide nutrients by using up foreign exchange and spending revenue. The second column shows that other consumption activities provide nutrients by using up commodities drawn from within Area I. The latter activities do not use foreign exchange and have no direct effect on the objective function.

The model includes the following types of activities: consumption, which provides nutrients and uses up agricultural output ($j \epsilon C$); production (growing), which provides output and uses up resources[10]; processing, which converts agricultural output into other forms for export or for use[11]; buying, which transfers agricultural produce from one area to another ($j \epsilon B$); and exporting, which disposes of agricul-

Area		I					II					III					IV					V					VI				
	Activities	C	C	G	P	B	E	C	C	G	P	B	E	C	C	G	P	B	E	C	C	G	P	B	E	C	C	G	P	B	E
	Revenue	-x		x	-x	x	x	-x		x	-x	x	x	-x		x	-x	x	x	-x		x	-x	x	x	-x		x	-x	x	x
	Restraints Foreign exch.	-x		x		x		-x		x		x		-x		x		x		-x		x		x		-x		x		x	
I	Nutrient	x	x																												
	Commodity	-x	x	-x	x	-x					-x						-x						-x						-x		
	Resource		x																												
	Max. limit		x																												
II	Nutrient							x	x																						
	Commodity				-x			-x	x	-x	x	-x	x				-x						-x						-x		
	Resource								x																						
	Max limit								x																						
III	Nutrient													x	x																
	Commodity				-x						-x			-x	x	-x	x	-x	x				-x								
	Resource																		x												
	Max limit																		x												
IV	Nutrient																			x	x										
	Commodity																-x			-x	x	-x	x	-x	x				-x		
	Resource																				x										
	Max. limit																				x										
V	Nutrient																									x	x				
	Commodity																						-x			-x	x	-x	x	-x	
	Resource																							x							
	Max. limit																							x							
VI	Nutrient																									x	x				
	Commodity				-x						-x						-x						-x			-x	x	-x	x	-x	
	Resource																										x				
	Max. limit																										x				

Key: C = Consume ; G = Grow or Produce ; P = Process ; B = Buy ; E = Export.

Figure 2. *A Sketch of the Model*

tural output in exchange for revenue and foreign exchange ($j \epsilon E$). In all, there are 462 activities.

The foods consumed through consumption activities may be produced either within Nigeria or outside the country. If the former, they may come either from the agricultural or the nonagricultural sector. (Dried freshwater fish and European-style beer illustrate the latter category.) If from the agricultural sector of Nigeria, they may be produced under conditions that give rise to data concerning yields and input requirements, or they may be gathered, collected, grown in compounds, and so forth, with the result that data concerning production conditions are not available.

Foods in the latter category include insects, snails, native poultry (and their eggs), wild animals ("bush meat"), bananas, pineapples, citrus and other fruit, leaves, and many vegetables. Because these constitute an important component of the Nigerian diet, the model includes a consumption activity that provides the quantities of nutrients estimated to be obtained in each area from the consumption of gathered and collected foods. These quantities are specified when

setting up the model; they do not vary in response to the other conditions of the problem.

If a consumption activity uses up food produced within Nigeria, it does not directly add to or subtract from the revenue produced by the agricultural sector. Those consumption activities that represent the consumption of foods imported from outside the country (stockfish and sugar, for example) have negative revenue components. That is, they impose charges against the revenue provided by the agricultural sector. They also use up foreign exchange. The model requires the total amount of foreign exchange provided by the agricultural sector to be reduced by the amount of foreign exchange spent on imported foods.

Most production activities simply transform physical resources, land and labor, into other physical resources, commodities. Because peasant agriculture makes little or no use of inputs purchased from outside the agricultural sector, most such activities do not, in themselves, either provide revenue or incur monetary costs. (They have no revenue components.) Similarly, they have no direct effect upon the foreign exchange situation. Commodities become sources of revenue and foreign exchange when they are captured and disposed of by selling or export activities.

No export activity is needed if a crop has no other use than to be exported or sold to the nonagricultural sector. In such a case the revenue and foreign exchange items appear as components of the production process itself. A few activities, like the commercial production of maize or chickens, have negative revenue components because they require payments to the nonagricultural sector for such inputs as fertilizer or baby chicks.

Because intercropping is common throughout Nigeria, there are two sets of production activities for most of the field crops. One contains coefficients intended to describe the inputs of labor and outputs of products when only one crop is planted on a single piece of land. The other, for production under conditions of mixed cropping, contains a set of coefficients intended to describe yields and labor inputs when each crop shares the land surface with one or more others.

This model does not try to deal with the problem of mixed cropping in a sophisticated fashion, but its existence is recognized, both to take account of the fact that the number of crops sharing the surface of a single piece of land varies from area to area and to acknowledge the

existence of differences in input and yield coefficients when crops are grown as mixed rather than as sole crops.

Although tree crops commonly are grown with other crops, all tree crop data have been converted to a basis appropriate for production as the sole crop on the land.

Frequently, agricultural crops require processing before they are ready for use or sale. The model contains processing activities which convert bitter cassava root into gari, groundnuts (peanuts) into groundnut oil and cake, oil palm fruit into palm kernel and palm oil, and, in turn, palm kernel into kernel oil and cake. While producing palm wine actually is an alternative to the production of palm fruit, in the model it is treated as equivalent to a way of processing the fruit. The model contains two activities for the production of chicken feed. One represents the operation of the Pfizer Company and the other the operations of the appropriate Ministries of Agriculture. There also are activities that convert millet and sorghum (guinea corn) into millet beer and guinea corn beer. Producing European-style beer is regarded as an activity of the industrial sector.

Processing activities use up a commodity of one sort and produce a commodity of another sort. Thus they are likely to have negative entries on the commodity rows representing their raw materials and positive entries on the rows representing their outputs. Figure 2 shows only the negative entries. Processing activities do not necessarily have revenue or foreign exchange components, but they may have. The production of chicken feed, for example, involves payments to the nonagricultural sector for certain ingredients in the feed, and Pfizer feed production involves a foreign exchange payment. If one of the products of a processing activity has no use except sale for export, the revenue and foreign exchange received from this sale will appear as components of the processing activity column. No separate export activity is required in the model in this case.

In the eastern moist forest (Area V) there is one activity, listed with the processing activities, which represents the fact that extra arable land can be made available there only by reducing the fallow period. This in turn reduces yields per acre. The model assumes that the new land is equal to the old in quality, but that shortening the fallow period reduces yields on all land. The reduction in yield assumed would amount to 5 percent if all of the extra land allowed by the model (332,027 acres, or 9.5 percent of the harvested acreage in 1963) were to be put into cultivation.

Buying activities are included in order to transfer a commodity produced in one area into another area where it can be consumed or used. Such activities ordinarily involve a negative revenue component to cover the transportation costs. Transportation revenues are regarded as accruing to the nonagricultural sector. Consumption activities that use foods produced within Nigeria normally do not contain either positive or negative revenue components in themselves, but if a buying activity must operate in order to provide the food in the right area, the use of the buying activity imposes a negative revenue charge against the income from agriculture.

There are no importing activities as such in this model. If a production activity uses imported materials (such as fertilizer), their cost becomes a negative revenue component for that activity. If a consumption activity uses a food from outside Nigeria, the cost of that food becomes a negative revenue component for that activity. The foods the model regards as imported are wheat flour (and wheat in the eastern moist forest and the forest-savanna mosaic), stockfish (dried cod), and sugar. Dried freshwater fish and European-style beer are regarded as bought from the nonagricultural sector of Nigeria. However, it is likely that much of the fish comes from outside the country.

The formal structure of the model assumes no imports of foods other than those mentioned here. There is, of course, local trade in foods across the borders of the country. Perhaps most important is a net importation of cattle (perhaps 200,000 animals per year) from neighboring countries.[12]

Export activities take commodities from the areas in which they are produced and ship them out of the country. The entries in the model represent the revenue obtained and the foreign exchange portion of that revenue. The export activities that appear explicitly in the model are those for groundnut seed, groundnut cake, soybean, groundnut oil, red palm oil, and palm kernel cake. The export activities for hides and skins usually have been consolidated with the consumption activities that determine the amount and location of animal slaughter. The export or sale activities for cotton, tobacco, cocoa, rubber, palm kernel oil, and sometimes palm kernel have been consolidated with the appropriate production or processing activities.

The revenue figures for exported goods represent values free on board ship. They represent the social returns from exports. For the major export crops they do not represent the value to the farmer who

produces them because the marketing boards often retain a large share of the export price for their own purposes. The prices used here are consistent with maximizing the contribution of agriculture to Nigeria, but the resultant production pattern would not be consistent with profit maximization for the individual farmer who does not receive the full value of the product. Our model is intended to determine a socially advantageous pattern of production, but where there are interferences with the free pricing system individuals may find it unwise to form their own activities into a socially advantageous pattern.

The Restraints

From these 462 activities, the problem is to choose a smaller set that will provide the nutrients called for in each of the areas and provide them in such a way that the revenue producing activities that can be supported by the remaining resources will yield the maximum revenue possible under the conditions of the problem. The size of this maximum, of course, depends upon the restraints imposed upon the selection of these activities.

Those restraints fall into five main groups: (1) nutritional restraints ($i \epsilon N$); (2) conventional or habit restraints ($i \epsilon H$)—not shown in Figure 2; (3) commodity balance restraints ($i \epsilon A$); (4) resource use limits ($i \epsilon R$); and (5) maximum limits upon the levels of individual activities ($i \epsilon M$).

Each area is subject to its own set of restraints, and each of the five types of restraints applies in each area. In addition, there is one restraint upon the use of foreign exchange ($i \epsilon F$) which requires that agriculture shall not use up more foreign exchange than it provides for the economy.

The foreign exchange restriction has been inserted primarily in order to have a record of the net contribution of agriculture to the foreign exchange supply of the economy. It is not likely to be limiting in this problem, for it seems unlikely that it would be efficient for the agricultural sector to use more foreign exchange in the purchase of imported food, feed, and fertilizer than it is able to provide through the sale of its export crops. However, the possibility must not be ruled out entirely. It is conceivable that agriculture might be unable to produce enough foreign exchange to pay for the imported foods it would be economical to purchase, but it seems more likely that what would

limit the use of foreign foods would be the opportunity to produce domestic foods more cheaply. The foreign exchange restriction applies to the country as a whole, not to each of the individual areas.

The nutritional restraints ($i \epsilon N$) require that the model provide in each area appropriate quantities of each of nine nutrient elements and five amino acids or groups of acids. They also ensure that the protein be of satisfactory quality. The quantities to be provided were determined by applying a scale of per capita allowances, classified by age and sex, to the population figures. Chapter 3 explains the nutritional model in detail.

The conventional restraints ($i \epsilon H$) take into account food habits and preferences. In principle the diet can be made as palatable and as representative of customary food habits as one likes simply by increasing the number of restrictions in this conventional category. In this model such restrictions are used for three purposes: (1) to require the consumption of beer or palm wine at average per capita levels in the appropriate areas; (2) to require a minimum level of kola nut consumption in the savanna areas and the western moist forest; and (3) to prevent extraordinary dependence on the consumption of the most economical foods. As a general rule, the model limits the per capita consumption of any food in a given area to a maximum of four times our estimate of actual per capita consumption in that area in 1963.

The commodity constraints ($i \epsilon A$) require that the aggregate use of any commodity in an area shall be no more than the area can provide by production, purchase from other areas, or importation from abroad. At this point account is taken of losses due to wastage (spoilage, insect damage, spillage, and so forth). The yield figures used in the model report the quantities produced at harvest time, at the farm. Losses in storage and handling range as high as 40 or 45 percent and must not be ignored. In addition, the edible portion of many food products is only a fraction of the weight of the commodity which is received or purchased by the housewife.

These facts are built into the model in two ways. The first involves the consumption activity. A typical consumption activity reports the nutrients provided by some multiple of 10 kg. (22 lb.) of the edible portion of the food. If the edible portion is 100 percent and there is no wastage between the point of production or processing and the receipt of the commodity by the housewife, the consumption of 22

lbs. of the commodity is recorded on the commodity row as using up 22 lbs. of the amount produced.

If the edible portion is two-thirds and there is again no wastage between the point of production and the receipt of the commodity by the housewife, the consumption of 22 lbs. of the commodity uses up 33 lbs. of the amount produced. If the edible portion is two-thirds and the wastage between the farm and the household is 10 percent, the consumption activity uses up 36.7 lbs. for every 22 lbs. of edible portion consumed. That is, $z = 22 \div [(1-w_1)(1-w_2)]$, where z is the entry in the commodity row, w_1 is the fractional wastage between the weight as purchased and the edible portion, and w_2 is the fractional wastage between harvest and household.

The model does not take into account seasonal variation in the amount of wastage between harvest and household. Storage losses increase the longer a crop is held beyond harvest, but a single figure is used here to represent the whole year.[13] Furthermore, no account is taken of the fact that storage losses for some commodities may affect some nutrients more than others. (For example, weevils seem to prefer the germ of the cowpea, the portion that is richest in protein and the B-vitamins.)

The second way in which wastage enters the model involves the buying activities. For simplicity, most of these are written as though the same number of pounds is delivered in the buying area as is purchased at the farm. Of course, this is untrue. Some of the wastage previously discussed occurs during the passage through transportation and marketing channels. Cattle lose weight during transportation, especially when they travel on foot. Cowpeas lose weight as the weevils eat them, spillage occurs, and so forth.

However, even when it is necessary to harvest 36.7 lbs. in order to provide 22 lbs. of edible portion for consumption, it will not be necessary to transport the full 36.7 lbs. if part of the wastage occurs before shipment. Therefore, individual charges for transportation have been adjusted downward in accordance with the proportion of the total harvest-to-household wastage that occurs before shipment. This recognizes that when the model says 36.7 lbs. of the harvest is brought from another area and used up by a consumption activity, the actual amount transported will be somewhat less, so the total charge for its transportation must be reduced proportionately.

Some types of losses of nutrient content are ignored in the model.

The loss or destruction of nutrients during cooking and the waste of food cooked but not eaten—"plate waste"—are ignored. The former, at least, contributes significantly to the nutritional problem.

The restrictions on resource use ($i \epsilon R$) are very few in number, largely because the traditional production pattern uses a limited number of resources. In this model the field crops are regarded as requiring only labor and arable land. Labor is divided into labor available in May and June (in most of the country the months of heaviest labor requirements) and labor available during the remainder of the year. Commercial beef production makes use of arable land, but the land used for the other animal industries (bush pasture) is not regarded in the model as being currently available for field crop production. Except for the commercial production of poultry products and beef, the labor required for the animal industries is regarded as noncompetitive with the labor available for other agricultural enterprises.

It is assumed that the agricultural labor force grew in the same proportion as the total population between 1963 and 1967 (by 9.5 percent). Thus the quantity of labor available in May and June of 1967 was estimated for each area as 1.095 times the quantity of labor required (according to our estimates) at the 1963 levels of the various activities. The labor available for the rest of the year was estimated by multiplying the May-June quantity by a factor that converts from a two-month to a ten-month period and adjusts for differences between the May-June period and the rest of the year in the length of the working day and the number of holidays taken.

In effect, it has been assumed that the quantity of labor available for agriculture, over this short period of time, will not be affected appreciably by changes in rural-urban wage-price ratios. Given sufficient time, the proportion of the population which engages in agriculture undoubtedly does respond to changes in the relative urban-rural real wage ratio, the availability of urban employment, and other factors. A more elaborate model than this might allow the supply of farm labor to be dependent upon these and other variables, but such extension of the present model would divert attention from the principal task, namely, determining how given quantities of resources can be used with maximum nutritional efficiency.

Except in the eastern moist forest, the quantity of arable land available in each area likewise was estimated as 1.095 times the

quantity of land required (according to the model) to carry on agricultural activities at their 1963 levels.[14] In the eastern moist forest, population pressure has reduced the fallow period and lowered yields below the levels obtained in other rain forest areas. Therefore, the quantity of land available for use has been set equal to our estimate of the quantity cultivated in 1963. The model allows for expansion of the land in use in this area by 9.5 percent (322,027 acres), but at the expense of a reduction in yields on all land in use in the area. This reduction would be as large as 5 percent if all of the 322,027 acres were brought into use.

The quantity of bush pasture in Area I, the dry savanna, was set equal to our estimate of the quantity used at the 1963 levels of the animal industries less the amount of the increase in arable land in Area I between 1963 and 1967. (There is evidence that in that area the quantity of bush pasture available is fully used; indeed, some overgrazing appears to have occurred.) In the other areas the quantities of bush pasture available were set at various multiples of the quantities that were estimated to be in use at 1963 levels of activity, for in these areas there are considerable amounts of unused bush pasture.

The maximum limit restraints ($i \epsilon M$) generally prevent the solution from containing production activities at levels more than 20 percent above 1963 levels.[15] One may assume that resources of the same quality as those used at 1963 levels normally would be available if output expansions did not exceed 20 percent,[16] so the coefficients used in the model would remain reasonably accurate at the new levels of output. One would not, however, want to make this assumption if acreage expanded much more than 20 percent. Likewise, up to 20 percent the complications resulting from new problems of disease or insect infestation are not likely to be serious. Moreover, variations in output of this degree would be possible without requiring farmers to grow unfamiliar crops or use unfamiliar techniques.

In general, the model allows each production activity to expand some 20 percent above our estimate of its level for 1963. Available arable land and manpower, however, are only 9.5 percent above 1963 levels. Under these conditions, crop activities that expand to their maximum limits can do so only by forcing other activities to contract. It will be the activities with superior productivity that will survive if there is not enough land and labor for all.

In this model, however, the traditional animal industries do not compete against other activities for either arable land or labor.[17] Except in Area I, there is not even any competition among themselves in this model, for the quantity of bush pasture available outside Area I is more than enough to allow each of the traditional animal activities to expand to its limit. In the dry savanna, however, there is competition for land among the three traditional animal industries.

Note that the conventional restraints on consumption ($i \epsilon H$) allow much more variation from customary patterns than do the maximum limits on specific production activities. The consumption of a particular food may increase as much as 300 percent in any one area, while production is limited to a 20 percent increase in any area. Thus the consumption limits cannot, in general, confine production activities to the customary pattern. When a food is unusually efficient in nutritional terms, two things happen: (1) Its output tends to increase to its maximum level, and (2) at that level the activity provides nutrients worth considerably more than the resources devoted to their production.

Several features of the model protect against adverse consequences from the data deficiencies that must be expected in those countries where malnutrition is most likely to be serious. For example, eliminating the need for market prices for food produced within the agricultural sector frees one from concern about lacking representative food prices when food is largely homegrown.

Acreage limits on individual crops, the limits on total resources available, and limits on aggregate consumption levels also restrict the potential effects of data errors. An overestimate of yields or an underestimate of input requirements for a particular crop cannot have major effects upon the solution as a whole because no individual crop can expand more than 20 percent above the 1963 level in a single area. That is, data errors cannot cause an individual crop to dominate a solution or have major effects on its general characteristics. If the data understate labor requirements in proportion to land, the limit on the total quantity of land that can be used in each area keeps our estimate of total production within bounds. Conversely, if the data understate land requirements in proportion to labor, the limited quantity of total labor available keeps total output figures in line. If both land and labor requirements are understated (or overstated) by the data, the quantities of land and labor available are under- or

overstated in the same proportion. (The quantities of land and of labor available in 1963 were estimated by calculating the quantities that would be used, given the coefficients included in the model, to produce the quantities of product harvested in that year.) Last, the restrictions that prevent expanding the per capita consumption of food by more than 300 percent above the 1963 level provide some protection against errors that distort yields or input requirements among areas, or errors in the nutrient composition data, or in our estimates of wastage. No area in which a certain food traditionally has been a minor consumption item can suddenly become a major customer for food brought in from another area. To be sure, a 300 percent expansion in the consumption of a major item might have considerable effect upon the solution as a whole, but such an expansion almost certainly would be prevented by the 20 percent limit on production expansion in any one producing area.

The model allows production and consumption patterns to change enough to show in which directions 1963 patterns would need to alter in order to improve the efficiency of nutrient production. It limits the amount of change in recognition of the fact that many social and environmental barriers exist that are likely to make a highly disruptive reorganization of the structure of production and consumption certain to fail, although there is not enough information about these factors to permit their use in the model in detail.

The Data

Data on the nutritional composition of foods came primarily from B. S. Platt, M. L. Orr and B. K. Watt, and the FAO compilation, *Amino Acid Content of Foods.*[18] Our calculations assume that the nutrient quantities listed in the food composition tables are fully available to the body, although this is not true for all nutrients. The major source of data on food consumption and an important source of data on aggregate output levels was the FAO publication, *Agricultural Development in Nigeria, 1965–1980.*[19] Ephraim O. Idusogie, our nutritionist, was principally responsible for that part of the work which dealt with nutrient allowances, the nutrient composition of foods, food consumption, and nutrient levels.

Data on agricultural yields, acreages, labor requirements, and revenue coefficients were the primary responsibility of John Whitney, agricultural economist. When work began in fall 1966, the major pub-

lished sources available were the FAO report cited above and the Nigerian *Rural Economic Survey* reports for 1963–1964 and 1964–1965.[20] The former contained estimates of food consumption and production for 1963–1964. As the base period for the study 1963 was chosen because it was the most recent year for which data were available, and the years 1963 and 1964 were relatively free from the political disturbances that began soon thereafter. The 1963 census also provided the necessary population statistics.

Mr. Whitney drew heavily on the *Rural Economic Survey,* but he also made extensive use of the FAO's *Agricultural Development in Nigeria,* of *An Agricultural Notebook,*[21] and of information from many other sources, including experimental farms and the various advisors and production experts scattered in government offices, research stations, and universities throughout the country. He proceeded with as much caution as possible, comparing estimates from one source with those from others and supplementing material from statistical sources with the judgments of informed agricultural production specialists.

The problem was to make the best use possible of the data that were available. By 1963 Nigeria had been developing and improving its system of sample surveys for a number of years, but had not yet surmounted all problems. Consequently, error margins are large in some of the data. Nonetheless, in developing the agricultural production estimates presented in *Agricultural Development in Nigeria,* the FAO decided to use the sample surveys carried out between the years 1957–1958 and 1959–1960, with appropriate adjustments for population growth. The resultant production estimates led to figures of per capita protein and calorie intake that agreed fairly well with independent medical observations concerning the nutritional status of the people in the different regions.[22] Our data are based on the more recent surveys of 1963–1964 and 1964–1965,[23] somewhat modified and adjusted as seemed indicated by the other information available. The *Survey* data were particularly unreliable for estimates of trends, since an under-reporting bias existed that shifted through time. In this study the *Survey* was not used to measure trends, however, but to provide estimates of relative crop acreages and related data within a single year. We made certain that the product of each yield estimate and acreage figure was consistent with the data available on the total output of the crop. After an early version of the model was completed,

it was run to obtain calculated outputs of crops and nutrients for the 1963 production pattern, and these were checked for general consistency with other estimates of crop production levels and aggregate nutrient intake. Further adjustments in the data were made when informed observers of the Nigerian economy felt they were out of line. Table 1 gives the yield figures used in the model being discussed here.

Data on labor requirements were based primarily on *An Agricultural Notebook*,[24] adjusted to take account of regional differences in rainfall and soil type plus other relevant considerations. Considerable labor requirement information was also available from agricultural production specialists and from university and experiment station research. The division of the annual labor requirements into those for May and June and those for the remainder of the year was made by Mr. Whitney, based on information concerning labor requirements for specific operations (such as weeding) and knowledge concerning the time when those operations were performed. Estimates of May-June labor requirements also are shown in Table 1. (The requirements for the rest of the year never played a significant role in the calculations.)

Transportation cost estimates usually were based on figures obtained by Mr. Whitney from Armel's Transport Services Limited. They were adjusted downward in some cases where local carriers charged lower rates.

The model uses 1963 as a base year. Data are intended to be descriptive of the acreages harvested and the technical relationships, price patterns, and transportation patterns prevailing at that time, when political conditions in Nigeria were still comparatively normal.

The data are not as dependable as one might desire, but they cannot be much worse (or much better) than those used by anyone else who has been concerned with Nigeria as a whole. Those countries where immediate attention is required to find means for the efficient production of adequate nutrition are also those where data are either poor or lacking altogether. Decisions must be made concerning nutritional policy, based on whatever information is available. The full implications of that information are not always known, however, especially when nutritionists do not talk to agriculturists, and development planners talk to neither. Our problem was to see whether contructing a systematic model for the agricultural sector could bring out the implications of such information as did exist concerning the condi-

Table 1. ***Yield and May-June Labor Requirements per Acre***

CROP		AREA											
		I Dry savanna		*II Intermediate savanna*		*III Western moist forest*		*IV Central moist forest*		*V Eastern moist forest*		*VI Forest-savanna mosaic*	
		Yield (pounds)	*Labor (man-days)*	*Yield (pounds)*	*Labor (man-days)*	*Yield (pounds)*	*Labor (man-days)*	*Yield (pounds)*	*Labor (man-days)*	*Yield (pounds)*	*Labor (man-days)*	*Yield (pounds)*	*Labor (man-days)*
Maize Bush	Sole	1,200	15	1,300	15	850	6	1,870	6	n.a.		1,240	6
	Mixed	1,050	12	1,250	12	800	4	810	4	440	4	560	4
Commercial	Sole	n.a.		n.a.		1,700	10	n.a.		1,800	5	1,400	5
Millet	Sole	580	20	600	20	n.a.		n.a.		n.a.		n.a.	
	Mixed	540	15	540	15	n.a.		n.a.		n.a.		n.a.	
Rice	Sole	600	15	640	15	n.a.		940	40	1,200	40	1,040	40
	Mixed	400	12	400	12	n.a.		1,310	20	800	20	400	20
Sorghum	Sole	860	20	1,330	20	n.a.		n.a.		n.a.		n.a.	
	Mixed	590	17	640	17	n.a.		n.a.		n.a.		n.a.	
Wheat	Sole	1,500	24	n.a.		n.a.		n.a.		n.a.		n.a.	
Cassava[a] Bitter	Sole	n.a.		3,150	12.5	4,720	15	5,260	15	5,760	15	3,530	15
	Mixed	n.a.		2,000	10	3,870	10	5,270	10	2,000	10	1,810	10

Table 1—*Continued*

CROP		AREA											
		I Dry savanna		*II Intermediate savanna*		*III Western moist forest*		*IV Central moist forest*		*V Eastern moist forest*		*VI Forest-savanna mosaic*	
		Yield (pounds)	*Labor (man-days)*	*Yield (pounds)*	*Labor (man-days)*	*Yield (pounds)*	*Labor (man-days)*	*Yield (pounds)*	*Labor (man-days)*	*Yield (pounds)*	*Labor (man-days)*	*Yield (pounds)*	*Labor (man-days)*
Cassava[a]													
Sweet	Sole	2,100	12.5	2,200	12.5	n.a.		n.a.		n.a.		n.a.	
	Mixed	1,450	10	1,450	10	n.a.		n.a.		n.a.		n.a.	
Potato													
Irish	Sole	4,000	27	4,500	30	n.a.		n.a.		n.a.		n.a.	
	Mixed	1,500	20	1,500	20	n.a.		n.a.		n.a.		n.a.	
Sweet	Sole	7,000	24	6,000	24	n.a.		n.a.		n.a.		n.a.	
	Mixed	3,800	20	4,200	20	n.a.		n.a.		n.a.		n.a.	
Cocoyam	Sole	n.a.		n.a.		5,750	30	4,620	30	4,300	30	n.a.	
	Mixed	n.a.		n.a.		2,500	20	4,200	20	3,390	20	n.a.	
Yam	Sole	5,990	36	7,520	40	5,860	54	7,190	54	5,200	54	5,630	54
	Mixed	7,000	24	7,180	28	7,000	40	4,750	40	4,620	40	4,790	40
Cowpea	Sole	800	20	400	20	n.a.		n.a.		n.a.		570	20
	Mixed	140	12	160	12	n.a.		n.a.		180	10	90	10
Groundnut	Sole	600	20	600	20	n.a.		n.a.		n.a.		610	24
	Mixed	570	18	600	18	n.a.		n.a.		n.a.		460	22

Table 1—*Continued*

CROP		AREA											
		I Dry savanna		*II Intermediate savanna*		*III Western moist forest*		*IV Central moist forest*		*V Eastern moist forest*		*VI Forest-savanna mosaic*	
		Yield (pounds)	*Labor (man-days)*	*Yield (pounds)*	*Labor (man-days)*	*Yield (pounds)*	*Labor (man-days)*	*Yield (pounds)*	*Labor (man-days)*	*Yield (pounds)*	*Labor (man-days)*	*Yield (pounds)*	*Labor (man-days)*
Soya bean	Sole	n.a.		n.a.		n.a.		n.a.		n.a.		2,100	20
Melon seed	Sole	540	4	480	4	340	5	430	5	200	5	420	5
	Mixed	400	1	510	1	250	5	350	4	100	4	330	4
Okra	Sole	n.a.		n.a.		n.a.		n.a.		n.a.		200	5
	Mixed	n.a.		n.a.		n.a.		n.a.		100	3	100	3
Oil palm	Sole	n.a.		n.a.		2,200	4	2,200	4	2,200	4	2,200	4
Cotton	Sole	290	20	370	20	n.a.		n.a.		n.a.		n.a.	
	Mixed	200	18	260	18	n.a.		n.a.		n.a.		220	22
Tobacco	Sole	514	4	516	20	n.a.		n.a.		n.a.		n.a.	
Cocoa	Sole	n.a.		n.a.		400	10	225	3	n.a.		n.a.	
Kola nut	Sole	n.a.		n.a.		440	10	n.a.		n.a.		n.a.	
Rubber	Sole	n.a.		n.a.		300	60	300	60	300	60	n.a.	

NOTE: Information given is based on the techniques being used in 1963 and 1964.

n.a.: The activity is not present in the model for this area.

[a] Half of the acre being planted in the current year; half, planted the year before, being harvested in the current year.

tions of production, consumption, and nutrition. The best evidence that the data were sufficiently accurate to be useful is the fact that the results are consistent with what is known about the nutritional situation in Nigeria from quite independent sources (medical observations, biochemical analysis, and nutritional intake studies).[25]

We wish to provide nutrients for a population of 61 million, a 9.5 percent increase from the 55.67 million reported by the 1963 census. This figure probably was reached by 1967.[26] Table 2 gives the distribution of this population among the six areas used in this study.

Table 2. *Population Estimates for Nigeria, November 1967, in Thousands*

Area	*Population*
Dry Savanna (I)	21,375
Intermediate Savanna (II)	10,386
Western Moist Forest (III)	11,000
Central Moist Forest (IV)	2,407
Eastern Moist Forest (V)	11,528
Forest-Savanna Mosaic (VI)	4,263
Total	60,959

The levels of nutrient availability specified are indicated in Table 3. This table presents average daily per capita allowances for Nigeria as a whole. The allowances in any particular area will vary somewhat from this average because of differences among areas in the age and sex distribution of the population. (Even differences in the proportion of urban to rural population affect the per capita figures, since the urban population has a different age and sex distribution than that of the rural areas.)[27]

Conventional practice was followed in developing the allowances: Aggregate figures were based upon the allowances for individuals

Table 3. *Daily per Capita Nutrient Allowances for Nigeria as a Whole*

Nutrient	*Daily per capita allowance*	
Calories	2266.	k cal
Reference protein	34.4	g
Calcium	388.7	mg
Iron	13.3	mg
Vitamin A	4433.	IU
Thiamin	1.135	mg
Riboflavin	1.02	mg
Nicotinamide	11.47	mg
Ascorbic acid	27.49	mg

without attempting to make adjustments for inequalities in the distribution of food among the population. It follows that attaining these aggregate levels would not of itself be enough to eliminate malnutrition within Nigeria. Although the necessary quantities of the nutrients would be available, malnutrition would persist as long as some people received more than they needed of the scarce nutrients, while others received less.

Customary practice also has been followed in not allowing for the loss of nutrients in cooking or the extra nutritional needs that arise as a result of disease or parasitic infestations. Allowance has not been made for the special food needs of children under five,[28] nor is account taken of the differences in the seasonal availability (storability) of foods. The diets obtained in the solutions represent annual consumption rates.

Given the number of problems not resolved in establishing these allowances, it must be agreed that the goals set for Nigerian agriculture are modest. Even so, the goals for two nutrients are very near the maximum levels attainable under the conditions of the model. The daily calcium allowance (389 mg per capita) is 91 percent of the maximum (427 mg) attainable at the present riboflavin level, and the riboflavin allowance (1.02 mg) is 88 percent of the maximum (1.16 mg), given the present level for calcium. While both allowances would be regarded as acceptable by many nutritionists, others would prefer higher levels; opinion differs widely. The evidence available has not established a consensus in favor of a narrowly defined range of allowances for either of these nutrients.

When developing the first nutritional model for a country suffering from malnutrition, there is always the chance that the nutritional goals specified in the model will turn out to be unattainable. Therefore, it seems better, until something is known about a nation's nutritional capacity, to set modest goals that have a reasonable chance of being realized. Not much can be learned from an infeasible solution. Goals set so high that they cannot be achieved may result in discouragement and resignation rather than in efforts to improve the situation. Attainable goals, on the other hand, enable one to find out how to move toward doing what can be done. The allowances set in this model provide this kind of information.[29]

Summary

This volume presents the first nutritional model constructed for the whole of an agricultural sector.[30] It regards that sector as a system for the production of nutrients and income. The model can determine what production patterns would be efficient for the attainment of specified nutrient goals and identify those foods, crops, and methods that are nutritionally efficient.

The model is designed to make use of the data available in the best way possible. It uses an improved formulation of the protein requirements problem (to be explained in detail in chapter 3) and takes account of social and environmental barriers to change.

One objective has been to design a model that can be revised as improved data become available. Frequent revisions should be expected, partly to take advantage of improvements in the data, and partly to keep the model responsive to substantive changes in the quantitative relationships involved. In a country as dynamic as Nigeria those changes are likely to be large.

The results obtained from a single application of the model are significant, but much more important is the existence of a structure which, first, can be kept current and, second, extended to provide detail about aspects of the system that have been greatly compressed in this version. Changes in agricultural techniques, developments in the processing and transportation sectors, changes in the size and distribution of the population, and alterations in the prices of revenue commodities will occur. With the basic model already at hand, the repercussions of such changes throughout the agricultural economy can be examined in an efficient manner.

Appendix

Two earlier models used excessively high estimates of the 1963 output levels of the traditional animal industries, and a low estimate of milk output from the nomadic cattle herds.[31] The estimates of meat output levels were much higher than most authorities gave. Our maximum limits for the traditional animal industries allowed an annual slaughter of 2,860 million pounds,[32] while the total of the FAO slaughter estimates for cattle, goats, and sheep for 1959–1962 was only 691 million pounds.[33]

In the present model output estimates for the traditional animal industries have been adjusted, and estimates of 1963 slaughter levels for bush cattle, goats, and sheep (for Nigeria as a whole) agree with the FAO figures for all cattle, goats, and sheep (409, 198, and 84 million pounds, respectively).[34] The maximum limits on output in the present model permit an aggregate slaughter level from the traditional animal industries of 833 million pounds, only 29 percent of the level allowed in the previous models. (The estimate of the amount of bush pasture available for the nomadic herds also has been reduced in this model to preserve consistency with the lower estimate of the animal population and a higher estimate of pasture requirements per carcass of output.)

The earlier models also seriously underestimated the milk output of the nomadic cattle by comparison with the FAO estimate of net milk available for consumption—1,266 million pounds (including camel milk).[35] The present model allows the milk available for consumption from Area I herds to be as much as 1,512 million pounds.

3

The Nutritional Model

The nutritional composition of a satisfactory diet usually is described by listing the quantities of the principal nutritional elements that the diet should contain. Many nutrients known to be essential to good nutrition are omitted from such a listing, either because the quantities needed are not accurately known or because a diet that is adequate with respect to some ten or so principal nutrients, if it is sufficiently varied, usually is adequate with respect to the remainder. The nutritional allowances usually are specified as minimum quantities; excesses of individual nutrients ordinarily are not harmful unless they are unusually large. The caloric allowance is an exception to which we shall return later.

In some cases the quantity of a nutrient needed cannot be specified without knowing the quantity of some other nutrient or nutrients. The B-vitamins and protein are important examples. This problem can be handled either by stating some of the allowances in ratio form or by requiring that certain allowances be satisfied exactly so that the quantity in the diet becomes a known constant.

The principal problem yet unsolved is how to handle the protein allowance. It is particularly difficult to state, in part because a protein is not a single, well-defined substance, but simply any member of a group of related substances with widely varying composition. How

much protein is needed depends upon the composition or "quality" of the protein. When protein *quality* becomes a variable, the *quantity* of protein needed also becomes variable.

To meet man's protein needs in the most economical way, it is necessary to choose the most economical *combination* of quality and quantity. What this combination will be depends upon the relative prices of foods or, more fundamentally, upon the agricultural production pattern which exists in the location for which the diet is being developed.

The quantity of food protein required varies for other reasons as well. How much is required depends not only upon the quality of the protein, but also upon the dietary circumstances under which it is consumed, that is, the total number of calories provided by the diet and the proportion of those calories that the protein itself provides.[1] If the model is simplified by predetermining the amino acid composition or the "protein calories percent,"[2] one risks forcing inefficiencies upon the solution since the most economical combination of quality and quantity, or the most economical protein calories percent, cannot be determined before solving the problem.

The formulation of the protein problem set forth here is based upon the work of D. S. Miller and P. R. Payne (cited below), plus the 1965 *Protein Requirements: Report of a Joint FAO/WHO Expert Group* (Rome: *FAO*). The 1973 Expert Committee report, *Energy and Protein Requirements,*[3] has a different mode of statement of the protein allowances. Unfortunately, the new formulation is less well adapted than its predecessors for use in determining the most efficient ways to meet the nutritional needs of a population.

The Protein Allowance

Because the quantity needed depends upon the quality of the protein and the dietary conditions under which it is consumed, the protein allowance cannot be stated as a fixed quantity of ordinary food protein. To state the allowance as a fixed amount it is necessary to standardize both the quality and the dietary circumstances under which it is consumed. Nutritionists have approached this problem by introducing the concept of *reference protein*: "A protein of high biological value, containing a specified pattern of amino acids completely utilizable for anabolic purposes at maintenance levels." An alternative definition states that reference protein "is completely utilized for

anabolic purposes."[4] Apparently such a protein does not exist except when fed at a minimal—submaintenance—level. "The amount of protein needed to meet the full requirement, to provide for growth and to cover the effects of stress, is necessarily higher, and it is probable that no protein, even if it had an ideal amino acid pattern, would be completely utilized at this level of intake."[5]

In any case, actual levels of protein intake vary widely, so when applying a protein allowance stated in terms of reference protein it is necessary to take account of the percentage of utilization to be expected under the anticipated conditions of protein intake. An allowance stated in terms of reference protein specifies the quantity of protein needed if all of it were completely utilized in tissue formation. The concept of net protein utilization relates the quantity actually needed to the quantity stated in terms of reference protein.

Net protein utilization is the percentage of actual nitrogen (protein) intake that is retained by the body for maintenance and/or growth.[6] Let z be net protein utilization (expressed as a percentage), r the quantity of reference protein (in grams per person per day), and t the quantity of actual food protein required (in grams per person per day). Then

$$\frac{z\,t}{100} = r \qquad (3)$$

shows that t grams of actual protein, with a net protein utilization of z percent, are equivalent to r grams of reference protein.

How effective any particular protein is in meeting the protein needs of the body depends upon the level of net protein utilization associated with its consumption. Net protein utilization depends, in turn, upon the quality of the protein itself and the circumstances under which it is consumed.

Protein Quality

Protein quality refers to the suitability of a particular protein for use in tissue formation within the body. In the normal processes of metabolism, the body continually is destroying existing tissues and forming new ones. (In the growing child, there is net formation of new tissues; in the adult, tissue formation may be limited to replacement needs.) In either case, protein is required so that new tissues can be formed.

In the process of digestion protein is broken down into the various amino acids of which it is composed. The body selects from these the particular combination which is required for protein formation within the body. In many cases, if a particular amino acid is not present within the food consumed, the body can produce it from others that are present, but there are eight which cannot be synthesized within the body. These are called the "essential" amino acids. If a protein is to be completely utilized in tissue formation it must contain all of the essential amino acids in the proportions required unless other foods in the diet provide supplementary quantities of the amino acids not present in sufficient amount. A fully utilizable protein may be defined as one which contains the essential amino acids in the required proportions. Such a protein could be a reference protein if consumed under the appropriate circumstances.

The nutritionist often measures the quality of a protein by its chemical score, which states, essentially, how much fully utilizable protein can be formed from a given weight of a specific protein. If a protein is fully utilizable, its score is 100. A score of 80 means that at least one of the essential amino acids present in 100 g of the protein is sufficient to form only 80 g of a fully utilizable protein. There is a deficiency of one or more of the essential amino acids.

Assume that the deficiencies are limited to the following four amino acids: lysine, methionine, threonine, and tryptophan. Assume also that in 100 g of fully utilizable protein there must be the following quantities of these essential acids: lysine, 4.000 g; methionine, 1.712 g; threonine, 3.168 g; and tryptophan, .992 g.

A protein that contains 80 percent as much lysine (3.200 g) and more than 80 percent as much of each of the others would have a protein score of 80. The body could construct 80 g of the fully utilizable protein from 100 g of this protein, but not more, for there would not be enough lysine to combine in proper proportions with the other seven essential amino acids provided. In this case, lysine could be the limiting amino acid, the one most deficient in comparison with the quantities required for the fully utilizable protein that serves as the standard, and therefore the one that limits the quantity of fully utilizable protein that can be created from the protein under consideration.

From such a protein, only 80 percent of the nitrogen in the food protein absorbed will be utilized in tissue formation. The essential

and nonessential amino acids that remain will be utilized as sources of food energy, with the nitrogen they contain being excreted as waste.

Useful as the chemical score can be, it does not reveal what role a particular protein should play in an economical diet. For that purpose one must look at the diet as a whole, not just at individual proteins. Two proteins with scores of 70 may have a combined score well over 70 if each one has a different limiting amino acid. To evaluate the quantity of fully utilizable protein contained in the diet as a whole, it is helpful to distinguish two aspects of such protein: (1) the proportions in which the essential amino acids are to be combined and (2) the minimum proportion of essential to nonessential amino acids.

Essential Amino Acids: Proportions. Nutritionists have discovered that the structure of naturally occurring proteins is such that only four of the eight essential amino acids are likely to be limiting in fact; the others normally are present in greater proportion than is required. Therefore, in constructing the model only these four will be considered: methionine, tryptophan, lysine, and threonine. Cystine, although not itself an essential amino acid, has a methionine-sparing effect because one of the uses of methionine is for the synthesis of cystine. Thus cystine and methionine (the sulfur-containing amino acids) will be combined and regarded as essential.[7] If the sulfur-containing amino acids plus tryptophan, lysine, and threonine are present in adequate amounts, one can assume that the remaining essential amino acids also will be present in adequate amounts.

Human milk and the whole egg of the hen provide perhaps the closest approximations to a protein which is completely utilizable for tissue formation. The second FAO report on protein requirements adopted the essential amino acid pattern of whole egg protein as the pattern for its reference protein (see Table 4).[8]

To avoid treating cystine as equivalent to methionine for purposes which only methionine will serve, to the requirements in Table 4 will be added the condition that 50 percent of the sulfur-containing amino acid group must be methionine. E. W. Hartsook and H. H. Mitchell found that the methionine requirement of the rat ranged from 43 to 47 percent of the total sulfur-containing amino acid figure, depending upon the age of the animal.[9] Our figure, which will apply to all ages, contains a small safety margin at every age.

Essential and Nonessential Amino Acids: Proportions. The second FAO report did not adopt egg protein as such as the reference

Table 4. ***Milligrams of Specified Amino Acid per Gram of Total Essential Amino Acids in Egg Protein***

Amino acid	*Milligrams*
Lysine	125
Total sulfur-containing amino acids	107
Threonine	99
Tryptophan	31
Other essential amino acids	638[a]
	1,000

SOURCE: Food and Agriculture Organization, *Protein Requirements: Report of a Joint FAO/WHO Expert Group*, FAO Nutrition Meetings Report Series no. 37 (WHO Technical Report Series no. 301) (Rome: FAO, 1965), Table 7, p. 37.

[a] Adjusted from 637 to make total equal 1,000.

protein since the egg contains more than twice the quantities of the essential amino acids required for full utilization of its protein.[10] Two proteins, both completely utilizable in tissue formation, may contain different amounts of the nonessential amino acids. Suppose the quantity of Protein A absorbed contains one gram of the essential amino acids, in the ideal proportions, plus two grams of other amino acids, and suppose this protein can be used to form three grams of protein in the body. In Protein B the quantity absorbed contains three grams of the essential amino acids, in the ideal proportions, and none of the nonessential ones. It, too, forms only three grams of protein in the body. Two grams of the essential amino acids must be used to replace the nonessential ones. If the latter had been available they could have formed two-thirds of the weight of the tissue formed in the body, and a total of nine grams of protein could have been formed. The amount of tissue formed in the body can be limited either by the total quantity of nitrogen available (from any of the amino acids) or by the quantity of that essential amino acid which falls farthest below the ideal proportion.

Although egg protein may be regarded as containing the essential amino acids in the ideal proportions, these acids will not be utilized with maximal effect in tissue formation unless a supplementary source of nonessential amino acids is provided. Only 48.8 percent of egg protein, by weight, consists of nonessential amino acids.[11] The nitrogen provided by these nonessential amino acids is insufficient to allow full utilization of the essential amino acids in the roles that

only the essential acids can play. Consequently, "the minimal quantity [of egg alone] that will maintain nitrogen balance in the adult provides more than double the estimated requirement of each essential amino acid."[12]

The provisional reference pattern proposed by the FAO Committee on Protein Requirements in 1957 called for 2,016 mg of the essential amino acids per gram of total nitrogen.[13] One gram of nitrogen corresponds approximately to 6.25 g of protein, so a ratio of 2.02 g of the essential amino acids to 6.25 g of protein exists, or 32.32 g of the essential amino acids to 100 g of protein (more precisely, 31.4 g per 100 g of protein).[14] In the 1965 report on protein requirements the FAO/WHO group carefully avoided making a recommendation concerning the ratio of essential to nonessential amino acids, although it pointed out that if this ratio is too low, the essential acids will be used as a source of nitrogen for the synthesis of the so-called nonessential amino acids. The group declared that there was an obvious need to determine the minimum ratios of the essential to the total amino acids.[15]

If the model is to provide protein in an economical way, it must not allow scarce essential amino acids to be used to replace the relatively abundant nonessential acids. Therefore, it will be assumed that not more than 32 percent of the total weight of absorbed protein fully used in tissue formation need consist of the essential amino acids. This is consistent with the recommendations of the 1957 Committee on Protein Requirements and not in contradiction with the 1965 report. By implication, the earlier recommendation established a ratio between the essential and the total amino acids. This implication was carefully avoided by the 1965 group, not because the earlier figure had been shown to be incorrect, but because no unique figure could be set on the basis of existing knowledge.[16] In the present study no unique figure is assumed, but the ratio of essential to total amino acids is not allowed to fall below 32 percent, essentially the level of the 1957 recommendation. This level apparently has been satisfactory, although it may not be the lowest satisfactory level.

The effect of applying such a ratio can be seen by examining the result to be expected from supplementing 100 g of egg protein with 50 g of nonessential amino acids. The resultant mixture contains 51 g of the essential and 99 g of the nonessential acids,[17] with the essential amino acids representing roughly 33 percent of the total by

weight. Hen's egg alone provides tryptophan in the amount of 100 mg per gram of total nitrogen and provides the sulfur-containing essential amino acid group in the amount of 346 mg per gram of total nitrogen. These quantities are more than double the estimated requirements for these essential acids.[18] Thus the quantity of whole egg that would maintain nitrogen balance in the adult for one week would suffice to maintain this balance for two weeks with the supplementation proposed here. Roughly half of the essential amino acids in egg protein are converted to nonessential acids in the absence of supplementation; with supplementation, the whole quantity of the essential amino acids may fulfill the roles that none of the other amino acids can fill. The mixture including the supplement would contain 50 percent more nitrogen; therefore, the ratios of tryptophan and the sulfur-containing essential amino acids to total nitrogen would become approximately 67 mg and 231 mg per gram, respectively. These figures may be compared with the ranges of 60 to 70 mg of tryptophan and 190 to 220 mg of the sulfur-containing essential amino acids per gram of nitrogen, ranges that the 1965 expert group regarded as preferable to the 1957 reference pattern.[19]

A Fully Utilizable Protein. A fully utilizable protein that economizes on the use of the essential amino acids must not require unnecessary quantities of the latter.[20] In this study at least 32g of the essential amino acids (including cystine) are required in 100 g of fully utilizable protein. As many as 168 g may be nonessential. If the 32 g are distributed in the proportions found in hen's egg (see Table 4), 11.584 g will consist of lysine, threonine, tryptophan, and the sulfur-containing amino acids. Column 2 of Table 5 states the quantity of each of these four components.[21] The remaining 20.416 g of essential amino acids are included with the 68 g of nonessential amino acids as "unspecified." (As these remaining essential amino acids are rarely limiting, it is not necessary to treat them separately from the nonessential acids. Indeed, if the diet contains extra amounts of the specified essential amino acids, these may be included in the "unspecified" group.)

Column 1 of Table 5 shows the quantities of these amino acids found in 100 g of the protein from hen's egg. The proportions are the same as in column 2, but the quantities are more than can be used effectively with the amounts of the nonessential amino acids found in the egg.[22]

Table 5. ***The Amino Acid Composition of a Fully Utilizable Protein, in Grams***

Amino acid	*(1) Hen's egg protein*	*(2) Pattern used in this model*
Lysine	6.400	4.000
Total sulfur-containing amino acids (cystine and methionine)	5.500	3.424
Methionine	(3.100)	(1.712)
Threonine	5.100	3.168
Tryptophan	1.600	.992
Unspecified amino acids	81.400	88.416
Total	100.000	100.000

SOURCE: (Column 1) Food and Agriculture Organization, *Protein Requirements: Report of a Joint FAO/WHO Expert Group*, FAO Nutrition Meetings Report Series no. 37 (WHO Technical Report Series no. 301) (Rome: FAO, 1965), Table 6A, p. 36.

Comparison of column 2 in Table 5 with the 1957 provisional pattern of the FAO (Table 6) shows that our allowances for the total sulfur-containing amino acids, as well as for methionine and tryptophan, are significantly below the recommended 1957 pattern. Because there is responsible nutritional opinion to the effect that the requirements for methionine and the sulfur-containing group should not be less than the 1957 pattern, in the model used in Part Two of this study those allowances have been increased, to 4.2 g for the sulfur-containing group and 2.1 g for methionine.[23] Consequently, the weight of unspecified amino acids in that model drops to 87.640 g.

Other Factors

Even if all the protein consumed were fully utilizable, net protein utilization usually would be less than 100 percent. Part of the protein

Table 6. ***The 1957 FAO Provisional Pattern for Five Essential Amino Acids or Groups of Acids, in Grams***

Amino acid	*Grams*
Lysine	4.000
Total sulfur-containing amino acids (cystine and methionine)	4.200
Methionine	2.200
Threonine	2.800
Tryptophan	1.400
Total weight of protein	100.000

SOURCE: Food and Agriculture Organization, *Protein Requirements: Report of a Joint FAO/WHO Expert Group*, FAO Nutrition Meetings Report Series no. 37 (WHO Technical Report Series no. 301) (Rome: FAO, 1965), Table 6A, p. 36.

eaten, whatever the quality, is not available for tissue formation, and part of the protein absorbed may be used instead for energy production. In the latter case at least two mechanisms are at work, one of which is associated with the caloric adequacy of the diet and the other with the concentration of the protein in the food mixture.[24]

First, if the diet does not provide sufficient food energy (calories) from nonprotein sources, some or all of the protein absorbed will be utilized as food energy. If the food energy requirements for metabolism cannot be fulfilled otherwise, *all* the protein will be converted into food energy, and none will be available for tissue formation. This mechanism need not cause difficulty in determining least-cost diets, for the minimum calorie allowance normally will be set high enough to provide adequate amounts of food energy without impinging upon the protein needed for tissue formation.

Second, even though the diet does provide sufficient food energy from nonprotein sources so that no protein need be diverted from tissue formation to energy needs, the concentration of protein still affects the quantity of protein used for tissue formation. Regardless of quality, the greater the diet's protein concentration (above a certain minimum level), the larger the fraction of absorbed protein converted to food energy and thus *not* utilized in tissue formation.

Fortunately, the quantitative relationship between the concentration of protein in the diet (the protein calories percent), the quality of the protein, and the net protein utilization (NPU_{op}) is known.[25] Let u equal the quantity of fully utilizable protein (in grams per person per day) and C the total number of metabolizable calories in the diet (in k calories per person per day). Then $(100)u/t$ is the protein score and $4(100)t/C$ is the protein calories percent (the "protein content of a diet in terms of calories expressed as a percentage of the total metabolizable calories" in the diet).[26] These two quantities determine the net protein utilization (operative) according to the following formula:[27]

$$z = \left(\frac{100u}{t} + 8\right)\left(1 - 0.019\frac{4(100)t}{C}\right). \tag{4}$$

The Protein Model

Let x_j be the quantity of food j consumed and a_{ij} the number of units of the ith nutrient provided by one unit of food j. Let the total caloric requirement of the diet be a fixed amount, b_1. Require this

restraint to hold as an equality. Let u be the activity of constructing one gram of fully utilizable protein and s the quantity of food protein in the diet that is *not* used in constructing fully utilizable protein.

Then the diet must meet the following requirements (along with others):

$$\Sigma a_{1j}x_j = b_1, \quad \text{Calories (k calories)} \qquad (\text{I})$$

$$\left.\begin{array}{lll} \Sigma a_{2j}x_j - u - s = 0, & \text{Food protein (grams)} \\ \Sigma a_{12,j}x_j - .04000\,u \geqq 0, & \text{Lysine (grams)} \\ \Sigma a_{13,j}x_j - .03424\,u \geqq 0, & \text{Sulfur-containing amino acids (grams)} \\ \Sigma a_{14,j}x_j - .01712\,u \geqq 0, & \text{Methionine (grams)} \\ \Sigma a_{15,j}x_j - .03168\,u \geqq 0, & \text{Threonine (grams)} \\ \Sigma a_{16,j}x_j - .00992\,u \geqq 0, & \text{Tryptophan (grams).} \end{array}\right\} (\text{II})$$

The first restraint in set (II) requires that the total weight of food protein in the diet must be at least equal to the quantity of fully utilizable protein in the diet. This places an upper limit on the amount of that fully utilizable protein. The total weight of the amino acids in fully utilizable protein cannot exceed the weight of the amino acids provided in the form of food protein. The remaining restraints in set (II) place minimum limits upon the quantities of the individual essential amino acids that must be provided by the foods in the diet. Their aggregate amounts depend upon the total quantity of u to be provided.

The exact quantity of u to be included in the diet must lie between the upper limit just mentioned and a minimum limit that depends upon the unknown quality of the total food protein and the unknown concentration of total protein in the diet. Given a fixed dietary allowance in terms of reference protein, $\bar{r}$, this minimum limit can be determined by the simultaneous solution of equations (5) and (6) below, the equations that relate the reference protein requirement to the total quantity of protein, its quality, and the proportion of the total calories in the diet that the protein provides.

$$\bar{r} = \frac{z\,t}{100}. \qquad (5)$$

$$z = \left(\frac{100u}{t} + 8\right)\left(1 - 0.019\,\frac{400t}{C}\right). \qquad (6)$$

Eliminating z,

$$u = \frac{\bar{r}}{1 - \frac{7.6t}{C}} - .08t; \tag{7a}$$

$$u\left(1 - \frac{7.6t}{C}\right) + .08t\left(1 - \frac{7.6t}{C}\right) = \bar{r}, \tag{7b}$$

which sets the minimum quantity of u needed to provide the required amount of reference protein for any level of t which may be provided in the diet. (C in this expression is a known constant because the calorie restraint was written as an equality rather than an inequality. There are nutritional reasons for not wanting the caloric requirement to be overfulfilled, but the computational advantage this convention provides is reason enough.)

The protein model is completed by two restraints:

$$u \quad + s \quad - t \quad = 0; \tag{III}$$

$$u\left(1 - \frac{7.6t}{C}\right) + .08t\left(1 - \frac{7.6t}{C}\right) \geqq \bar{r}. \tag{IV}$$

Restraint (III) defines t in terms of the $u + s$ previously defined as equal to the total quantity of food protein in the diet. Restraint (IV) ensures that u will be adequate for whatever level of t may prove to be most economical.

The effect of restraints (I), (III), and (IV) is to define an acceptable region for u as a function of t, given specified values for $\bar{r}$ and C. When graphed, that region appears as in Figure 3. Because u cannot be greater than t or less than $\bar{r} \Big/ \left(1 - \frac{7.6t}{C}\right) - .08t$, a minimum level is set for t itself, at the intersection of $u = t$ and $u = \bar{r} \Big/ \left(1 - \frac{7.6t}{C}\right) - .08t$.

At the lowest feasible level of t, u must equal t, so the protein score must be 100, that is, $100u/t = 100$. As the level of food protein in the diet rises, the minimum acceptable ratio of u to t diminishes, that is, the acceptable protein score falls. With this model, the computer will determine the least costly combination of quality and quantity that exists within the acceptable region. If meeting the

reference protein requirement is costly because one or more of the essential amino acid requirements is costly to satisfy, the optimal solution will be on the lower boundary of the acceptable region. If none of the essential amino acid requirements is costly to satisfy, at any level of t, but if there is a marginal cost involved in attaining the required levels of total protein, the optimal solution will be on the left-hand boundary of the region. If neither total food protein nor any of its components is costly, the optimal solution will be somewhere within the region.

The numerical values plotted in Figure 3, which apply to the intermediate savanna area, are from a preliminary study.[28] The quantities u, t, r, and C are not per capita figures, but aggregates for a population of 10,400,000 persons. For this population the aggregate annual caloric allowance arrived at was 86,464 hundred million k calories, and the desired minimum reference protein level was 1,328.9 hundred metric tons per year, as is shown by the formula for the lower boundary of the acceptable region.

In this study the least costly diet available in this area was at point P, on the lower boundary. It contained an annual total of 2,001.7 hundred metric tons of actual food protein and provided 1,448.6 hundred metric tons of fully utilizable protein. On a daily basis, the

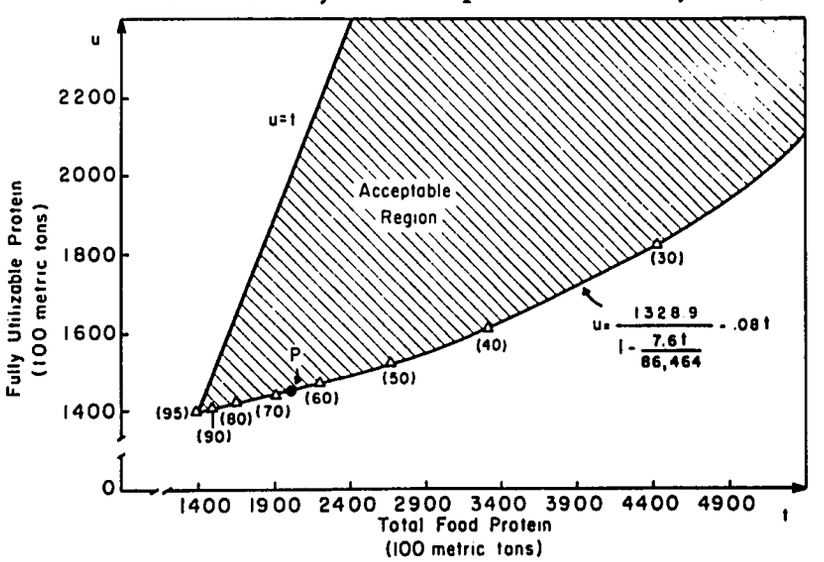


Figure 3. ***Acceptable Region for Variations in Protein Quality: The Intermediate Savanna***

diet provided 52.7 g of food protein, 38.2 g of fully utilizable protein, and 35.0 g of reference protein per person. It met the minimum reference protein allowance for the area with nothing to spare. The sulfur-containing amino acids were limiting.

Net protein utilization (operative) in this diet was 66.4 percent.[20] (The numbers in parentheses in Figure 3 give the net protein utilization values associated with the corresponding points on the lower boundary.) The protein score was 72.6. If either a higher or a lower protein score had been specified, any diet that met the specified allowance for reference protein would have been more costly than this one. (The total cost of this diet for an adult male in his thirties was calculated at 1.14 Nigerian shillings, or about 15 cents per day.)

The Complete Nutritional Model

The nutritional model may be completed by adding the requirements for the remaining nutrients. The complete set of nutritional restraints is stated in Table 7. There is one such set of restraints for each of the six geographical areas comprising Nigeria. The right-hand side values are per capita figures, but the values actually used in computation are aggregates for the whole population of the area.[30]

Note that C_0, in the fourth restraint, is not a variable, but a constant. In Table 7 it has a value of 2,266 k calories. Its value in each geographical area is equal to the caloric allowance for that area.

Note also that the a_{ij} values may be expressed in different units from one restraint to another.

There is one new variable, n, in this model (in restraints x and xvi). One of the amino acids, tryptophan, may be converted into nicotinamide at the rate of 60 mg of tryptophan to one mg of nicotinamide instead of being used for tissue formation. The variable n represents the level of an activity that transfers tryptophan from use in tissue formation to use as a precursor of nicotinamide.

Although restraint xvi is an equality, excesses of tryptophan are allowed in the solution. They will appear, however, in the form of their nicotinamide equivalents, an overfulfillment of restraint x.

In the complete model of Nigerian agriculture the nutritional model is used six times, once for each of the six geographical areas. Thus there are six of the nonlinear protein restraints to be satisfied.

Computing time for the complete model, with a total of 462 activi-

Table 7. *The Complete Nutritional Model*

Restraint number	*Restraint*						*Purpose*
I	$\Sigma a_{1j}x_j$					$= 2266$ k cal	Provides a predetermined amount of food energy.
II	$\Sigma a_{2j}x_j$	$-u$	$-s$			$= 0$ g	Provides food protein at least equal to the quantity of fully utilizable protein in the diet.
III		u	$+s$	$-t$		$= 0$ g	Defines the total food protein variable, t, as equal to $u + s$. Using (II), $t = \Sigma a_{2j}x_j$.
IV		$(1 - 7.6t/C_0)u$		$+ 0.08(1 - 7.6t/C_0)t$		$\geqslant 34.4$ g	Provides the minimum fully utilizable protein required to attain a reference protein level of 34.4 g or more.
V	$\Sigma a_{5j}x_j$					$\geqslant 388.7$ mg	Provides a minimum quantity of calcium.
VI	$\Sigma a_{6j}x_j$					$\geqslant 13.3$ mg	Provides a minimum quantity of iron.
VII	$\Sigma a_{7j}x_j$					$\geqslant 4433.$ IU	Provides a minimum quantity of vitamin A.
VIII	$\Sigma a_{8j}x_j$					$\geqslant 1.135$ mg	Provides a minimum quantity of thiamin.
IX	$\Sigma a_{9j}x_j$					$\geqslant 1.02$ mg	Provides a minimum quantity of riboflavin.
X	$\Sigma a_{10,j}x_j$				$+ 100n$	$\geqslant 11.47$ mg	Provides a minimum quantity of nicotinamide.
XI	$\Sigma a_{11,j}x_j$					$\geqslant 27.49$ mg	Provides a minimum quantity of ascorbic acid.
XII	$\Sigma a_{12,j}x_j$	$-0.04000u$				$\geqslant 0$ g	Provides the minimum ratio of lysine.
XIII	$\Sigma a_{13,j}x_j$	$-0.03424u$				$\geqslant 0$ g	Provides the minimum ratio of the sulfur-containing amino acids.
XIV	$\Sigma a_{14,j}x_j$	$-0.01712u$				$\geqslant 0$ g	Provides the minimum ratio of methionine.
XV	$\Sigma a_{15,j}x_j$	$-0.03168u$				$\geqslant 0$ g	Provides the minimum ratio of threonine.
XVI	$\Sigma a_{16,j}x_j$	$-0.00992u$			$-6n$	0 g	Sets the quantity of tryptophan available for use, in fully utilizable protein or for conversion to nicotinamide, equal to the quantity provided by the diet.

ties and 541 rows, amounted to about 17 minutes using the Control Data Corporation OPTIMA routine and the CDC 3600 computer.

OPTIMA contains a separable programming feature for use in obtaining linear approximations to nonlinear restraints. The nonlinear function is replaced by a set of linear chords, defined by their endpoints. The purpose of the separable programming subroutine is to assure that only two of these endpoints enter the optimal solution and that they will be adjacent (so that they never define a chord unnecessarily far removed from the nonlinear curve because it is formed by the endpoints of two shorter chords). In the least-cost diet problem, however, this feature need not be used. When protein is a costly nutrient the cost minimization procedure itself assures that only two points will appear in the solution and that they will be adjacent.

To adapt the model to a computer routine designed for linear programming, one may replace the nonlinear relationship between t and u (restraint IV) by a piece-wise linear approximation. In the process restraint IV will be replaced by a set of restraints, IV: a, b, c, and d.

First, introduce the new variable, u', where u' is the minimum acceptable level of u for any t (defined by restraint IV as a function of t). Restraint IVa requires that u attain at least this level:

$$u \quad - u' \geqq 0. \tag{IVa}$$

The original restraint IV now may be regarded as an equality relating u' to t. It is no longer present in the programming model, but it is used in deriving restraints IVb and IVc. Restraint IV, as an equality, is plotted in Figure 4, which reproduces the lower curve from Figure 3. The smooth curve is replaced by a series of linear segments defined by their endpoints, A, B, C, D, and E. (One may use as many segments as are required by the level of accuracy desired.) In the programming model each endpoint is represented by a column vector whose elements are the coordinates (t, u') of each point, plus a weighting factor, one. Thus the column vector $P_A = (1400, 1400, 1)$, $P_B = (1900, 1440, 1)$, and so forth, where the coordinates t and u' are calculated by hand from the equality form of restraint IV.

Let $y_a, \ldots, y_e$ be the variables whose coefficients are given by these column vectors. Now one can write restraints IVb, c, and d.

$$-t \quad + 1400y_a + 1900y_b + 2660y_c + 3300y_d + 4400y_e = 0 \quad \text{(IVb)}$$

$$-u' \quad + 1400y_a + 1440y_b + 1520y_c + 1600y_d + 1800y_e = 0 \quad \text{(IVc)}$$

$$1y_a + \quad 1y_b + \quad 1y_c + \quad 1y_d + \quad 1y_e = 1 \quad \text{(IVd)}$$

Equation (IVd) states that the weighted sum of the levels of the new variables used in the solution must equal unity. That is, the solution may contain any one of these five variables, but none other, or any weighted sum of them that equals unity, such as $.7y_a + .3y_b$. The latter sum represents a point with coordinates $t = .7(1400) + .3(1900) = 1550$ and $u' = .7(1400) + .3(1440) = 1412$. It lies on the chord between A and B of the curve that defines the minimal acceptable points for u'.

Any point on the linear segments between A and E can be chosen by an appropriate selection of levels for $y_a, y_b, \ldots, y_e$.

One interpretation of the new equations is that equation (IVb) requires that $y_a, \ldots, y_e$ be chosen so as to give a t coordinate that equals the value of t in the solution. This done, equation (IVc) determines the level of u' required for this amount of t.

A glance at Figure 4 indicates that if u' so defined is to be a minimum for any given t, no more than two of the y variables may be used

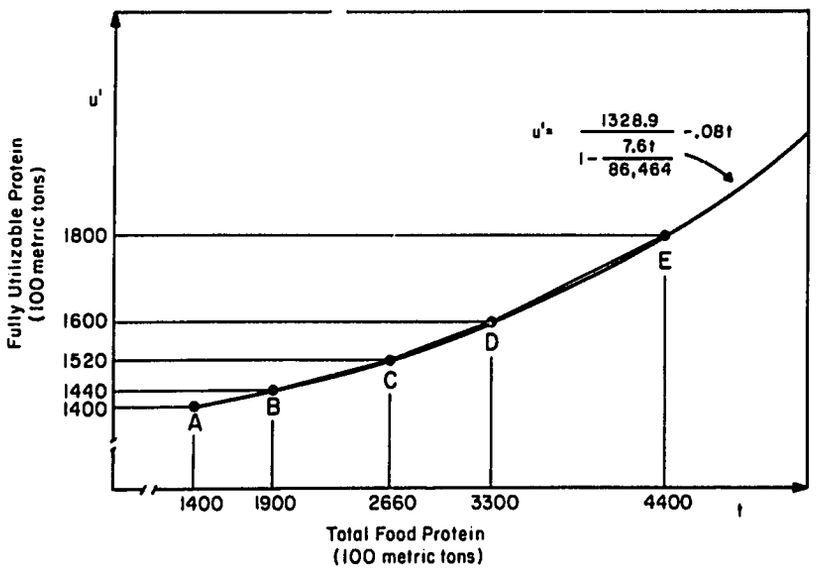


Figure 4. ***Linear Approximation to the Nonlinear Restraint***

at a positive level, and those two must be adjacent. Thus, if fully utilizable protein is costly to provide in adequate amounts, the computer, seeking a minimum level for u' will reject all combinations of the y variables except pairs of adjacent points.

Of course, if fully utilizable protein is not costly (as may well be the case), restraint (IVa) will be satisfied as an inequality, and it will not matter how u' is calculated by (IVc), for u will exceed u'.

Conclusion

Because protein may be used either for food energy or for tissue formation (but not always in the same proportions), and because its efficiency in tissue formation depends upon the kind of protein it is, protein needs cannot be stated as so many grams per day for a person of a given age, sex, and body weight. The efficiency of any protein in tissue formation depends not only upon what kind of protein it is but also upon what else is in the diet as a whole. Only with a model that includes these relationships can the least costly way of meeting the protein requirement be found. Fixing the protein quality in advance rules out opportunities to economize by consuming a smaller quantity of higher quality or a larger quantity of lower quality. Letting both quality and quantity be variable involves a nonlinear restraint, to be sure, but the restraint has a simple shape. The problem can be solved with ease by using existing methods for the linear approximation of a nonlinear restraint.

4

The Costs of Individual Nutrients

Efficiency in the production of nutrition requires that one know how to allocate resources, what crops to produce, and where to produce them. The principles by which these decisions should be made are clear enough, but applying them can be difficult.

For example, should a given set of resources be used to produce food or to produce income (products not used for food within Nigeria)? The answer is food, if the nutrients in the food are worth more than the income; income, if the reverse is true. To apply this rule, however, one must be able to determine the values of individual nutrients.[1]

Among the food crops, which one should be produced on a given piece of land? Naturally, most appropriate would be the one that yields the most valuable collection of nutrients, after paying for the land and other resources employed. However, this rule, too, requires that one be able to measure the values of individual nutrients.

Among the cash crops, which should be produced? The answer again is the crop that yields the greatest value surplus after paying for the resources required. In this case, however, no new problem

arises, for income is measured in the usual way, by the market value of the product.

What if a crop, such as groundnuts, can be used either for food or (when exported) for income? Its produce should be divided between consumption for food and sale for export in a ratio such that the value of an acre used for food and an acre used for income are equal. Again it is necessary to be able to measure the value of the nutrients provided when used as food.

In which areas should food be produced for consumption in other areas? If the sum of the cost of production in area A and the cost of transportation and marketing to area B is less than the value of the nutrients in area B, the food shall be produced in A for consumption in B.

In which areas should crops be grown for export? The reply is wherever the cost of production, transportation, and marketing is less than (or possibly equal to) the value of the crop at the port.

In every case, of course, production in a single area is limited by the acreage suitable for use for a particular crop. In this model such limitations are represented by the maximum limits set for each crop.

How are the nutrient values needed for the application of these principles to be determined? The incremental or marginal costs of production of the individual nutrients (when produced in the most economical way) should be used. *Value* is thus identified with the cost of obtaining the nutrient. The model requires that the specified allowances be satisfied at whatever cost is necessary, which implies that each nutrient is indeed worth whatever it may cost to obtain it. Its worth therefore can be measured by that cost.

To measure the incremental (marginal) cost of a food element, such as calories, let the caloric allowance be increased by 100 k calories. If the cost of producing the diet increases, the increment in cost will be the cost of producing 100 k calories: It is the appropriate measure of the value of calories. This cost is measured, in this model, by the value of the export production that must be given up in order to provide the resources needed to produce the extra calories.

If the cost of producing the diet does not increase when the allowance for one of the nutrients, such as thiamin, is increased by one milligram, the incremental cost of thiamin is zero. We say then that the value of thiamin is zero. This is not to say that thiamin serves no nutritional purpose. *Value*, as used here, does not measure the contribution of a nutrient to nutritional well-being; rather, it measures

the cost of obtaining a little more of that nutrient at specified levels of total nutrient availability.

Efficiency in the production of nutrition requires that economical sources of production be found for those nutrients that are necessarily costly. (Not all nutrients need be costly in this sense.) *Economizing* means economizing in terms of the costly nutrients, which are the controlling ones. It is the necessity of providing specified quantities of these nutrients that limits the ability to use Nigerian resources for other purposes and controls the pattern of resource use that is developed. The more costly a nutrient, the more influence it has on the form of the efficient production pattern. This chapter will identify the nutrients that are necessarily costly in the Nigerian production situation, provide measures of their costs, and identify certain foods that are unusually economical sources of these nutrients.

Résumé of the Model

In this model agricultural produce may be used as food or exchanged for income. When produce is used for food within Nigeria, it provides nutrients, but those nutrients are not included within *income* as the term is used here. If not used for food within Nigeria, the produce is sold to provide monetary income. The problem is to find the set of agricultural activities that maximizes the agricultural earnings of Nigeria, subject to the requirement that the levels of nutrient availability set forth in Table 3 have been attained.

Production activities, in general, can be carried on at some 120 percent of our estimates of their 1963 levels. Consumption activities, with some exceptions, may rise to four times our estimates of 1963 levels. (The per capita consumption of alcoholic beverages is set equal to 1963 levels.)

A population of 61 million (9.5 percent above the 1963 level) is to be fed with land and labor resources that are assumed, for the most part, to be 9.5 percent greater than the quantities in use in 1963.[2] Agricultural techniques are representative of those in use in 1963.

The Controlling Nutrients

If a feasible solution exists for the problem, it will provide exactly the quantities of some nutrients specified by the allowances and larger quantities of the others. In the optimal solution the allowances

for some nutrients can be satisfied only by giving up income-earning possibilities. Consequently, they are satisfied at the minimum levels allowed. These are the controlling or limiting nutrients. To have more of one of them would raise the cost of the diet because it would require incurring an opportunity cost—giving up something of value. In the economic sense these are the scarce, or costly, nutrients.

When all of the costly nutrients are provided in adequate quantity, unspecified quantities of the other nutrients also will be made available. (There are few foods that do not provide several nutrients at the same time.) These quantities will be equal to or greater than the amounts required by the allowances (otherwise these nutrients also would have been costly), so obtaining them adds nothing to the cost of the diet. These are not costly nutrients. Nothing must be given up in order to reach the specified levels of the allowances. The necessity of providing these nutrients has no influence on the economizing process and no effect upon the pattern of production and trade that results.

The solution of this model reveals that, with the production techniques in use in 1963, finding an efficient pattern of nutrient production means finding efficient sources of only four food elements or nutrients: calories, calcium, riboflavin, and vitamin A. These four are the controlling nutrients. Providing these in an efficient manner requires a pattern of production and exchange that also provides as much as was specified (or more) of each of the remaining nutrients.

It will be surprising to many that protein does not appear among the controlling nutrients.[3] This solution shows that if traditional Area I cattle production can be carried on at 1963 levels, expanding goat and sheep production by 20 percent above 1963 levels in Area I and all three of the traditional animal industries by 20 percent in the remainder of Nigeria can provide adequate quantities of protein. However, there must be appropriate supplementation from vegetable proteins, the small commercial beef industry of Area VI, and purchases of dried freshwater fish. This question will be returned to shortly.

For two of the controlling nutrients it not only was costly to meet the allowance levels specified but also impossible to meet levels much higher than these. The calcium and riboflavin allowances used in this model are well below those hoped for when work first began. Initial specifications led to daily per capita allowances for Nigeria as a whole of 567.5 mg of calcium and 1.362 mg of riboflavin. These levels are unattainable under the conditions of the problem.[4]

At riboflavin levels of 1.02 and 1.09 mg per capita per day the highest daily calcium allowances attainable are 427 and 422 mg per capita. At a calcium level of 389 mg, the highest daily riboflavin allowance attainable is 1.16 mg per capita. As Figure 5 makes clear, these data indicate that calcium and riboflavin are substitutes in production at calcium and riboflavin levels above 389 mg and 1.02 mg, respectively. The higher the level of calcium required, the lower the maximum level of riboflavin that can be attained, and vice versa. It is not possible to provide combinations of calcium and riboflavin levels that will be satisfied in each of the six areas of Nigeria if those combinations lie outside the area identified as "feasible" in Figure 5.[5]

In the present state of nutritional knowledge, minimum adequate levels of calcium or riboflavin cannot be specified with precision. The original allowances were set toward the upper side of the range within which such allowances usually are established, so when they were found to be unattainable it seemed reasonable to lower them. The present model provides levels of 1.02 mg for riboflavin (75 percent of the original figure) and 388.7 mg for calcium (68.5 percent of the original figure). Both allowances are near the upper boundary of the attainable range for Nigeria under the conditions of the model,[6] but lie in the lower portion of the range that nutritionists are likely to find acceptable.

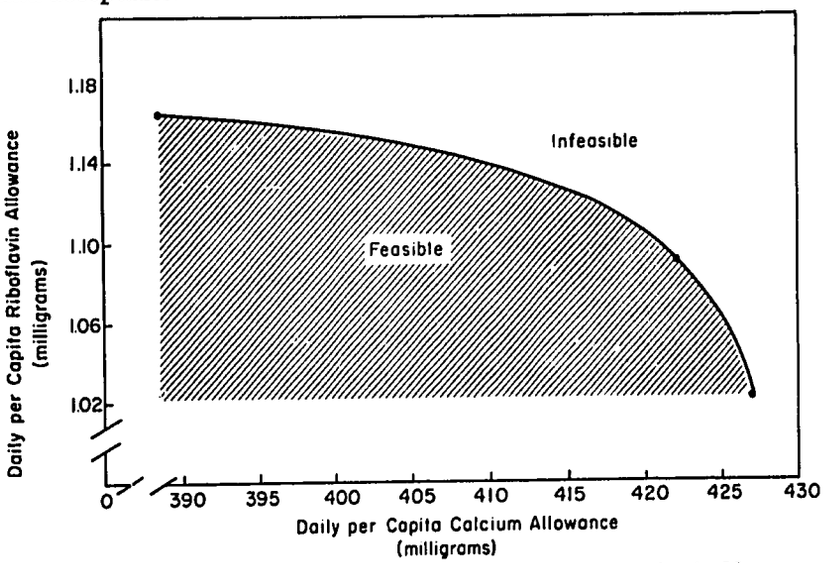


Figure 5. ***Maximum Riboflavin and Calcium Allowances Attainable***

As the population continues to grow, Nigeria soon will reach a state in which even the present levels of the allowances for calcium and riboflavin will be impossible to attain in all parts of Nigeria unless there are significant improvements in agricultural techniques or new ways of providing the riboflavin and calcium needed. This may be unimportant for calcium since there is little evidence that significant calcium deficiencies are common at the present time. The riboflavin problem, however, already is regarded as serious by some nutritionists. The 1965 survey team reported: "From biochemical, dietary, and clinical evidence, deficiency of riboflavin is severe and widespread. . . . Food sources of riboflavin are limited."[7]

Two points deserve comment. First, providing adequate quantities of riboflavin is primarily a problem of the rain forest zone. In the savanna areas riboflavin is not a controlling nutrient, as will be seen. Second, to a limited extent, Nigerian capacity to provide riboflavin rises as the level of calcium produced diminishes. Thus some small substitution of riboflavin for calcium is possible. How much could be gained by reducing the calcium production goal below 389 mg per capita per day remains unknown. These calculations have not been made, but it is likely that any additional production capacity for riboflavin would be small.

Although the present calcium and riboflavin allowances are near the limits of Nigeria's physical capacity to produce these nutrients, the most serious nutritional problems arise from inadequate intakes of calories and protein. With an efficient organization of its agriculture, Nigeria can produce the quantities called for by our allowances, but producing enough is only a part of the problem. To eliminate nutritional deficiencies it also must be possible to store and transport food so that it will be available at the proper times and places. Incomes must be high enough and distributed equitably enough so that the poor can afford the food they need. The distribution of food within the family must take more account of the needs of the small child. Consumers must choose the proper foods and prepare them wisely. (Dietary habits, food preparation methods, and child feeding practices may create a problem with respect to one or more nutrients even though no production problem exists.) Last, diseases and parasitic infestations that increase the need for protein must be controlled.

The production problem, however, is basic since it will remain even though all other contributing causes are removed. Given Nigeria's production capabilities, four food elements (calories, calcium, ribofla-

vin, and vitamin A) are necessarily costly if they are to be provided in the amounts called for by our nutritional goals. When adequate quantities of these nutrients are made available in an efficient manner, each of the allowances for the remaining nutrients is also satisfied.

Costs of Individual Nutrients

While riboflavin, calcium, calories, and vitamin A are the controlling nutrients, they are not equally important in determining the form of an efficient pattern of production, exchange, and consumption. The importance of an individual nutrient is indicated by the incremental cost of providing the quantity of that nutrient that the allowances specify.

The value of a given nutrient in any area equals the revenue which would be lost by diversion of resources from revenue production to nutrient production if it were necessary to provide a little more of that nutrient in that area. This value depends upon the quantity of the nutrient needed for consumption in the area or for sale to other areas and upon the ease of obtaining that quantity. The latter reflects the physical efficiency of resources in the production of nutrients in that area or in the areas producing food for that area. It also reflects efficiency in the production of revenue. An area where resources are of little value for production for export markets may provide nutrients at a relatively small sacrifice of revenue, even though its physical efficiency in producing nutrients is low. (The value of resources in producing revenue in any area depends, in part, upon the accessibility of markets and the prices of goods sold for export or for nonfood use within Nigeria.)

Table 8 gives the incremental cost of each nutrient, according to the optimal solution. These are the least costs—the unavoidable costs—when attaining these allowance levels under the conditions of the model. Patterns of production and consumption that are less efficient nutritionally would involve higher costs.

Costs are measured in 1963 Nigerian shillings, as are all cost and revenue figures in this analysis. (On 1 January 1973 Nigeria shifted from a monetary system based on pounds and shillings to a decimal system, with the naira as its basic unit. One naira is equivalent to 10 of the former Nigerian shillings.[8])

Naturally, the costs of nutrients vary considerably from area to area. For the whole set of nutrients the cost of meeting the average

Table 8. ***Costs of Nutrient Elements in Average Daily per Capita Allowances, in Shillings***

Nutrient	*Area* I	II	III	IV	V	VI
Calories	— 0.090	.794	.900	.526	.487	.650
Calcium	1.340		.046	.030	.047	.068
Vitamin A	.097	.018				.022
Riboflavin			.395	.944	.438	
Total cost of average daily allowances for all nutrients	1.35	.81	1.34	1.50	.97	.74

NOTE: These are the least costs of expanding the intake of a single nutrient by one unit, in a single area, subject to all the limits on the levels of production and consumption activities and the constant quantities of resources available. The daily per capita nutrient allowance used as a unit here is the average for Nigeria as a whole.

daily allowances ranges from .74s in the forest-savanna mosaic to double that (1.50s) in the central moist forest. (See Table 8.) This may seem inexpensive, but incomes are also low in Nigeria. Even if we assume a Gross Domestic Product as high as £33 per capita in 1967,[9] daily per capita GDP would be only 1.81s. Under these circumstances a minimum adequate diet would take from 41 to 83 percent of the GDP per capita. Average incomes may be higher in the areas where adequate nutrition is more costly, but, even so, when such a high proportion of the average GDP is required for adequate nutrition, none can deny the need for improved food production.

For planning purposes, more important than the cost of the whole diet are the costs of individual nutrients. For most nutrients, this cost is zero. (Such nutrients are not listed in Table 8.) When a production and consumption pattern has been found which provides the specified quantities of each nutrient in the most economical way, it usually provides larger quantities of many nutrients than are necessary. Therefore, the cost of meeting slightly higher allowances for any of these nutrients would be zero.

For other nutrients, however, any increase in the quantity required by the model would lower the revenue obtainable from Nigerian agriculture (raise the cost of the diet). In this solution the nutrients for which this is true in one area or another are calories, calcium, vitamin A, and riboflavin. The most expensive allowance to attain, in most parts of Nigeria, is that for calories.

Riboflavin is expensive in the three moist forest areas, but is present in excess of allowance levels in the remainder of Nigeria. In the

eastern moist forest, riboflavin accounts for almost half the cost of the average daily allowances for all nutrients, and in the central moist forest it accounts for nearly two-thirds of the cost. Attaining the specified vitamin A allowances involves a small cost outside the moist forest areas. (Inside those areas the vitamin A requirement is overfulfilled, probably because red palm oil is consumed to meet caloric needs.)

Calcium involves a modest cost in four of the six areas, but in Area I, the dry savanna, meeting the calcium allowance accounts for practically the whole cost of a day's nutrients. (Dried freshwater fish with edible bones—an important source of calcium—are purchased by each of the five areas in which meeting the calcium allowance is costly.)

The necessity for meeting the calcium allowance dominates the solution in Area I. However, that allowance (392 mg per capita per day) is higher than is necessary. Some nutritionists believe that 300 mg per day is acceptable.[10] Neither dietary intake surveys nor biochemical and medical investigations have found evidence that calcium deficiency is a probelm in Nigeria.

It also may be that the actual intake of calcium exceeds the quantities estimated in the model. The amount of calcium obtained from gathered and collected foods—the eggs of bush poultry, insects, leafy vegetables, and so forth—may have been underestimated. No account has been taken of the consumption of edible earths or native salts. John F. Annegers has pointed out that edible earths are important in some parts of West Africa,[11] and in Mali as much as 26 percent of the calcium in the diet is derived from wild sources.[12]

The calcium provided by the millet grown in the most northerly parts of the dry savanna probably has been underestimated. In the model, *millet* means bulrush millet (*Pennisetum americanum*), but finger millet (*Eleusine coracana*), grown in the Lake Chad and Katsina areas, is 14 times as rich in calcium (350 mg per 100 g of edible portion, in contrast to 25 mg).

Under these circumstances it would be unwise to base policy decisions upon the numerical results obtained for the dry savanna. They depend too heavily upon a calcium allowance that seems to be higher than need be. However, to the extent that the actual calcium intake consists of gathered and collected foods, including the edible earths, the results reported here may be representative of a situation that already exists in urban areas (such as the densely settled populated

area around Kano) and that will become increasingly widespread as urbanization increases.

In the case of calories an interesting situation exists. In all but one area an increase in the caloric allowance would raise the cost of the diet. In the dry savanna (Area I), however, a larger caloric allowance would lower the cost of the diet, so the cost of adding calories in that area is negative. This negative cost figure would not appear if excess quantities of calories were permitted in the diet, but the model does not allow them. An excessive caloric intake leads to overweight, with an associated complex of health problems. Moreover, increases in caloric intake require increases in the intake of protein and the B-vitamins, otherwise nutritional deficiencies are liable to appear with respect to the latter nutrients.

Allowing higher caloric levels in Area I would lower the cost of the diet because there are sources of calcium available that are less expensive than some of those now in use. These presently can be used only in limited amounts because they provide too many calories in proportion to the calcium they contain. Three such sources are rice, maize, and millet, which provide 28, 33, and 69 mg of calcium per 1,000 k calories, respectively. In contrast, foods like Irish potatoes, sweet cassava, sweet potatoes, and cowpeas provide 133, 185, 219, and 265 mg.

Adequate protein can be had without reducing the revenue from agriculture because the least expensive sources of the costly nutrients are also sources of protein. Milk from the Fulani herds is needed for calcium in Area I and for calories in Area II; it provides protein and riboflavin in each area, but at no additional cost. In the rain forest areas riboflavin and calories are costly; the millet, maize, and meat that enter these areas from the savanna areas and the forest-savanna mosaic are also sources of protein. Given the riboflavin allowances in the model, when the moist forest areas have enough riboflavin, they have enough protein. If the specified nutrient allowances are to be provided in the most economical fashion, given the technical coefficients and other conditions of this model, there will be more than enough protein provided (and that protein will be of excellent quality) when production levels are adequate to provide the specified quantities of calcium, calories, vitamin A, and riboflavin. It is necessary, of course, that there be appropriate exchanges of foods among areas in order that the nutrients be made available where they are most needed.[13]

The Protein Problem

From the standpoint of the basic problem of providing the specified quantities of the several nutrients, it is clear that the most pressing production problem, with the agricultural techniques in use in 1963, is not how to produce enough protein but how to produce enough riboflavin and calories. When the latter are produced efficiently, the protein problem is solved without further expense. Protein is provided in this solution at levels in excess of the allowances.[14] The quality, as measured by the chemical score, is excellent. It exceeds the level necessary to provide an average daily reference protein allowance of 34.4g by some 30 percentage points in three of the six areas. The margin is least in the western moist forest (Area III), where a minimum score of 80 is needed. The actual score there is 83.[15]

It is worthy of note that the combination of quality and quantity which is economical in this solution varies considerably among areas. As the data in the two previous footnotes indicate, scores of 55 and 57 percent would be adequate in the dry savanna and the forest-savanna mosaic, respectively. There the total food protein provided by the solution amounts to 74 and 69g per capita per day. At the other extreme, a score of 80 percent is needed in the western moist forest, where the solution provides only 46.6g of protein daily per person. Permitting such flexibility in choosing the way to meet the reference protein requirement is a major advantage of the type of protein model developed for this study. In each area the most efficient of the various possible combinations is chosen during the solution of the problem; what that will be may vary from area to area and will depend upon ecological and other conditions in the particular area.

While the present solution meets the specified protein goals efficiently, the test of efficiency is essentially the cost of meeting the riboflavin and calorie allowances (along with those for vitamin A and calcium). We economize in terms of the costly nutrients.

This emphasis on the cost of meeting the riboflavin allowances seems ill-advised to Dr. J. M. Gurney, formerly a member of the Food Science and Applied Nutrition Unit at the University of Ibadan, Nigeria. Believing that riboflavin deficiencies do little physiological harm, and dubious as to whether they even exist, he would prefer the emphasis to be on protein, lack of which is unquestionably a frequent cause of illness and death in Nigeria.[16] However, the main causes of the acknowledged deficiencies in protein intake may not lie in the

sphere of production. They may involve (and certainly some of them do) problems in storage and transportation, the distribution of income, consumption practices, or the prevention of diseases and parasites. This study is concerned with the efficient production of nutrients. At the production level, our protein allowance is easier to meet than our riboflavin allowance (in part because, as Gurney points out, riboflavin and protein tend to be found together).

The Riboflavin Allowance

Is our riboflavin allowance (1.02 mg per person per day) too high? In principle, no. This allowance is 20 percent below the intake recommended by the 1965 Joint FAO/WHO Expert Group.[17] That intake, .55 mg per 1,000 calories, works out at 1.246 mg per day for the average caloric level used in this study (2,266 k calories). It is intended to provide sufficient riboflavin for the maintenance of health in nearly all people.[18] Our level corresponds to the .44 mg per 1,000 calories (.997 mg per day at the caloric level used here) that the Expert Group considered adequate for the needs of an average adult, without allowance for individual variation. At intake levels much below .44 mg per 1,000 calories, marked decreases occur in riboflavin excretion.[19]

Reducing the riboflavin allowance would lower the cost of the diet somewhat in the three areas where it is one of the costly nutrients, but usually at the expense of reducing the quantities of those nutrients that the present solution provides in excess of the allowances. The present riboflavin allowance of 1.02 mg adds about .4s to the cost of the diet in the western moist forest. To reduce the per capita allowance by one one-hundredth of a milligram would lower the cost of the diet there by .004s.

The maximum saving to be expected from a 20 percent reduction in the allowance (lowering the figure from 1.02 mg to .8 mg) would be about one penny (.08s and .09s, respectively) in the western and eastern moist forests and in the central moist forest no more than .19s (about two pence).[20]

One would hesitate to reduce the allowance below .8 mg since clinical evidence of deficiency has been observed at intakes below .7 mg per day.[21] Moreover, an allowance of 1.02 mg makes no provision for variations in individual needs, so even at that level the amounts received would be inadequate for some people although every adult received the same amount. Reducing the allowance to .8 mg means that some individuals will have much less than they need.

Savings of one or two pence daily are not negligible; they amount to 6, 9, and 13 percent of the respective costs of the diets in these areas. As providing a minimum adequate diet may require from 41 to 83 percent of the GDP, these are appreciable savings. At lower costs the diets would be available to more people.

Actual savings would be less than this, not only because the rate at which savings accrue tends to diminish as the riboflavin requirement is reduced, but also because, at some point, some other nutrient is likely to begin to require extra expenditure. As riboflavin levels are lowered, production and consumption patterns change. The excesses of protein and other nutrients over the specified allowances diminish until the minimum set by some other allowance is reached.[22] Beyond this point that other nutrient (which might be protein) becomes a costly element. Whatever savings are still to be made by reducing the riboflavin allowance are offset at least in part by the extra cost now involved in satisfying the requirement for this new costly nutrient.

Whether it is worth an extra penny or two a day to have a diet containing 1.02 mg rather than .8 mg of riboflavin is for the nutritionist or the policy maker to decide. Nutritionists are often reluctant to say that one nutrient is more important than another, but in a world of scarcity, where some people cannot afford the complete set of nutrients that one would desire for them, such a choice may be necessary. These calculations provide the economic data needed if the choice is to be a wise one.

If the riboflavin allowance is reduced while the present levels of protein provided (which exceed the minimum levels required by the model) are maintained, one must expect even smaller savings in the cost of the diets. Under these circumstances, protein is likely to become a costly nutrient very quickly as the riboflavin allowance is lowered, so part of what might be saved by providing less riboflavin would have to be spent in order to maintain the present protein levels.

A Higher Protein Allowance

If an increase in protein production above the levels obtained in this solution is sought, holding the riboflavin allowances where they are, it is likely that protein eventually would become one of the costly elements, at least in two or three areas. Because riboflavin so often is found along with protein, it is also likely that even at the present level of 1.02 mg per person per day riboflavin then would become less costly or even a "costless" food element. Given the frequent incidence

of serious cases of deficient protein intake, such an increase in production levels might be desirable as one means of dealing with various problems that originate outside the sphere of production. These include: (1) losses to insects and spoilage as the result of inadequate marketing and storage facilities; (2) weight losses incurred in the transportation of meat to market (or high costs in the transportation of food in general); (3) wastes that occur in food preparation;[23] (4) increased needs for protein that arise from disease, stress, and parasitic infestations; and (5) an unequal distribution of income that permits the well-to-do to purchase more protein than the poor. It is possible that a sufficient increase in protein production would be a more economical solution to protein deficiency problems arising from one or more of these sources than would a direct attack on the basic difficulty.[24] This model could be used to make an estimate of the cost of providing enough protein to offset such wastes, but this has not been done in this study.

While the nutrient allowances provided by the model are adequate in total amount (that is, on the average), they will not be adequate for all if one fraction of the population obtains a disproportionate share. The allowances were not set at a level that would allow for unequal distribution, nutrient losses in cooking, or the extra nutrient needs associated with parasitic infestations and disease.[25]

This study is concerned with the possibility of obtaining adequate nutrition at low cost. To do so, Nigeria must eliminate wastes associated with these problems. If it does not, larger quantities of nutrients must be provided to offset these wastes.

It would be worthwhile to apply the model with allowances for all nutrients at levels that would allow for production of the extra food needed to offset wastage, losses to worms and weevils, and the extra demands imposed by diseases and parasitic infestations, as well as to meet the special dietary needs of the very young and to allow the well-to-do to consume what they wish while still leaving enough food available to meet the nutrient needs of the less affluent. Solving the model for these allowance levels would provide a different evaluation of the nutritional efficiency of the various crops and perhaps an evaluation that would be more directly relevant to the circumstances of the real world than the one that is presented here. Such information would be useful. It might turn out to be less costly to produce the food needed to offset these wastes and inequities than to make serious efforts to reduce the wastes and maldistribution that exist.

Such a solution, however, would not provide us with the least costly means of providing adequate nutrition for those whose incomes are limited but who are willing to adopt the practices necessary for improved health and nutrition. The present solution does this. It reveals what is the best attainable under the conditions of the model and provides a standard toward which to work. It states what would be possible if wastes and inequity were eliminated. Rather than assuming that these cannot be eliminated, it provides a means of estimating the benefits to be sought by doing what can be done.

The present levels of the nutritional allowances have another advantage as well. They are based on the scientific information available concerning physiological needs. They represent a more objectively quantifiable standard than any set of allowances intended to include the additional nutrients needed to offset wastes and distributional inequities. Estimates of the latter quantities would be very crude indeed.

Allowing for wastage and maldistribution would change the proportions in which the nutrients would be required. Since the proportion of wastage involved is not likely to be the same for all nutrients, the list of economically scarce (costly) nutrients might change. The present solution shows that it would be impossible to increase the allowances significantly for calcium or riboflavin, but higher allowance levels could be attained for a number of nutrients, including protein.

There is a possibility that the protein allowances would need to be raised in greater proportion than most of the others. The sources of animal protein tend to be preferred foods, relatively high in price even in the areas in which they are produced. In addition, prices in the consuming areas of the south must compensate for weight losses and the expense involved in moving animals or their products down from the north. Consequently, the unequal distribution of incomes within the country may have more adverse effects upon the consumption of protein by low income families than upon the intake of other nutrients. If the protein allowance were raised in greater proportion than those for other nutrients, the point eventually would be reached at which protein would become one of the costly nutrients.

The Limiting Amino Acids

The results from the present model provide a forecast of what the nature of the protein problem would be at the higher allowance level. The nutritional adequacy of the protein produced in a country depends upon the quality of the protein as well as upon its quantity.

The quality of protein is determined by the quantity of that essential amino acid which is limiting in the diet—the amino acid that the body runs out of first as it combines the various amino acids in the proportions required for the formation of body tissue. These calculations show that in Nigeria the limit will be set by methionine and cystine, the sulfur-containing group of the essential amino acids. To increase the level of protein availability, developmental research should seek to increase the quantities of these acids in the diet. That in itself would raise the quality and therefore lower the quantity of protein required by the Nigerian consumer. Unfortunately, while some attention is being given to the levels of the amino acids in Nigerian plant breeding programs, the attention seems to be misdirected. A high-lysine maize variety, Western White 1, has been produced, but in Nigeria inadequate lysine production does not appear to be limiting in the human diet.[26] Indeed, the new high-lysine maize has less of the sulfur-containing amino acids than does the indigenous maize, so the introduction of Western White 1 into the Nigerian diet might be expected to make the protein problem worse rather than better.

Customary methods of planning plant breeding programs are conducive to this kind of error. Those designing such programs often have too little detailed knowledge concerning the nutritional situation. Unless the plant breeder works in consultation with those who have a thorough understanding of the nutritional situation, including the economic aspects of the problem, his work may be wasted as far as nutrition is concerned. The level of information possessed by the ordinary, well-informed citizen is not enough. It will not do to know simply that the per capita protein intake is inadequate. One must know why. A protein shortage may exist because the caloric intake is so low that what protein is consumed is being converted into energy rather than used for tissue formation. If this is so, breeding programs need to be concerned with increasing the output of calories as well as, or perhaps rather than, protein. If caloric levels are satisfactory but protein production inadequate, one must know what kind of protein is needed. In one country the limiting amino acids may be the sulfur-containing group (methionine and cystine), as is the case in Nigeria; in another they might be lysine or tryptophan. What is important, moreover, is which essential amino acid is limiting in the diet as a whole, not which is limiting in a particular food. Plant breeding programs must give special attention to increasing the quantities of the limiting amino acids in the diet as a whole.

Presumably the decision to develop a high-lysine maize for Nigeria resulted from the fact that the high-lysine gene (Opaque II) was available and that similar work in Colombia had been successful. Maize protein is low in lysine and tryptophan; introducing the Opaque II gene increases both. Colombian diets, often heavily based on corn, well might be improved by increasing the lysine and tryptophan content of the maize consumed. In the Nigerian situation, however, the limiting essential amino acids are characteristically methionine and/or cystine, as is indicated in several studies. Apparently attention was concentrated on the fact that the quality of maize protein taken by itself can be increased by increasing the lysine-tryptophan content. What was neglected are the facts that maize constitutes a rather small proportion of the Nigerian diet and that the quality of dietary protein as a whole is limited by the composition of the diet as a whole, not by the qualities of the individual proteins involved. It is unfortunate that the decision was made to develop high-lysine maize for use in this setting, particularly when a Floury II gene was available that could have been used to increase the methionine content of the maize. Furthermore, using the high-lysine gene lowered the yields attainable with the new variety.

The Most Economical Foods

Among the customary Nigerian foods are some particularly well suited for providing low cost nutrition. These appear in much larger quantities in low cost than in customary diets. Table 9 includes a group of these foods, specifically, those that appear in the low cost diets of the optimal solution at levels four times as great as our estimate of the customary per capita consumption in a particular area in 1963.[27] If the model permitted them to be used in even larger amounts, the costs of the diets would be lower, that is, less revenue would need to be given up in order to attain the nutrient levels specified. Each numerical entry in the table shows the amount by which the aggregate revenue produced by Nigerian agriculture would rise if the diet in the given area were to contain one kilogram more of the food specified. To provide more of this food would use extra resources, but the nutrients in the food are worth more than the resources required to produce or buy an extra unit of the food. Table 9 shows the excess of the value of the nutrients in the food over the value of the resources required to produce or buy another unit of it. These ex-

Table 9. ***Potential Gains from Expanding or Contracting Those Consumption Activities Significantly Constrained by Their Maximum or Minimum Levels, in Shillings per Kilogram***

Food	*Area*					
	I	*II*	*III*	*IV*	*V*	*VI*
Activities at maximum levels						
Maize, whole, white				.72		
Sorghum			.31			
Potato, Irish	.13					
Cowpea					.28	
Groundnut, seed				.43		
Oil, groundnut		.88	.99			.22
Fish, dried, freshwater	98.					
Beef				1.4		
Goat meat (chevon)				4.1	1.6	
Mutton				2.3	.51	
Beer, millet	.017					
Activities at minimum levels[a]						
Beer						
Millet		.076				.055
Guinea corn		.076				
Wine, palm			.16	.031	.077	
Kola nut	2.8	1.7				

NOTE: If the maximum level were raised, or the minimum lowered, the revenue provided by the solution would increase.
[a] Because required by the model.

cesses are the surpluses associated with the consumption of one unit of the food.

The greatest surplus is found in the dry savanna (Area I), where dried freshwater fish with edible bones provides nutrients worth 98s per kilogram more than the cost of obtaining the fish. Obviously this is because this fish is an economical source of calcium, which is extremely expensive. If one were to be satisfied with a lower calcium allowance, dried freshwater fish would provide less surplus.

It also must be noted that the customary consumption of dried fish is very low in the two savanna areas, so the maximum limit on dried fish consumption there is only .65 kg per capita per year.[28] If the limit were higher, the cost of calcium would be lower, and the surplus nutrient value of dried freshwater fish would be less.

The other foods that offer surpluses of nutrient value provide them in much smaller amounts. Most significant are the animal meats (goat, mutton, and beef), whose surpluses range from .5s to 4s per kilogram in the central and eastern moist forest areas (Areas IV and V). They are valuable for their riboflavin and calories, however, not for their protein. The ranking of their surpluses (goat, mutton, and

beef) reflects the importance of their riboflavin content. Goat meat (chevon) provides .35 mg of riboflavin per 100 g of the edible portion, while mutton provides .25 mg and beef only .20 mg.

Groundnut oil provides surplus nutrient value in three of the six areas. It is an economical source of calories. A few other foods provide surpluses in individual areas.

Foods that do not contain sufficient nutrients to be worth the resources required to produce them do not appear in the diet at all unless the model specifically requires them in accordance with some customary dietary practice. There were such conventional requirements for beer, palm wine, and kola nuts in certain areas. Foods that appear in the model only because of such a requirement are listed in the lower section of Table 9.

Millet beer is an interesting case. In the dry savanna (Area I) it plays a significant nutritional role, yielding a small surplus of nutrient value (.017s per kilogram). In the intermediate savanna and the forest-savanna mosaic (Areas II and VI), calcium is less valuable, and calories are more valuable. There the nutrients in millet beer are not worth the cost of the resources employed in providing them, as Table 9 shows. Beer consumption in the intermediate savanna falls short by .076s per kilogram of providing nutrients worth the resources devoted to this purpose. Millet beer is as economical a means as exists of satisfying the minimum consumption requirement in Areas II and VI, but in Area II the requirement is principally satisfied by guinea corn beer. The aggregate consumption of millet beer that this solution provides for Area II is 63 million kg, but the optimal consumption level for guinea corn beer is 1,614 million kg.

Summary

This study seeks an efficient organization of Nigerian agricultural resources, given that specified levels of nutrient availability must be attained before resources can be devoted to the production of income. Under these circumstances, the cost of the daily least-cost diet per capita, using 1963 prices for revenue crops, ranges from .74s to 1.50s. This may represent as much as 41 to 83 percent of the GDP, depending upon the area.

The allowances for four nutrients are controlling. Calories, calcium, riboflavin, and vitamin A cannot be provided in adequate amounts in each part of Nigeria without using resources that otherwise could

have been used to produce income. The most costly allowance to attain in most parts of Nigeria is the caloric one, but calcium is extremely expensive in the dry savanna, and riboflavin is quite costly in the moist forest area.

When adequate amounts of these four nutrients are provided in an economical way, the allowances for the other nutrients are more than adequately satisfied. This finding is particularly significant in the case of protein. There is, to be sure, a widespread problem of protein-calorie malnutrition in Nigeria, but it is clear from these results that the problem does not lie primarily in the sphere of production. The most pressing production problems are for calories and riboflavin, not for protein. Nigeria is quite capable of producing the quantities of protein specified by our allowances. Whether that protein is being satisfactorily distributed among areas and among people is another matter.

5

Geographical Specialization And Internal Trade

The total value of the nutrients provided for Nigeria in this solution, at the point of consumption, is 25.6 billion shillings.[1] This sum includes the value of transportation services and food obtained from outside the Nigerian agricultural sector. Of this amount, 9.4 billion shillings is the value of the calories required for all of Nigeria, 11.0 billion is the value of the calcium (10.5 billion of this for the dry savanna alone[2]), and 4.3 billion is the value of the riboflavin (which has value only in the three moist forest areas). Using these valuations one might say that 40 percent of the value of the resources devoted to the provision of nutrients in this solution was spent in providing calories, 40 percent in providing calcium, and nearly 20 percent in providing riboflavin. The gathered and collected foods used in this solution provide 25 percent of the value of the nutrients available for Nigeria.

Aggregate Output of the Agricultural Sector

To arrive at the total value of the aggregate output of the agricultural sector the value of the nutrients consumed must be adjusted by subtracting the value of food obtained from outside the Nigerian agri-

cultural sector (from fishing or from outside the country) and the payments made to the nonagricultural sector for transportation services used in moving food from production to consumption areas. The revenue obtained from the income producing activities of agriculture (activities that do not produce food used within Nigeria) then must be added. The result is an aggregate output of 26.6 billion shillings, as shown in the tabulation below, given in billions of shillings.

Value of nutrients consumed within Nigeria		25.6
Obtained from outside the Nigerian agricultural sector:		
Purchased food	.4	
Transportation services	1.2	
	1.6	—1.6
Provided by the Nigerian agricultural sector		24.0
Provided by gathered and collected foods	6.5	
Provided by the activities included in this model	17.5	
	24.0	
Revenue from nonfood producing activities of the agricultural sector		2.6
Value of aggregate output of the Nigerian agricultural sector		26.6

It is evident that the agricultural sector, using 1963 levels of technique, is capable of producing enough to provide 61 million people with the nutrients specified by our allowances and have a small margin left over. By producing 24.0 billion shillings worth of food and exchanging 1.6 billion shillings of nonfood income for transportation services and food from outside the agricultural sector, the agricultural sector can provide Nigeria's people, urban and rural alike, with food worth 25.6 billion shillings. It also can provide an extra nonfood income of 1.0 billion shillings, which amounts to about 4 percent of the value of the food provided for Nigerian consumption. The margin by which Nigeria's total agricultural capacity exceeds that required to

feed its whole population at the specified levels of nutrition is positive, but very small.[3]

Nigerian nutritional needs press hard upon the food production capacity of the agricultural sector. A lag of no more than four years in the level of technology employed places Nigeria perilously close to its limits. Using 1963 methods to feed the 1967 population of 61 million, with production and trade patterns organized for maximum nutritional efficiency, 96 percent of the 1967 production capacity would be required to provide daily per capita nutrient intakes of 2,266 k calories, 34.4g of reference protein, 389 mg of calcium, 1.02 mg of riboflavin, and so forth. Two nutrients in particular would be near the limits of feasibility: calcium (at 91 percent of the maximum possible under the conditions of our analysis) and riboflavin (at 88 percent of the maximum).

The 1963 population of 56 million may become 95 million by 1985. Nigeria's capacity to continue to meet its basic nutritional needs will depend upon its ability to achieve a high level of efficiency and to maintain a satisfactory rate of technical progress in nutrient production. The margin of safety is very small.

Revenue Producing Activities

Given the agricultural techniques in use in 1963, the optimal allocation of revenue producing activities among areas would provide the results shown in Table 10. The pattern, much like that already prevailing in Nigeria, is evidence that the existing allocation of export production is fundamentally sound.

According to this solution, a total agricultural income of 2.6 billion shillings (£130 million) is possible without lowering levels of nutrient availability below those specified in this model. Although no effort was made to design the model so that the figures for aggregate revenues earned would be directly comparable with the actual sales levels of the various revenue producing industries, our figure of £130 million may be compared with John Cownie's estimate of £98 million as the contribution of Nigerian agricultural exports to 1967 Gross Domestic Product.[4]

Our figure would be expected to depart from the record of observed experience for a number of reasons. First, our revenue levels are optimal in the sense of the model—optimal for a nation that provides adequately for the nutrition of its people before it attempts to

maximize the return from its production of nonfood income. There is no reason to believe that the Nigerian economy as it actually operates provides an optimal result in this respect. Second, when the model determines the quantities of the major export crops to produce and sell it takes account of the full value of the revenue they produce; in reality, the Nigerian farmer, who actually makes the decisions that govern total output levels, is allowed by the marketing boards to retain only part of the value of the crop he produces.[5] Under these circumstances he is not to be expected to make decisions that would be optimal from the standpoint of the country as a whole.

Table 10. ***Income Producing Activities, in Millions of Shillings***

Activity	*Area*						*Total*
	I	*II*	*III*	*IV*	*V*	*VI*	
Export hides and skins[a]							
Beef			34.1	17.2	22.1		73.4
Goat			24.6	7.9	85.7		118.2
Mutton			4.7	5.0	31.3		41.0
Sell cotton							
Produced as a sole crop	47.5	83.3					130.8
Produced as a mixed crop		21.9				7.7	29.6
Export							
Groundnuts, seed	493.8						493.8
Groundnut cake	48.8						48.8
Sell tobacco	3.6	10.4					14.0
Export							
Cocoa			927.2	20.4			947.6
Rubber			9.3	157.9			167.2
Export							
Palm kernel				13.3	171.2	66.8	251.3
Red palm oil					219.8		219.8
Palm kernel oil			60.2				60.2
Palm kernel cake			25.8				25.8
Total	593.7	115.6	1,085.9	221.7	530.1	74.5	2,621.5
Net foreign exchange earnings							2,845.2
Total per capita, in shillings	27.8	11.1	98.7	92.1	46.0	17.5	43.0

[a] We assume that all hides and skins are sold for export.

Our figure also may be compared with the total value of the major Nigerian agricultural exports: £142 million in 1966 and £130 million in 1967.[6] These export values, of course, do include the value of the transportation and merchandising services utilized in delivering these crops to the port, but our figures do not. Partially offsetting this fact is

our assumption that all hides and skins are exported, which is not the case. Our figures also include small items of nonexport revenue such as the sale of cotton and tobacco within Nigeria. In addition, they take no account of any effects from the war then going on within Nigeria.

This solution provides net foreign exchange earnings of 2.8 billion shillings (£142 million). This figure includes the value of transportation to the port, but excludes the foreign exchange used for imports of food and fertilizer The latter figure does not exceed 110 million shillings (£5.5 million). (See Table 11.[7])

The major revenue producing area in the optimal solution is the western moist forest, with export earnings from cocoa alone of 900 million shillings (Table 10). Next in importance are the dry savanna and the eastern moist forest (Areas I and V). Groundnuts form the major revenue crop for the dry savanna, and palm products for the eastern moist forest.

Table 11. ***Expenditures on Food and Fertilizer***

Item	*Area*						*Total*
	I	*II*	*III*	*IV*	*V*	*VI*	
			Million shillings				
Food							
Fish, dried freshwater	71.5		143.6	27.7	80.8	14.4	338.0
Sugar, white			106.1				106.1
Total food	71.5		249.7	27.7	80.8	14.4	444.1
Fertilizer							
For maize, commercial			1.2		.8	1.4	3.4
Total	71.5		250.9	27.7	81.6	15.8	447.5
			Shillings				
Per capita							
Food	3.3		22.7[a]	11.5	7.0	3.4	7.3
Fertilizer			.1		.1	.3	.1
Total	3.3		22.8	11.5	7.1	3.7	7.3[b]

[a] Of which 13.1s are for fish.
[b] The discrepancy between the sum and the parts is caused by rounding errors.

The central moist forest is more important as an exporting area than appears at first glance. Although its total export product is only about half that of the eastern moist forest, on a per capita basis the central forest ranks well ahead of both the eastern moist forest and the dry savanna, and only slightly behind the western moist forest.

In this solution, hides and skins worth 230 million shillings are exported from the moist forest areas.[8] Most of these come from animals produced in the savanna areas but consumed in the moist forest areas. (In this least-cost solution no beef, goat meat, or mutton is consumed in the savanna areas or in the forest-savanna mosaic. However, the milk from the northern herds is consumed in the two savanna areas.)

Palm products account for 557 million shillings of revenue altogether, with most of this coming from the eastern moist forest.

Purchases from Outside Nigerian Agriculture

To attain these levels of export production, Nigerian agriculture must be assisted by the transportation sector (which provides for movement of food between areas) and must purchase some food and fertilizer from outside Nigerian agriculture.

Nigeria's actual food imports in 1967 amounted to £21 million in value. The principal items were fish, wheat, milk and cream, and sugar.[9] As Table 11 shows, purchases of this magnitude still would be desirable in an economy organized with a single-minded concentration on nutrition and income. Food purchases worth 444 million shillings (£22 million) are optimal for the present model, but they are concentrated on two of these four items: fish and sugar. The optimal fish, however, are the dried freshwater variety, with the bones included,[10] not stockfish, the principal type actually imported.[11] Because the bones are included, dried freshwater fish provide an economical source of calcium, one of the controlling nutrients in every area except the intermediate savanna. They also provide about twice as much food energy and riboflavin per kilogram as do stockfish. In the dry savanna calcium is so difficult to obtain from other sources that the value of the nutrients provided by dried freshwater fish exceeds the market price of the fish by 98s per kilogram (Table 9).

Important as the fish are to attaining the nutritional levels specified by the model, the optimal expenditures on them are relatively small. In the dry savanna only 3s per capita per year are required; in the central and western moist forests 11.5s and 13s respectively. Even the latter figures, however, represent less than 3 percent of the total cost of the diet in these areas.

The only other food that is economical to purchase from outside Nigerian agriculture is sugar. In this solution the major importing area, the western moist forest, buys 100 million shillings' worth to augment its internal supplies of food energy.[12]

As Table 11 shows, it is profitable to purchase small amounts of fertilizer for use in commercial maize production in each of the areas in which the activity exists in the model.[13]

The largest payments provided by the nonagricultural sector are for the transportation services required to move food from producing to consuming areas within Nigeria. Table 12 shows the amount of income generated in this solution by the transportation activities associated with these food movements. This income is in addition to the revenue earned by the agricultural sector.

In the aggregate, food transportation payments amount to more than 2.5 times the total expenditure on food from outside the Nigerian agricultural sector. On a per capita basis as well as in the aggregate, the eastern moist forest requires the most transportation services for food obtained from other areas (52 shillings' worth annually), and the dry savanna makes the largest use of transportation services for the shipment of the food it sends to other areas.

Table 13 summarizes the relationship between the revenues (exclusive of the value of food produced) that can be earned by Nigerian agriculture and the expenditures on goods and services from outside the agricultural sector that are necessary if those revenues are to be attained. If the maximum income from agriculture is to be had, food expenditures from outside agriculture must equal nearly one-sixth of the total nonfood revenues from agriculture. Without these purchases, resources would have to be converted from income production to nutrient production. The reduction in income could not possibly be less than 444 million shillings (for the existing solution is optimal); it almost certainly would be a great deal more than that.[14]

Table 12. ***Payments for Transportation of Foods Produced by Nigerian Agriculture, in Millions of Shillings***

Activity	*Area*						*Total*
	I	*II*	*III*	*IV*	*V*	*VI*	
From Area I							
Millet					598.4	69.7	668.1
Millet for beer						23.2	23.2
Rice			99.7				99.7
Groundnuts				3.0			3.0
Groundnut oil		17.9	8.2			7.7	33.8
Beef cattle[a,b]		0.0	0.0	0.0			
Goats[a]		0.0		0.0			
Sheep[a]		0.0		0.0			
Subtotal (Area I)		17.9	107.9	3.0	598.4	100.6	827.8

From Area II							
Maize			31.9				31.9
Rice			6.3				6.3
Sorghum			10.0				10.0
Gari			3.4				3.4
Cowpeas	54.0						54.0
Groundnuts			2.2				2.2
Melon seed			7.8				7.8
Red palm oil[c]	12.4[c]						12.4
Beef cattle[a]						0.0	
Goats[a]			22.8		0.0		22.8
Sheep[a]			2.2			0.0	2.2
Subtotal (Area II)	66.4		86.6				153.0
From Area III							
Red palm oil		16.0					16.0
Kola nuts	48.8	19.9					68.7
Subtotal (Area III)	48.8	35.9					84.7
From Area IV							
Gari			14.5				14.5
Yams			1.7				1.7
Subtotal (Area IV)			16.2				16.2
From Area V							
Rice				1.5			1.5
Red palm oil				1.8			1.8
Subtotal (Area V)				3.3			3.3
From Area VI							
Maize				3.3	3.8		7.1
Rice				2.5			2.5
Gari				4.8			4.8
Cowpeas					.01		0.01
Melon seed				1.0			1.0
Okra					.05		0.05
Red palm oil		61.3					61.3
Beef cattle[a]					0.0		
Goats[a]					0.0		
Sheep[a]					0.0		
Subtotal (Area VI)		61.3		11.6	3.9		76.8
Total (Areas I-VI)	115.2	115.1	210.7	17.9	602.3	100.6	1,161.8
Total per capita, in shillings							
Shipments to area	5.4	11.1	19.2	7.4	52.2	23.6	19.1
Shipments from area	38.7	1.5	7.7	6.7	0.3	18.0	19.1

[a] Zero transportation costs for meat animals indicate that the animals are brought in on foot. In these cases, bringing the animals to market is regarded as a part of agricultural production.

[b] The nomadic herds identified as Area I animals in this model actually spend about two-thirds of their time within the geographical boundaries of Area II.

[c] This oil originated in either Area III or Area VI.

Table 13. *Summary of Revenue Transactions*

Transaction	*Area* I	II	III	IV	V	VI	*Total*	*Area* I	II	III	IV	V	VI	*Nigeria as a whole*
	Million shillings							Shillings per capita						
Revenues from income producing activities	594	116	1,086	222	530	75	2,622	27.8	11.1	98.7	92.1	46.0	17.5	43.0
Expenditures														
Food not obtained from Nigerian agriculture	72		250	28	81	14	444	3.3		22.7	11.5	7.0	3.4	7.3
Fertilizer			1		1	1	3			.1		.1	.3	.1
Transportation of food	115	115	211	18	602	101	1,162	5.4	11.1	19.2	7.4	52.2	23.6	19.1
Revenue less expenditures[a]	407	1	624	176	—154	—42	1,012	19.1	0.0	56.7	73.2	—13.3	—9.8	16.5

[a] Any discrepancies between the sum and the parts are caused by rounding error.

In the same way, if it were impossible for one area to obtain food from another, many resources available for income production in this solution would have to be devoted to food production. In this solution, expenditures on food transportation were worthwhile that amounted to 1,160 million shillings (nearly half the total revenue from income producing activities).[15] The food transported was worth 1,160 million shillings more in the areas where it was consumed than in the areas where it was grown. If transportation had not been available, the value of the resources required to produce the extra food in the consuming areas would have been at least 1,160 shillings more than that of the resources they would replace in the producing areas, so there would have been a net reduction in the value of production for export of at least this amount. The value of trade as a means of permitting a nation to take advantage of its ecological diversity is indicated by this figure, but in all probability the reduction in the output of the income producing activities would have been much greater than 1,160 million shillings.

It is economical for such important exporting areas as the dry savanna and the western moist forest to spend about 20 percent of their earnings from export production on transportation charges for bringing food in. In the western moist forest it is worthwhile to spend another 25 percent on food from outside Nigerian agriculture. In the eastern moist forest and the forest-savanna mosaic, the total value of earnings from production for income is insufficient to pay the transportation cost of food brought in from other areas, let alone the cost of food obtained from outside the agricultural sector. As will be seen, the forest-savanna mosaic sends out more pounds of food in this solution than it receives from other areas, so it may be able to exchange some of this for transportation services; this is not true for the eastern moist forest. Although in every area the nonagricultural sector does in fact exchange its own goods and services for food, it is only in the eastern moist forest that the agricultural sector appears to be unable, by the exchange of its own produce, to bring in the food needed to supplement its own production so that all people, both in the agricultural and the nonagricultural sectors, can meet the nutritional levels specified in this study. This is evidence of the relative seriousness of the food (or population) problem in that area.

Internal Movements of Food

Figure 6 shows the principal food movements that are necessary if optimal levels of revenue producing activities are to be attained with-

out reducing nutrient availability below the levels here specified. (Table 14 gives the complete record.) The major movement is of millet. Two billion pounds of it move into the eastern moist forest (Area V) in this solution, and another 600 million pounds into the forest-savanna mosaic (Area VI). Millet is nutritionally important in Area V as a

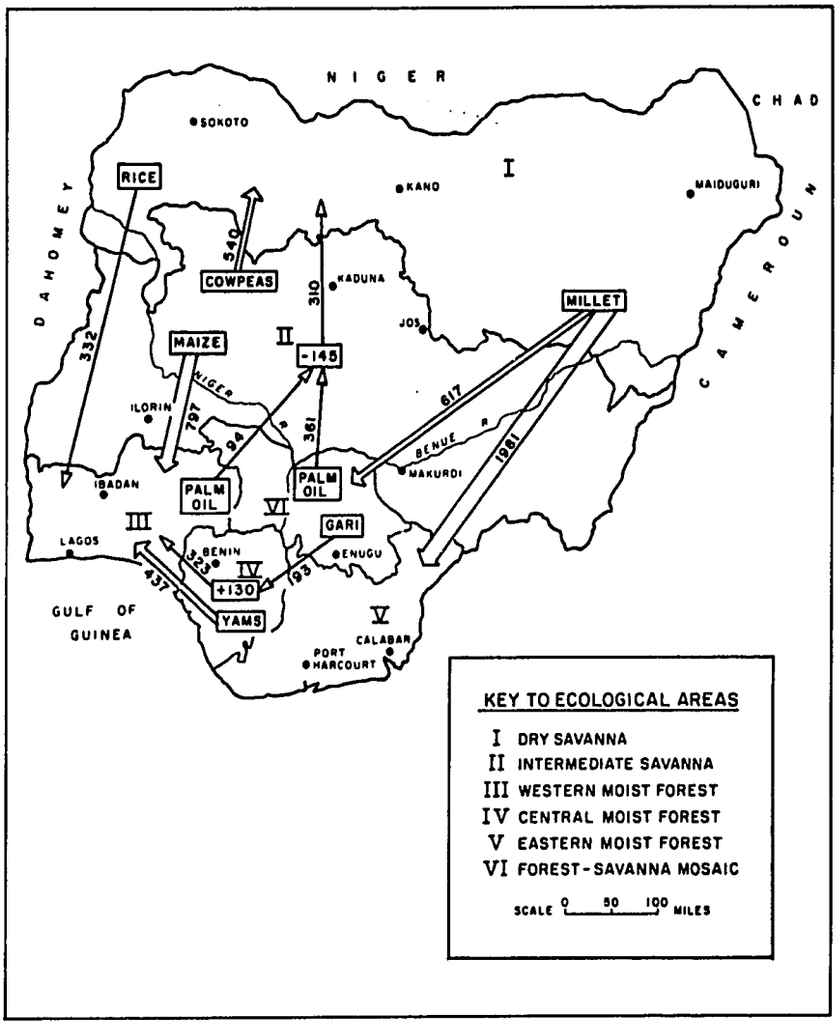


Figure 6. *Major Food Movements*

source of riboflavin and calories. The fact that it is present in such large quantities partially explains why the protein allowance specified for this area is heavily overfulfilled. In Area VI, the caloric contribution of millet is the principal source of its importance; riboflavin is not a scarce nutrient in that area.

Unfortunately, although large quantities of millet are economical in Area V, it is not a food that is widely consumed there. Therefore, quick results normally could not be expected from efforts to improve diets in this area by promoting its consumption. However, the Ibos who returned from the north after the riots of September 1966 knew how to cook guinea corn and millet and were accustomed to eating them. Consequently, the use of such foods in the eastern moist forest might be more easily brought about now than formerly.

About one billion pounds of maize move into the rain forest areas, most of it into the western moist forest. As is millet in Area V, it is nutritionally important for the calories and riboflavin it provides.

Other cereal foods traded in large amounts in this solution are gari (580 million pounds altogether), cowpeas (540 million pounds), and rice (510 million pounds). The western moist forest is the principal recipient of gari and rice, but the cowpeas go almost entirely into the dry savanna. (Cowpeas provide the high ratio of calcium to calories that is needed in the latter area to meet the specified nutritional allowances.)

Table 14. *Quantities of Nigerian Foods Transported between Areas, Weight at Farm, in Millions of Pounds*

Item	*Receiving area*						*Total*
	I	*II*	*III*	*IV*	*V*	*VI*	*sent out*
From Area I							
Millet					1,981	462	2,443
Millet for beer						155	155
Rice			332				332
Groundnuts				11			11
Groundnut oil		106	26			37	169
Beef cattle		35	193	98			326
Goats		133		12			145
Sheep		47		12			59
Subtotal (Area I)		321	551	133	1,981	654	3,640
From Area II							
Maize, local white			797				797
Rice			63				63
Sorghum			77				77
Gari			67				67

Cowpeas	540						540
Groundnuts			7				7
Melon seed			65				65
Red palm oil[a]	310[a]						310
Beef cattle						120	120
Goats			41		140		181
Sheep			10			61	71
Subtotal (Area II)	850		1,127		140	181	2,298
From Area III							
Red palm oil		94					94
Kola nuts	113	55					168
Subtotal (Area III)	113	149					262
From Area IV							
Gari			323				323
Yams			437				437
Subtotal (Area IV)			760				760
From Area V							
Rice				30			30
Red palm oil				25			25
Subtotal (Area V)				55			55
From Area VI							
Maize, local white				133	125		258
Rice				83			83
Gari				193			193
Cowpeas					1		1
Melon seed				35			35
Okra					5		5
Red palm oil		361					361
Beef cattle					125		125
Goats					6		6
Sheep					73		73
Subtotal (Area VI)		361		444	335		1,140
Totals (Area I–VI)							
Gross purchases	963	831	2,438	632	2,456	835	8,155
Purchases net of offsetting sales[b]	963	819	2,438	502	2,456	818	7,996

[a] This originated in Areas III and VI.
[b] Of individual commodities.

Red palm oil moves into the two savanna areas. In the intermediate savanna it is useful primarily for its caloric content, but in the dry savanna its vitamin A content is the only reason for its presence in the solution.[16] Yams move from the central to the western moist forest, where the calories they provide are more valuable.

Beef, goat meat, and mutton move into the moist forest areas, some-

times passing through Area VI (the forest-savanna mosaic). (In this solution, none is consumed outside the moist forest areas.) The meats owe most of their importance to the riboflavin they provide, although their caloric content is not to be ignored. Adequate quantities of protein are provided when the needs for calories, riboflavin, and calcium are met, so the protein content of meat is *not* the reason for its purchase by any area in this solution.

If Table 14 is viewed in terms of areas rather than commodities, from the area totals it can be seen that the savanna areas and the forest-savanna mosaic are the principal providers of food for other areas, while the eastern and western forest zones are the principal recipients. Area I, the dry savanna, provides millet, rice, groundnut oil, and meat, receiving cowpeas, red palm oil, and kola nuts from Areas II, III, and VI. Area II, the intermediate savanna, provides maize, cowpeas, meat, and assorted field crops, sending cowpeas north and the other products south; it receives groundnut oil, palm oil, and kola nuts. The meat animals recorded in the table as moving into Area II moved on out to other areas, along with animals produced in Area II. Actually, a large fraction of the cattle and goat output of Area I might well be credited to Area II. The nomadic herds that are identified in this model as Area I animals roam over a geographical range that lies within both areas. They may spend as much as two-thirds of their time within the spatial boundaries of Area II.

Area III, the western moist forest, receives a variety of foods from the savanna areas, plus gari and yams from the central moist forest. It provides only palm oil and kola nuts for other areas.

Area IV, the central moist forest, receives mainly meat from Area I and field crop products from Area VI. Area V, the eastern moist forest, takes mainly millet (from Area I), but supplements this with meat from Areas II and VI, maize from Area VI, and a few minor items. It provides very little food for other areas. Area VI, on the other hand, receives almost nothing except millet (from Area I); the meat that comes in from Area II moves on again. Area VI itself provides field crop products and some meat to Areas IV and V, plus red palm oil for the savanna areas.

In this solution, one of the major exporting areas, the dry savanna, is also the most important source of food for other parts of the country. The other two, the eastern and western moist forests (Areas III and V), are the principal recipients of food from other areas and provide very little food in return. The central moist forest obtains

food from Areas I and VI, but provides gari and yams for Area III. Area VI, the forest-savanna mosaic, is an important supplier for both the north and the south, but receives in its turn almost two-thirds as much, over half of that being from the dry savanna. Area II, the intermediate savanna, likewise provides food for the areas both north and south of it, receiving palm oil, groundnut oil, and kola nuts. Area I, the dry savanna, is the major source of food for other areas, but requires cowpeas, palm oil, and kola nuts in exchange.

The entries in Table 14 make no allowance for the fact that some shipments into an area may be replacements for quantities of the same food that are being shipped out of the area, or may be merely passing through to another destination. The second-row totals at the bottom of the table give the purchases of each area after subtracting those that pass on to other areas or replace shipments to other areas of the same item. These do not differ markedly from the gross purchases totals.

Table 15 shows the pattern of such partically offsetting purchases or sales, by area and commodity. Area II is a net purchaser of red palm oil, Area IV is a net seller of gari, and Areas II and VI are net sellers of meat.

Without these internal movements of foodstuffs, Nigeria's capacity to earn income by production for export without lowering the quantities of nutrients available would be reduced. The resources required for the production of the nutrients provided in this model would be at least 1,160 million shillings greater if all nutrients had to be produced within the areas in which they are consumed.

The amount of the reduction in income which would have to occur in order to maintain the same level of nutritional availability if trade were reduced or cut off has not been calculated, but it could be done easily. Some nutrient levels might not be attainable at any cost if all trade were stopped. An earlier run of a related model already has shown that even a partial blocking of trade channels for red palm oil can make it impossible for all parts of the country to attain the vitamin A levels called for in the model.

Expanding food crops in the areas where such expansions can contribute most effectively to increased Nigerian nutrition and income means increased dependence upon specialization and increased dependence upon transportation and marketing processes. While the trade pattern contained in this optimal solution is a plausible one, consistent generally with commodity movements that are already

familiar within Nigeria, it seems unlikely that the actual volume of trade in certain items attains the levels called for in this solution. Certainly the volume of millet moving into the eastern moist forest and the forest-savanna mosaic is unusual. Even more startling is the fact that all of the meat animals produced by the animal industries of the savanna areas and the forest-savanna mosaic are sent to the rain forest areas. This provides adequate protein for those areas, turning the protein-short eastern moist forest into an area of protein abundance.

Table 15. ***Offsetting Purchases and Sales, in Millions of Pounds***

Item	*Purchases*		*Sales*		*Net sales*
	Origin	*Quantity*	*Destination*	*Quantity*	
Area II					
Beef cattle	I	35	VI	120	85
Goats	I	133	III	41	
			V	140	48
Sheep	I	47	III	10	
			VI	61	24
Red palm oil	III	94	I	310	
	VI	361			—145
Subtotal		670		682	—12
Area IV					
Gari	VI	193	III	323	130
Subtotal		193		323	130
Area VI					
Beef cattle	II	120	V	125	—5
Sheep	II	61	V	73	—12
Subtotal		181		198	—17
Total		1,044		1,203	159

This solution reveals opportunities that exist for improving Nigerian well-being by encouraging the development of efficient trade and transportation between the various parts of the country. Concurrent with this, of course, would be the development of improved food processing and storage enterprises. Concentrating solely on production is not likely to be the most efficient approach to Nigeria's nutritional problems.

6

Production Activities In the Optimal Solution

In this model, productive activities either yield revenue directly or yield nutrients that release resources that could be used in producing revenue directly. If an activity yields nutrients its productivity (the value of those nutrients) can be measured by the following test: (1) Reduce the level of the nutrient producing activity by one unit. (2) See what losses in nutrient availability result. (3) Replace these nutrient losses (except where the nutrient allowances are still satisfied even after these losses) by diverting resources from the production of income crops. (4) Determine the value of the income production that was lost by this diversion of resources.

The levels at which productive activities enter the optimal solution are limited by the yields they are able to earn on the scarce resources they require and by the maximum limits that the model imposes on individual activities. If an activity cannot earn as great a yield for the resources it employs as those resources would earn if made available for other activities, it does not appear in the optimal solution—its optimal level is zero.

If an activity can earn only as much as the resources it employs

could earn elsewhere, it is in the optimal solution, but may be below the maximum level permitted by this model. If an activity can earn more than the resources it employs can earn elsewhere, it is in the solution at the maximum level permitted by the model. In such a case the revenue from Nigerian agriculture could be increased if the maximum level were increased.

The total value of the output of any activity consists of the earnings of the resources it employs plus any surplus attributable to the activity as such. If a surplus exists, the activity is at its maximum level; permitting the activity to expand by one unit above its maximum level would add to the agricultural income of Nigeria. The amount of the surplus is a measure of the net contribution of one unit of an activity to Nigerian agricultural income—its contribution in excess of the use value of the resources it employs.

What a resource can earn (its use value) is measured by the reduction in the agricultural income of Nigeria that would occur if one unit of the resource were to vanish. This is essentially equivalent to the opportunity cost of the resource. In the case of land this would be the value that would be lost if land were withdrawn from its least profitable uses.[1] The value that would be gained by adding an acre of land is normally the same figure. However, as additions of land continue, the number of unused possibilities for its employment decreases, so at some point the benefit from adding an acre of land must decrease.

The optimal solution maximizes the income available from Nigerian agriculture after providing the quantities of nutrients specified by the model. It includes at positive levels only those activities that yield a product worth at least as much as the value of the resources used. It provides a standard of comparison for evaluating the actual pattern of production in Nigeria and points out directions of change that would benefit Nigeria in terms of either income or nutrient availability.

Is the actual production pattern already optimal, or can it be improved? More specifically, was the 1963 pattern of production at maximum efficiency as a means of maximizing agricultural income while maintaining the specified standards of nutritional adequacy? To test the hypothesis that the 1963 pattern was optimal we compare it with the pattern defined in this solution.

If the 1963 pattern was optimal for 1963 conditions, it still would be optimal in 1967 if the desired nutrient levels increased by 9.5 percent because the 1967 population had increased by 9.5 percent, as had

the labor and land resources available. In that case, the pattern would be the same for both the 1963 and 1967 levels of population, but in the solution for 1967 every production activity would be carried on at a level 9.5 percent above the 1963 level.

In actuality it is impossible to increase indefinitely all land and labor resources in proportion to the population growth. This limitation already is being felt in the dry savanna, where the expanding use of land for cropping is reducing the quality available for pasture, and in the eastern moist forest, where the fallow period has been shortened considerably because of population pressure on the land resources available. Outside these two areas, the model allows both arable land and bush pasture (as well as labor) to increase by 9.5 percent. In the dry savanna, the bush pasture available in the model is less than our estimate of the 1963 level by the amount of the increase in arable land in that area. In the eastern moist forest an increase in land under cultivation is allowed (by 9.5 percent), but only at the expense of a decrease in yields on all land in use.

Under the conditions of the model, therefore, the optimal solution for 1967 would not combine production activities in the same proportions as in 1963, even if the 1963 proportions were optimal. The limitations on bush pasture in the dry savanna would prevent the traditional animal industries from expanding by 9.5 percent in that area, while the reduced yields that result from increasing the use of arable land in the eastern moist forest would lead to a readjustment of cropping patterns there and in the areas providing food for the eastern moist forest. In general, the effects of these restrictions would be to require animal activities outside the dry savanna and some food crops in various parts of the country to expand by more than 9.5 percent to offset the relative lack of expansion of the traditional animal industries in the dry savanna and food crops generally in the eastern moist forest. The result would be diversion of some arable land from the production of cash crops, so the average expansion of income producing crops would be held to less than 9.5 percent.

The maximum limits on individual production activities are set at 120 percent of our estimates of 1963 levels. If the 1963 pattern was optimal, cash crop production levels in the 1967 solution generally should stand at something less than 92 percent of the maximum levels,[2] while food crop production activities should stand at something over this figure. If solution levels in the optimal solution are

found to deviate sharply from this pattern, the traditional patterns of 1963 were not optimal in terms of the goals set forth in this model.

Cash Crop Production

For most revenue crops the optimal production levels in the 1967 solution are well over 92 percent of their maxima. Indeed, they are *at* maximal levels for all except cotton as a mixed crop in the two savanna areas and rubber in the central and eastern moist forest. (See Table 16.) It follows that the 1963 production pattern was not optimal for the goals specified in this model.[3] A proportionate expansion of the 1963 pattern would have used for cash crop production only 91 percent of the total of the maximum acreages available for such crops in the model. If we include all the crops listed in Table 16 except the kola nut (which is a food, not a cash, crop), the present solution uses 95 percent of that total for revenue crops. Revenue crop production in 1963 could have been expanded without reducing nutrient availability below the levels specified in this model.

Of course, the potential revenue gain from expanding production would not be the same for each cropping activity. Measures of such gains, when acreages are at the optimal levels for the 1967 solution, are given in Table 17. This table shows the additional income that could have been earned by Nigerian agriculture as a whole if the maximum limit had been one acre larger for any one of these crops. The same figures also measure the loss of income associated with acreage levels that fall below the optimal levels as given by this solution.[4] They are conservative measures of this loss, however, for as acreage falls farther and farther below the solution level the loss per acre eventually begins to rise.

These loss measures could be used in assessing the economic significance of the usual marketing board policy of paying the farmer less than the full value of his produce. As the farmer determines his acreage on the basis of the price he actually receives, one would expect him to produce less than is socially optimal. Table 17 indicates that the loss to Nigeria when oil palm acreage in the western moist forest is below the optimal level for this solution is 489s per acre (or more if the divergence is large); the loss when cocoa acreage in that area is below the solution value is 390s per acre (or more).

The principal concern, however, is with the gains that could accrue from expanding production beyond the solution levels (for expansions

Table 16. ***Levels of Cash Crop Activities, in Thousands of Acres***

Crop	*Level*	*Area* I	II	III	IV	V	VI
Field Crops							
Groundnut[a]							
Sole	Sol	M	M	–	–	–	M
	Max	1,543	220	–	–	–	67
Mixed	Sol	M	M	–	–	–	M
	Max	3,416	370	–	–	–	101
Bean, soya[a]							
Sole	Sol	–	–	–	–	–	M
	Max	–	–	–	–	–	185
Cotton							
Sole	Sol	M	M	–	–	–	–
	Max	248	339	–	–	–	–
Mixed	Sol	0.0	12.9	–	–	–	M
	Max	248	359	–	–	–	52
Tobacco							
Sole	Sol	M	M	–	–	–	–
	Max	4	11	–	–	–	–
Tree Crops							
Oil palm[a]	Sol	–	–	M	M	M	M
	Max	–	–	1,265	223	2,409	964
Cocoa	Sol	–	–	M	M	–	–
	Max	–	–	1,325	52	–	–
Kola nut[b]	Sol	–	–	M	–	–	–
	Max	–	–	603	–	–	–
Rubber	Sol	–	–	M	409	0.0	–
	Max	–	–	24	482	48	–

Sol: Solution level.
Max: Maximum level.
M: At the maximum level.
–: The activity is not available in this area.
[a] Groundnut, soya bean, and oil palm are food crops as well as cash crops.
[b] The kola nut, although a food crop by the definitions of this model, is included here for comparison with the other tree crops.

that are not too large). These gains indicate for which crops it would be most profitable to seek expanded acreage. Among the field crops, expanding tobacco and soybeans would add the most to income at these output levels. An extra acre of tobacco could add 700s to 900s per year, and an extra acre of soybeans (in the forest-savanna mosaic) 800s. These are the *surpluses* being earned by these crops, that is, for each crop, the excess of the value of the crop over the value of the resources required to produce it.

Tobacco, while not limited in production by marketing board policies, was produced under contract to the Nigerian Tobacco Company, which had a monopoly at the time of this study. The high surplus

value per acre undoubtedly reflects the advanced production techniques being used, under the guidance of Nigerian Tobacco, and may reflect an element of monopoly discretion in controlling the quantity of output.

Table 17. *Additions to Revenue Possible if a Single Cash Crop Activity Were Expanded, in Shillings per Acre per Year*

Activity	*Area*					
	I	*II*	*III*	*IV*	*V*	*VI*
Field Crops						
Groundnut[a]						
Sole	114	156	–	–	–	266
Mixed	117	216	–	–	–	189
Bean, soya[a]						
Sole	–	–	–	–	–	837
Cotton						
Sole	23	56	–	–	–	–
Mixed	0.0	0.0	–	–	–	80
Tobacco						
Sole	866	673	–	–	–	–
Tree Crops						
Oil palm[a]	–	–	489	213	30	754
Cocoa	–	–	390	126	–	–
Kola nut[b]	–	–	127	–	–	–
Rubber	–	–	77	0.0	0.0	–

NOTE: The entries show the gain possible from expanding a single activity by one acre, with no increases in the total quantities of land or labor available, and with unchanged limits on other production and consumption activities.
–: The activity is not available in this area.
[a] Groundnut, soya bean, and oil palm are food crops as well as cash crops.
[b] The kola nut, although a food crop by the definitions of this model, is included here for comparison with the other tree crops.

The soybean case is quite different. This surplus reflects both the high yield figure (2,100 pounds per acre) used in this model and the value of soybeans when used as food. Although they are grown principally for export, the nutrients they provide in this solution are worth nearly twice the value of the beans if sold for export. To export any part of the soybeans produced would be to reduce the revenue obtainable from agriculture at the levels of nutrient production that are required in this model. Expanding soybean production could provide great nutritional benefit, if the beans were used as food. In practice, however, few soybeans are consumed because they are not well adapted to the Nigerian style of food preparation. However, soy-maize and

soy-cassava-maize mixtures now are being well received both in Nigeria and in the Congo.[5]

Groundnuts are used both for food and for export in the optimal solution, yielding modest surpluses. They appear more profitable as a mixed crop (intercropped) than when grown as a sole crop. With intercropping the same acre of land supports two or three crops at once, so the total surplus earned on the land may be estimated as the sum of the surplus for mixed groundnuts plus the surplus from whatever crop or crops is chosen to grow with it. In the forest-savanna mosaic, for example, if another mixed crop will yield a surplus as large as 78s per harvested acre, the two together will yield 189s + 78s = 267s, slightly more than groundnuts yield as a sole crop. Of course, this is only possible for those second crops that can be grown effectively with groundnuts.

Cotton yields very small surpluses when it yields any. In the dry savanna mixed cotton will not even pay for the resources it employs. In the intermediate savanna it can earn just enough to pay for the resources used, but only if output is restricted to 13,000 acres, or 3.6 percent of the maximum allowed by the model. (See Table 16.) Of the four field crops, cotton is clearly a poor candidate for promotion.

All the tree crops except rubber are worth producing at their maximum limits. At the prices used in this model, oil palm and cocoa, in the appropriate areas, are more promising candidates for expansion than groundnuts, but rubber is of limited value (Table 16). It drops out of the solution entirely in the eastern moist forest and produces a surplus over the value of the resources it employs only in the western moist forest, and there a small one (Table 17).

Kola nut production yields a modest surplus, partly because the model requires minimum quantities of the nuts in the diets of the dry and intermediate savannas, regardless of their nutrient content. In the western moist forest, however, kola nut consumption exceeds the minimum level required by the model; in that area the nutrients are worth the cost of producing them.

The largest surpluses among the tree crops are produced by oil palm in Areas III and VI (the western moist forest and the forest-savanna mosaic). At prices representative of 1963 conditions it is more desirable to expand oil palm than cocoa production in Area III, even though Area III is the major cocoa-producing area.[6]

A drop of one-third in the total market and nutritive value of palm products in this solution (which uses 1963 prices) would reduce the

surplus of an acre of oil palm in Area III to approximately 180s; it might wipe out the surplus entirely in some areas. However, the value of palm products used as food would not be likely to drop as rapidly as export prices, so this might set a lower limit to the fall of these surpluses. To know the optimal adjustments to a lower level of prices for palm products it would be necessary to recalculate the solution, using the new prices.

Whether or not the actual prices of palm products prevailing at any moment are well represented by those used in this model, the differences among the surpluses in the four areas in which oil palm is produced are significant. They are influenced only slightly by the level of prices of palm products. The same data on yields and input requirements were used in each area, for there was not sufficient information concerning the conditions of traditional small farmer production to warrant attempting to differentiate among areas. Differences in the total value of the product per acre could occur, however, because of differences in the cost of transportation to market, in the processing facilities available to a given area, in the proportions of the product used for food and for export, and in the value of the nutrients included in the portion used as food in a given area.

The major variations among the surpluses earned in each area are caused by differences in the alternative opportunities available for the resources needed for palm production. In Area III there are alternative activities in which an acre of land can earn 309s, but labor has no valuable alternative use. Adding the value of these resources to the surplus for Area III (489s) yields 798s, the total earnings from an acre of oil palm in the western moist forest. In the forest-savanna mosaic (Area VI), land has no valuable alternative uses, but May–June labor does. The four days of May–June labor required on an acre of oil palm are worth 12s. This plus the surplus of 754s gives a total value of 766s, slightly less than the total figure for the western moist forest. The difference between the two surpluses reflects chiefly the fact that in this solution there are valuable alternative uses for land in the western moist forest, but not in the forest-savanna mosaic. Similarly, there is little difference between the total earnings of an acre of oil palm in Areas IV and V (484s and 464s respectively), although the surplus is much higher in Area IV (213s as opposed to 30s).

For decisions concerning the desirability of expanding production in any area, the figures for the surpluses have more relevance than the total value of the production. If an acre of oil palm production were

added, only the surplus would be added to Nigerian agricultural revenue, for the resources employed on the added acre would have produced as much value in the uses from which they came as in the new use. Therefore, expanding oil palm production in Area VI would contribute more to Nigeria's income than would a similar expansion in Area III, even though the total value of production per acre might be higher in III. The reason is that in Area III land is fully employed, in the optimal solution, so producing more oil palm requires production of other products to be reduced. In Area VI, one percent of the land is going unused, so no loss of other production would be caused by an expansion of palm production except the 12 shillings' worth resulting from the diversion of labor from other lines of activity.[7]

Efficient Food Crops

A food crop is efficient if the nutrients it provides are worth at least as much as the resources used to produce it. The nutrients' worth is measured by the value of the resources required to replace them if the crop acreage were reduced. In short, a food crop is efficient if the value of the resources that the crop uses is equal to or less than the least value (of resources) that otherwise would have to be used to produce the same set of (controlling) nutrients.

Efficiency, in this setting, has to do with economizing on resource use. Resource use is economized because the fewer the resources required to produce food, the more are left to produce income. One economizes in terms of the *value* of resources in order to maximize the *value* of the (nonfood) income that can be produced with the remaining resources. The value of a resource is equal to the amount of income it can produce; the smaller the resource value devoted to food production, the smaller the amount of potential income sacrificed to obtain that food.

A production pattern consistent with maximizing the income earned from Nigerian agriculture without sacrificing nutritional standards will contain only efficient crops at positive levels. The controlling nutrients provided by inefficient crops can be had more cheaply—with the use of less valuable resources—if the resources are used in some other way. Inefficient crops will be at zero level in the optimal solution. If a crop is efficient, but other ways of providing the same nutrients are equally efficient (use resources of equal value), the crop may be in the optimal solution at any level from zero up to and including the maximum level permitted by the model.[8]

Table 18 gives the optimal food crop pattern. Evidently the 1963 pattern of production would not be optimal for the 1967 population. Most food crops are in the solution at their maximum levels, not at something approximating 92 percent of their maxima,[9] but a number of important crops are at zero levels or, at best, well below 92 percent of their maxima.

One such crop is bitter cassava, at zero level in the eastern moist forest (Area V) and, as a sole crop, in the western moist forest (Area III). As a sole crop it is in the solution at less than its maximum level in the intermediate savanna and the central moist forest and at its maximum level in the forest-savanna mosaic (Area VI). As a mixed crop it appears at its maximum level everywhere except in the eastern moist forest.

Although commonly considered an inexpensive source of food energy, cassava is a poor source of a number of other nutrients that are needed in the Nigerian diet. The calories it provides are not sufficient

Table 18. ***Levels of Food Crop Activities, in Thousands of Acres***

Crop	*Level*	*Area*					
		I	*II*	*III*	*IV*	*V*	*VI*
Maize, bush							
Sole	Sol	0.0	M	M	M	–	M
	Max	9.3	190	691	1.8	–	16
Mixed	Sol	0.0	M	M	M	M	M
	Max	28	440	646	66	437	425
Maize, commercial							
Sole	Sol	–	–	M	–	M	M
	Max	–	–	11	–	7	13
Millet							
Sole	Sol	262	M	–	–	–	–
	Max	2309	20	–	–	–	–
Mixed	Sol	M	M	–	–	–	–
	Max	8224	20	–	–	–	–
Rice							
Sole	Sol	M	M	–	M	20	M
	Max	554	95	–	13	101	78
Mixed	Sol	0.0	M	–	M	M	M
	Max	12	4.1	–	26	7	4
Sorghum							
Sole	Sol	M	M	–	–	–	–
	Max	2002	889	–	–	–	–
Mixed	Sol	M	M	–	–	–	–
	Max	6260	2629	–	–	–	–
Wheat							
Sole	Sol	M	–	–	–	–	–
	Max	73	–	–	–	–	–

Cassava, bitter[a]							
Sole	Sol	–	193	0.0	150	0.0	M
	Max	–	335	512	164	188	293
Mixed	Sol	–	M	M	M	0.0	M
	Max	–	80	640	133	525	647
Cassava, sweet[a]							
Sole	Sol	M	M	–	–	–	–
	Max	317	605	–	–	–	–
Mixed	Sol	M	M	–	–	–	–
	Max	317	760	–	–	–	–
Potato, Irish							
Sole	Sol	5.5	M	–	–	–	–
	Max	9.7	84	–	–	–	–
Mixed	Sol	0.0	0.0	–	–	–	–
	Max	4.2	8.4	–	–	–	–
Potato, sweet							
Sole	Sol	M	M	–	–	–	–
	Max	6	12	–	–	–	–
Mixed	Sol	M	M	–	–	–	–
	Max	18	36	–	–	–	–
Cocoyam							
Sole	Sol	–	–	M	M	M	–
	Max	–	–	25	5	62	–
Mixed	Sol	–	–	M	M	M	–
	Max	–	–	136	75	248	–
Yam							
Sole	Sol	M	M	M	M	M	M
	Max	455	449	470	39	277	240
Mixed	Sol	M	M	M	M	M	M
	Max	241	269	235	394	917	504
Cowpea							
Sole	Sol	M	M	–	–	–	M
	Max	15	20	–	–	–	1.4
Mixed	Sol	M	3323	–	–	0.0	188
	Max	3020	4325	–	–	1.2	884
Melon seed							
Sole	Sol	M	M	21	M	0.0	M
	Max	19	53	75	3.2	1.8	7.7
Mixed	Sol	M	M	M	M	0.0	M
	Max	39	78	85	133	316	96
Okra							
Sole	Sol	–	–	–	–	–	M
	Max	–	–	–	–	–	9.6
Mixed	Sol	–	–	0.0	0.0	0.0	M
	Max	–	–	264	89	60	30

NOTE: Crops that may be used either for food or income, plus the kola nut, are listed in Table 16.
Sol: Solution level.
Max: Maximum level.
M: At the maximum level.
–: The activity is not available in this area.
[a] It is assumed that on half the cassava acreage the crop is in its first year, and on the other half it is in its second year.

by themselves to justify producing it at maximum levels in all parts of Nigeria. This is particularly evident in the moist forest areas, where riboflavin is a scarce nutrient. Because cassava is a very poor source of riboflavin, it is not one of the more economical sources of food energy in those areas.

Nonetheless, before concluding that cassava production should be discouraged, one must remember that cassava performs two functions in the Nigerian economy that are not represented in this model. It can remain in the ground until needed, so it has special importance as a food for the hungry season when other crops have spoiled or have been consumed. Moreover, it can be grown at the end of the rotation period, or on poor land, so it makes use of land less well suited than the average for other crops. In view of these facts, it would be unwise to discourage cassava production without careful study of its special roles.

Other crops that have gone to zero level and thereby have released land and/or labor for other uses are melon seed and mixed cowpeas in the eastern moist forest, okra everywhere except in the forest-savanna mosaic, mixed Irish potatoes in both savanna areas, rice and cotton grown as mixed crops in the dry savanna, and maize in the dry savanna.

Although the yields estimated for bush maize in Area I (1,200 pounds per acre as a sole crop and 1,050 per acre as a mixed crop) are among the higher figures for the various parts of the country, maize does not apppear in the solution. To be sure, maize is not an important crop in the dry savanna, although it is important in several other areas of the country. That a zero output should be optimal, however, probably is explained by the level of the calcium allowance specified in this model. Given that allowance, the major nutritional problem in Area I is to obtain enough calcium without too many calories, and maize has a low ratio of calcium to calories.[10]

In Area I Irish potato acreage is held below its maximum by the maximum limit on consumption. Both output and consumption are at lower levels than would be nutritionallly advantageous for that area.

Two factors help keep rice below the maximum acreage allowed in Area I. As does maize, rice has a very low ratio of calcium to calories. In addition, our estimates of rice yields may be low for both savanna areas.[11]

Mixed cowpeas, although quantitatively important, are only marginally efficient (appear at less than their maximal levels) in the inter-

mediate savanna and the forest-savanna mosaic. Melon seed as a sole crop is marginally efficient in the western moist forest.

The fact that a crop disappears from the optimal solution indicates that on the average other crops will produce more income or more of the costly nutrients, but it is not conclusive evidence that such a crop should be eliminated from the Nigerian economy. The most economical sources of nutrients may not always be the foods most enjoyed by the population. The farmer may prefer to grow the food he enjoys, even though this leaves him with fewer resources to devote to producing revenue crops. The farmer who produces food for the market will maximize his income only if he produces the foods the market is eager to pay for. The foods for which people will pay the most need not be those that are the most efficient sources of nutrition.

The characteristics of the data themselves provide still another reason for caution before concluding that an activity that goes to zero in the optimal solution should be eliminated forthwith from Nigerian agriculture. Our data on yields and input requirements represent average figures. In cases where individual yields are higher or input requirements lower, any of these activities may be worthwhile.

Moreover, our data are averages for the area. If soil and weather conditions, market opportunities, and dietary needs change gradually from one area to another, this implies that an activity not worth using near the center of an area may be worth carrying on near the border between that area and another in which the activity is a productive one. Cassava may be a case in point. While it does not enter the optimal solution for Area V, it does appear in Area VI, where the competition for land is not severe.

It also must be remembered that the input data for mixed cropping are less reliable than those for sole crops and that yields under mixed cropping are likely to depend upon the combination of crops grown, a factor not taken into account in this model. Therefore, one must be somewhat skeptical when the solution says that the sole crop is highly productive but the mixed crop should be completely eliminated. If the sole crop is truly so productive, it is likely that the crop also will be worthwhile in some mixed cropping patterns.

Surpluses Earned

While only efficient crops are in the solution at a positive level, some crops are more efficient than others. Most cropping activities are

in the solution at their maximum levels. An activity at that level is likely to be earning more than the value of the resources employed upon it. When such is the case, the aggregate revenue from Nigerian agriculture will expand if still more land is devoted to that activity. Table 19 shows how much a one-acre expansion of a single activity would increase this aggregate revenue, given the quantities of resources available and the limits upon the other production and consumption activities in the model.

The figures in Table 19 also may be interpreted as the difference between the value of the nutrients produced by one acre of an activity and the value of the resources used by that activity. This is the "surplus" which an acre of the activity contributes to the revenue from agriculture, over and above the value of the resources used. Raising the level of an activity by one acre contributes the amount of this surplus to the aggregate revenue from agriculture. (The resources, including land, used by the extra acre of this one crop have been taken away from other activities, so their value does not represent a net addition to the aggregate revenue.)

To increase the land devoted to a food crop that earns a large surplus releases resources devoted to nutrient production elsewhere. Those resources have valuable uses, even within the maximum limits set in the model. It may be possible to expand an income producing activity that is not already at its maximum, or, because other food is now available, to export a larger share of the output of groundnuts or oil palm products.

Not all crops can be expanded at once, however, without severely reducing the surpluses available. Each surplus is calculated on the assumption that no other maximum limit is being relaxed. Expansion of one crop beyond this limit draws resources away from crops already in the solution, reducing the output level of activities that have zero surpluses. There is a limit beyond which this process is not profitable, even when only one crop is expanding. When several crops expand at once, they compete with each other as well as with crops already in

Table 19. *Additions to Revenue Possible if a Single Food Crop Activity Were Expanded, in Shillings per Acre per Year*

Activity	*Area*					
	I	*II*	*III*	*IV*	*V*	*VI*
Maize, bush						
Sole	0.0	565	220	520	–	478
Mixed	0.0	604	364	220	23	212

Maize, commercial						
Sole	–	–	641	–	233	353
Millet						
Sole	0.0	94	–	–	–	–
Mixed	31	145	–	–	–	–
Rice						
Sole	1	73	–	42	0.0	276
Mixed	0.0	41	–	381	123	92
Sorghum						
Sole	130	369	–	–	–	–
Mixed	61	126	–	–	–	–
Wheat						
Sole	315	–	–	–	–	–
Cassava, bitter, root[a]						
Sole	–	0.0	0.0	0.0	0.0	142
Mixed	–	1	96	156	0.0	66
Cassava, sweet, fresh[a]						
Sole	427	154	–	–	–	–
Mixed	283	107	–	–	–	–
Potato, Irish						
Sole	0.0	57	–	–	–	–
Mixed	0.0	0.0	–	–	–	–
Potato, sweet						
Sole	1498	442	–	–	–	–
Mixed	754	307	–	–	–	–
Cocoyam						
Sole	–	–	559	477	5	–
Mixed	–	–	244	438	180	–
Yam						
Sole	196	364	555	656	83	323
Mixed	382	467	899	483	293	293
Cowpea						
Sole	530	79	–	–	–	131
Mixed	21	0.0	–	–	0.0	0.0
Melon seed						
Sole	214	272	0.0	96	0.0	332
Mixed	175	364	94	175	0.0	261
Okra						
Sole	–	–	–	–	–	28
Mixed	–	–	0.0	0.0	0.0	12

NOTE: Crops that may be used either for food or income, plus the kola nut, are listed in Table 17. The entries in this table show the gain possible from expanding a single activity by one acre, with no increases in the total quantities of land or labor available, and with unchanged limits on other production and consumption activities.

–: The activity is not available in this area.

[a] The figures are for an acre of cassava, half of which was planted in the current year. The other half, planted in the previous year, is being harvested during the current year.

the solution, so the limit is reached much sooner. In view of this fact, wisdom suggests that development efforts be concentrated on a small number of crops in any one area, choosing among the crops with the highest capacity for earning surpluses.

In general, food crops yield surpluses comparable with those available from cash crops. In fact, Nigeria could increase its income more by expanding certain food crops beyond the maximum limits used in the model (releasing for export sale some output now consumed as food) than by direct expansion of such cash crops as groundnuts or cocoa (not to mention cotton or rubber) without the expanded production of food crops. (Compare Table 17.)[12]

Several food crops yield surpluses worth 400s to 900s per acre: yams in the intermediate savanna and the central and western moist forest; cocoyams in the latter two areas; "bush" maize (maize cultivated in the traditional way) in the intermediate savanna and, as a sole crop, in the central moist forest and the forest-savanna mosaic;[13] "commercial" maize (maize grown with modern techniques) in the western moist forest; cowpeas as a sole crop in the dry savanna;[14] soybeans in the forest-savanna mosaic; sweet cassava as a sole crop in the dry savanna; and sweet potatoes as a sole crop in the intermediate savanna. (According to this solution, sweet potatoes as a sole crop yield a surplus of 1,500s per acre in the dry savanna!)

High surpluses in the dry savanna (Area I) must not be taken too seriously, however. The high nutritional values of sweet potatoes, cowpeas, and sweet cassava reflect the excessive importance given to calcium in that area by the unnecessarily high level of the allowance employed. It is extremely difficult to find economical sources of calcium there without introducing too many calories into the diet. These three foods have high ratios of calcium to calories.[15]

Comparisons of the six areas shows that food crop expansion yields smaller surpluses, in general, in the eastern moist forest (Area V) than in any other area, which probably is the result of the comparative scarcity of land in that area.

Considering the country as a whole, traditional Nigerian staples such as yams and maize are usually efficient sources of the important nutrients. Cassava, on the other hand, appears inefficient, with the exception of sweet cassava in the dry savanna, but this result ignores the special role of cassava as food for the hungry season.

Table 20 lists the 27 field crop activities that provide the largest surpluses. Sole crops are listed separately from mixed crops (with

which are included crops grown by intercropping) because the figures for the two types of cultivation must be used differently. Given the data of this problem, planting an additional acre of one of the sole crops can be expected to yield the surplus listed, let us say 658s for yams in the central moist forest. With mixed crops, however,

Table 20. ***The Twenty-Seven Field Crop Activities with the Largest Surpluses***

Activity	*Surplus, shillings per acre harvested*	*Area* I	II	III	IV	V	VI	*Rank*
Sole Crops								
Potato, sweet	1,498	I						1
Tobacco	866	I						2
Bean, soya	837						VI	3
Tobacco	673		II					4
Yam	658				IV			5
Maize, commercial	641			III				6
Maize, bush	565		II					7
Cocoyam	559			III				8
Yam	555			III				9
Cowpea	530	I						10
Maize, bush	520				IV			11
Maize, bush	478						VI	12
Cocoyam	477				IV			13
Potato, sweet	442		II					14
Cassava, sweet, fresh[a]	427	I						15
Sorghum	369		II					16
Yam	364		II					17
Mixed Crops								
Yam	899			III				1
Potato, sweet	754	I						2
Maize, bush	604		II					3
Yam	483				IV			4
Yam	467		II					5
Cocoyam	438				IV			6
Yam	382	I						7
Rice	381				IV			8
Melon seed	364		II					9
Maize, bush	364			III				10

NOTE: If the surplus figure is underlined, the yield estimate used is in the range of yields obtainable from improved practices.

[a] The figures are for an acre of cassava, half planted in the current year. The other half, planted in the previous year, is the part harvested during the current year.

an additional acre of one crop does not make full use of the land; one or two other crops will be grown on the same piece of land. The surplus to be earned from an acre of land, therefore, is the sum of the surpluses from each of the crops grown on the same land.

Yams as a mixed crop in the central moist forest yield a surplus of 483s per acre, but bush maize can be grown with them. Adding the surplus that mixed maize can earn in Area IV, 200s (Table 19), gives a total surplus for the acre in mixed crops of 703s. The mixed combination is better than either sole yams or sole maize (Table 20), or, indeed, than any of the sole crops available in the central moist forest.

In fact, the average number of crops grown together in the central moist forest was somewhat more than two (2.25), so adding the surpluses from only two crops underestimates the earnings available from mixed cultivation.[16] Of course, there is no way of growing one-quarter of a crop. The average figure of 2.25 may be interpreted in either of two ways. If two crops are grown on most plots, but three are used on one plot in four, the average number of crops per acre will be 2.25. Alternatively, one may think of growing two crops together on three-quarters of the land and three crops on one-quarter. In the latter case, the surplus from the full acre can be calculated as 483s from yams, 220s from maize, and one-quarter of the surplus from whatever becomes the third crop in the combination. If that crop were melons (for seed), one-quarter of the surplus per acre would be 44s (see Table 19), so the total surplus earned from the acre of land would be 747s. On the other hand, if the third crop were okra, it would have a zero surplus, so the total still would be only 703s.

Two things become evident. First, the potential yield per acre in mixed cropping is considerably higher than the figure shown for an acre of any single mixed crop in Tables 19 and 20. Second, exactly what that potential yield will be depends upon what combination of crops it is feasible to grow together.

The yield from a crop grown under mixed farming naturally depends upon the density of planting (and therefore upon the number of other crops grown with it) and upon the particular kind or kinds of other crops grown on the same land. The yield figures used in the model are average results based upon the various combinations actually in use. The hypothetical statistically "average" combination to which they apply is not likely to coincide with any actual combination, so they are not exactly representative of what might be expected from any specific combination. Moreover, they are not equally rep-

resentative of all specific combinations. It was not our purpose to compare the merits of sole and mixed cropping, so the model was not designed to provide precise information in this respect. In addition, data on inputs and outputs for mixed crops are less dependable than data for sole crops. The agricultural scientist has devoted relatively little attention to the study of mixed cropping systems.[17]

For all these reasons, the data on surpluses available from mixed cropping must be regarded as indicative rather than definitive. Nonetheless, what they indicate may be significant. In most areas there are mixed crop combinations that yield surpluses equal to or greater than those that can be had from sole cropping.[18] In four of the six areas, if our data are reasonably accurate, the combination of yams and bush maize can yield a larger surplus than any of the sole field crops.[19] The dominance of mixed cropping patterns in Nigerian agriculture may be based on sound economic considerations and not simply be a matter of received tradition. The advantages of mixed cropping may not have been recognized fully by scientists trained in cultures where sole cropping predominates. There is less trouble with diseases and insects, and weed control may be improved (or made possible with less labor). Where it is man's work to prepare the field and plant the yams, while women are responsible for the other crops, the heavy labor of digging prepares the soil for her crops as well as for his yams. Where the timing and duration of rains is uncertain, as in the north, mixed cropping reduces risk. If the early rains come and the early crop succeeds, more food is available (and the hungry season is shortened); if not, the crops planted later can bear more of the responsibility for providing the necessary subsistence.[20]

In a few cases, a single mixed crop yields a larger surplus than the corresponding sole crop. One reason for this is that the mixed crop need earn only enough to cover the use-value of a fraction of an acre—.44 acre in the central moist forest—while the sole crop must pay for the whole acre. Where the use-value of land is high, this reduction in the value of resources used can result in a larger surplus for the mixed crop, even though the sole crop has a greater yield.

The purpose of this model is to identify crops that are economical sources of nutrition or income rather than to determine whether sole or mixed cropping is the more efficient. To determine the economical crops one can compare the surpluses of sole crops with each other and the surpluses of mixed crops among themselves. As has been seen, either comparison shows that yams and maize are highly efficient in

several parts of the country, with an assortment of other crops ranking high in particular areas.

Planning for development that promotes nutritional well-being as well as income should concentrate on crops toward the tops of these lists, in each area, if the developmental cost of obtaining a thousand-acre expansion in cultivation is the same for each crop.[21] However, it is likely that the cost per acre would be higher for a crop like sweet potatoes, of which some 40,000 acres were harvested in the intermediate savanna in 1963, than for sorghum, of which nearly 3 million acres were harvested. Moroever, 1,000 acres would be a 2.5 percent increase for sweet potatoes, but only 0.03 percent for sorghum. The larger the percentage increase in acreage obtained, the more likely it is that yields and input coefficients will change adversely as the acreage of a single crop expands.

Most areas have from four to six activities that yield surpluses in excess of 360s per acre per year. Area VI, however, has only two, while Area V has none at all. Area V is not the best place in which to expand food production.

Improved Techniques

For a number of field crops the yield estimates used here appear to represent cultivation by farmers using improved techniques.[22] To the extent that this is so, the surpluses listed in Tables 19 and 20 depend upon the use of these improved techniques.[23] Those figures that are underlined in Table 20 are for activities with yields in the range that one might expect from the use of improved practices.[24]

Two illustrations suffice. Our yield figure for cowpeas as a sole crop in the dry savanna is 800 pounds per acre. This is not attainable without the use of sprays and other improved practices. Sole cowpeas can earn a surplus, however, with yields as low as 195 pounds per acre. The traditional farmer does not grow cowpeas as a sole crop. Our estimate of the yield for mixed cowpeas (140 pounds per acre) seems appropriate for him, but the surplus in this case is only 21s per acre.

The soybean surplus, 840s per acre in the forest-savanna mosaic, is based on a yield estimate of 2,100 pounds per acre. This is probably much too high for the average farmer, but yields in excess of 2,000 pounds are obtained on the best farms, on bottomland soil along the Benue River. Any yield above 140 pounds per acre will yield a surplus.

Of the 27 activities yielding surpluses greater than 360s per acre, 14

have yields in the improved practice range. Of the 84 activities with surpluses under 360s per acre, only 8 have yields at the levels one might expect from improved practices. As one would expect, a disproportionate number of the activities with large surpluses are those with yields at the improved practice levels.

However, high yields do not necessarily mean large surpluses. Only in the intermediate savanna and the central moist forest does bush maize grown as a sole crop earn a surplus in excess of 350s per acre, yet our yield estimates for sole bush maize range from 1,200 to 1,870 pounds per acre in four of the six areas. Such yields are comparable with the 1,400 to 1,800 pounds that one might expect from using the practices recommended by the extension demonstration program in the savanna areas, or what we have called "commercial" maize production in the rain forest areas.

The cases in which yield data fall into the range that one might expect from improved practices are given in Table 21. Of the 20 food crops included, 12 produce surpluses of nutritional value in excess of 360s per acre. These are the surplus figures that are underlined in the table. To produce a nutritional surplus a crop not only must have a high yield but also must provide adequate amounts of the nutrients that are costly in the area. The greater yields made possible by improved techniques are important, however: Only 13 out of 89 of the field crop activities with yields in the range to be expected from traditional practices were able to show surpluses as high as 360s per acre.

The Animal Industries

One purpose of this study is to examine the animal-human nutrition balance, the extent to which it is desirable to use resources to produce feed for meat animals rather than to produce food directly from vegetable sources. Using the animal as a converter can improve the quality of the human diet by providing high-quality protein, but the output of food energy per unit of land is low. Where the land is not suited for the production of human food directly, but can produce forage suitable for animals, there is no conflict, but in other cases one must raise the question: To what extent is it economical to trade off food energy for a diet containing protein of better quality? The answer will depend in part upon how much protein is provided by those segments of the animal industries that do not compete for resources well suited to the direct production of food.

Table 21. *Activities that May Represent Improved Practices: Estimates of Yields and Surpluses per Acre*

Activity	Area I	II	III	IV	V	VI
Maize, bush–sole						
Yield (pounds)	1,200	1,300		1,870		1,240
Surplus (shillings)	0.0	565		520		478
Maize, bush–mixed						
Yield (pounds)	1,050	1,250				
Surplus (shillings)	0.0	604				
Maize, commercial–sole						
Yield (pounds)			,700		1,800	1,400
Surplus (shillings)			641		233	353
Sorghum–sole						
Yield (pounds)		1,330				
Surplus (shillings)		369				
Cassava, sweet, fresh[a]–sole						
Yield (pounds)	2,100	2,200				
Surplus (shillings)	427	154				
Yam–sole						
Yield (pounds)	5,990	7,520				
Surplus (shillings)	196	364				
Yam–mixed						
Yield (pounds)	7,000	7,180				
Surplus (shillings)	382	467				
Cowpea–sole						
Yield (pounds)	800	400				570
Surplus (shillings)	530	79				131
Bean, soya–sole						
Yield (pounds)						2,100
Surplus (shillings)						837
Tobacco–sole						
Yield (pounds)	514	516				
Surplus (shillings)	866	673				

NOTE: The underlined figures are the surpluses in excess of 360s per acre.
[a] The figures are for an acre of cassava, half of which was planted in the current year. The other half, planted in the previous year, is being harvested during the current year.

From the short-run point of view the traditional animal industries in Nigeria do not compete significantly with other agricultural production. Except for the herds belonging to Fulani tribesmen, most animals are scavengers, picking up scraps about the village or roaming

over lands that are not being cultivated. They are tended, for the most part, by children or elderly folk unable to work in the fields. When resources are diverted to the use of these animals instead of to food production, it is usually unintentional, as when the animals raid fields and gardens because the boy watching them is inattentive.

Cattle raising is a full-time occupation for the Fulani herdsmen of the north, but their animals roam over land not being used for field crops,[25] and the men themselves usually are not available for other kinds of agricultural work. The situation is changing, and the amount of land available for these migrant herds diminishes as the growth of population in the savanna areas increases the quantity of land devoted to arable uses. Nonetheless, this model assumes that neither the labor nor the land used by these herds has alternative uses. The same assumption is made for traditional animal production in all parts of Nigeria.

The "modern" animal production activities, on the other hand, use produced or purchased feeds, lands that otherwise could be used for arable crops, or labor that has alternative uses in agriculture or the nonagricultural sector. The model represents these facts.

Because the assumptions of the model embody the principal economic differences between the traditional and the modern animal industries, the results reflect the consequences of those differences. The traditional industries, because they do not draw resources away from other activities, have no difficulty in producing nutrients sufficient to earn them places in an efficient production pattern. It is only with respect to the modern animal industries that one asks to what extent it is economical to trade off food energy for a larger quantity of animal protein. These industries can find a place in an efficient pattern only if the nutrients they produce are at least equal in value to the nutrients that could be produced by using the same resources in the best alternative way. This standard, as will be seen, is not easily met.

Table 22 gives the optimal levels for the animal activities in this solution. Except for one case, the modern (commercial) animal activities are at zero level. Neither commercial pork nor commercial poultry production yields a product that is worth as much as the resources these activities require. The same is true for commercial cattle production in the intermediate savanna (Area II) and the eastern moist forest (Area V), but in the forest-savanna mosaic (Area VI), where the alternative value of the arable land used for pasture is zero, com-

Table 22. *Levels of the Animal Industries*

Activity	*Unit*	*Level*	*Area*					
			I	*II*	*III*	*IV*	*V*	*VI*
Cattle, bush	1,000 head—output	Sol	869	M	M	M	M	M
		Max	1072	370	1.2	1.2	3.6	31
Cattle, commercial	1,000 head—output	Sol	—	0.0	—	—	0.0	M
		Max	—	11	—	—	6	1.2
Goats	100,000 head—output	Sol	M	M	M	M	M	M
		Max	29	12	3.3	2.3	9.8	1.9
Sheep, bush	100,000 head—output	Sol	M	M	M	M	M	M
		Max	8	4.8	.61	.07	1.6	3.7
Swine, commercial	1,000 head—output	Sol	0.0	0.0	—	—	—	—
		Max	29	7.2	—	—	—	—
Chickens, commercial	100,000 chicks—input	Sol	—	0.0	0.0	—	0.0	0.0
		Max	—	5.3	7.9	—	*	*

Sol: Solution level.
Max: Maximum level.
M: At the maximum level.
—: The activity is not available in this area.
* Set by the limit on feed produced by the Ministry of Agriculture.

mercial cattle production can pay for the resources that it uses. (Indeed, as will be seen, it yields a surplus.)

The traditional animal industries are at their maximum levels everywhere in Nigeria, except for beef cattle in the dry savanna. The resources employed by these activities have zero opportunity costs in this model, with the exception of the bush pasture used for Area I animals. (This has alternative uses in the production of goats or sheep.) Outside the dry savanna, the need to earn enough to attract resources from a competing activity is not a factor, so each of the traditional animal industries expands to its limit. These industries can hold a place in the optimal solution regardless of how little they may earn for the resources they use.

In the dry savannna, however, the limited amount of bush pasture must be allocated among the competing animal industries. In the optimal solution, goats and sheep are at their maximum levels, while bush cattle production is about 80 percent of the maximum (essentially at the same level as our estimate of 1963 production, 890,000 carcasses). The optimal way to use the restricted amount of pasture is to expand goat and sheep production as far as the model allows and turn the rest of the pasture over to the nomadic cattle. If our estimates of pasture requirements are correct, goats and sheep in the dry savanna are more efficient contributors to the nutritional and income goals selected than are cattle.[26] The 1963 level of Area I cattle production essentially was adequate for meeting the needs of the population of 1967 in an efficient manner, given the goals specified in this model, but goat and sheep production should be expanded.[27]

It must be noted, however, that the animal production levels in this solution are adequate only upon the assumption that the meat is allocated on the basis of nutritional need, not the ability to pay for it. In this solution *all* meat other than that included in the gathered and collected foods (bush meat and native poultry) is consumed in the moist forest areas. If enough meat were to be produced to permit the usual consumption levels outside the moist forest, the expanded output requirements probably would lead to significant changes in the solution.

All activities that are at their maximum limits produce nutrients and income that have a value at least equal to the opportunity costs of the resources employed by those activities.[28] Most of such activities produce surpluses of nutrients and income, that is, produce value worth more than the resources they employ. Table 23 shows the

amounts of these surpluses. It indicates how much agricultural revenue could increase in Nigeria if the maximum limit on one of these animal industries were raised by a small amount, subject to the condition that the quantities of resources available and the maximum limits on other activities remain unchanged. As any increase in agricultural revenue is obtained by transferring a small portion of resources to the expanded activity and (if they already are fully employed elsewhere) away from others, the amount of the increase is the amount by which the earnings of the expanded activity exceed the earnings of the contracted activities. The latter will be, of course, the least profitable activities in use, the ones that are able to earn the opportunity-cost value of the resources they employ, but no more. Hence the addition to revenue obtainable by expanding an activity is the amount of the surplus being earned by that activity in the optimal solution.

Outside the dry savanna all the traditional activities are worth expanding beyond the levels allowed in the model if, in fact, the resources required for this expansion have no alternative opportunity costs. In this case, all of the activities can be expanded simultaneously, for none uses scarce resources. Nigeria would gain significant amounts from such expansions. The amounts per head of increase in animal output are given in the left half of Table 23. Outside the dry savanna each activity earns a surplus over its (zero) opportunity costs. In the intermediate savanna (Area II), for example, bush cattle output is worth 190s per head, while sheep production yields sheep worth 45s per head. These figures include both the value of any cash revenues provided by the industry and the value of the nutrients produced.[29] The output of milk provides a large part of the latter value for Area I cattle.[30] No account has been taken of actual or potential milk production from goats or sheep or from cattle outside the dry savanna.[31]

The surpluses per animal vary from one area to another because the animals are of different sizes (breeds) in different areas, the transportation costs for hides and skins sold differ from area to area, and the values of the nutrients differ among areas. If encouraging expansion of these activities requires promotional expenditures, as undoubtedly it does, wisdom suggests concentrating those expenditures on areas where the greatest benefits would accrue. The table shows those areas to be II and III for goats and sheep and III for bush cattle. The surpluses per head are largest for these areas, which fact reflects, among other things, differences in the costs of obtaining the nutrients these animals can provide in the different areas.

Table 23. *Additions to Revenue Possible if a Single Animal Activity Were Expanded*

Activity	*Unit*	*Shillings per unit of activity per year in area*						*Shillings per acre of pasture per year in area*					
		I	*II*	*III*	*IV*	*V*	*VI*	*I*	*II*	*III*	*IV*	*V*	*VI*
Cattle, bush	head—output	0.0	190	264	133	126	126	0.0	6.33	11	10.64	5.25	.90
Cattle, commercial[a]	head—output	—	0.0	—	—	0.0	347	—	0.0	—	—	0.0	69.4[a]
Goats	head—output	5.68	31.02	37.39	15.51	21.71	24.82	.47	3.88	20.77	7.76	12.06	4.96
Sheep, bush	head—output	22.28	45.46	31.62	27.03	25.46	29.09	1.49	4.55	10.54	9.01	8.49	3.64
Swine, commercial	head—output	0.0	0.0	—	—	—	—	[b]	[b]	—	—	—	—
Chickens, commercial	100 chicks—input	—	0.0	0.0	—	0.0	0.0	—	[b]	[b]	—	[b]	[b]

NOTE: These are the gains made possible by expanding any one activity by a small amount, given that the quantities of resources available and the limits upon other production and consumption activities remain unchanged.

—: The activity is not available in this area.

[a] The pasture for commercial cattle makes use of arable land.

[b] Not a pasture using activity.

Expansion of animal activities in the dry savanna involves different considerations. No activity can be expanded there without contracting another because all the bush pasture available for that area in this model is fully used. Although the resources used by the traditional animal industries in this area have no alternative uses outside the animal industries, there are alternatives available for bush pasture within the animal industries.

The least valuable activity is cattle production, so sheep and goats go to their maximum levels in this solution, with the remaining land being used for cattle. The cattle are worth 1,214s per head of output, taking into account the value of the hide and the nutrients provided by the milk from the herd as well as the meat from the slaughtered animal. At 1,214s per carcass of output, this is 2.8s per acre of land.

The land resource has acquired an opportunity-cost value, for it cannot be used wisely for any other purpose unless it earns at least the 2.8s per acre that it can earn in the production of cattle. For an animal activity to earn a surplus in the dry savanna it must produce a product worth more than 2.8s per acre of the bush pasture used.

Because expanding one activity requires contracting another, it is necessary to choose among them in this area. Goats and sheep earn surpluses of 5.7s and 22.3s per head of output in excess of the value of the land used (Table 23). Expanding cattle production would earn 2.8s per acre, but would lose the surpluses being earned by the goat or sheep production displaced, so cattle production should not expand. If the data are correct, either goat or sheep production would earn more than this, but which would it be worth more to expand? To answer this question one must express the surpluses in a common unit, one that is relevant for the economizing problem involved. Bush pasture is the only scarce resource in this situation, so surplus per acre of pasture is the appropriate measure. The right-hand side of Table 23 contains these data. Sheep production is the activity to expand since it earns the larger surplus, 1.5s per acre. Transferring an acre of bush pasture from cattle to sheep production would increase the value of Nigerian agricultural output by 1.5s at these levels of output. A transfer from cattle to goat production would be worth 0.5s per acre.[32]

As already has been pointed out, all the traditional animal activities may be expanded at once outside the dry savanna if there are, in fact, no scarce resources. If, however, the amount of extra bush pasture available is limited (but no other scarce resources are required),

the right-hand side of Table 23 provides a basis for selecting among the traditional activities available. The greatest return per acre of land employed comes from goats in the western and eastern moist forests. The local types of bush cattle yield the greatest return per acre in the intermediate savanna and the central moist forest.

Which animal yields the most surplus per unit of pasture depends upon a number of factors: pasture used per pound of output; weight loss in transporting the output to market; value of the hides produced; quantities and proportions of the nutrients produced; and values of those nutrients in the areas where the animals are consumed. In the dry savanna, for example, the milk output from the Fulani herds provides valuable calcium; this value is a component in the total value of the Area I cattle industry. In the intermediate savanna the value of the milk produced arises almost entirely from its caloric content. The value of the meat from the Fulani herds, however, derives from the riboflavin and calories it provides, for these are the important costly nutrients in the rain forest areas where these animals are being consumed in this solution. (When the specified quantities of riboflavin are provided, more than adequate quantities of protein also will be available.

If expanding beyond the maximum limits would require the use of labor that has a valuable alternative use (but no other inputs that are scarce), the choice among activities in any given area should be made by looking at the surplus per unit of labor. The data required to compare the activities on this basis are not available.

Where more than one factor is scarce, the gains from expansion must be compared with the costs of all the extra factors required, whatever they are. The factors that actually limit the output of the traditional village animal industries may be quite different from land or labor in the usual sense. Perhaps they include the sacrifice of present benefit that is involved in going without meat for an important feast in order to build up the size of the herd, or the damage done to gardens as the number of animals about the village increases. The analysis has not been pushed to this level of detail.

The only modern animal industry that will produce a product worth as much as the resources it requires is beef cattle production in the forest-savanna mosaic. It yields a surplus of 69s per acre over the value of the resources it uses. This is a far greater return per acre of land than is yielded by any other animal activity, which suggests that this should be the animal activity most vigorously encouraged. The

conclusion is correct as long as there is unused arable land in the forest-savanna mosiac.[33] (One percent of that land remains unused in this solution.) However, there are other potential claimants for this land. Table 19 showed a number of crops that would yield surpluses much larger than this. Indeed, only four of the food crops in Area VI yield surpluses smaller than 69s per acre per year.[34] If adequate nutrition at low cost is the objective, expansion of beef cattle production in Area VI must have a very low priority compared with the expansion of a number of field crops.

A similar conclusion is warranted with respect to each area in Nigeria. If expansions of the animal industries are to make use of land that could be used for arable crops, the nutrients to be obtained from the animal industries will be worth much less than the nutrients that could have been had from quite a number of food crops. The surpluses per acre in Table 23 are very small compared with the surpluses that Table 19 shows can be had from the expansion of selected food crops. It is well known that the animal industries are profligate users of land when their products are regarded as sources of food energy. These results show them to be relatively uneconomical users of arable land even when the whole set of nutrients is considered. Almost any cropping activity that earns any surplus over the value of the resources it employs earns a great deal more per acre than any of the animal industries. At the levels at which they appear in this solution, the animal industries play an important role in the nutrition of Nigeria, but they are not the industries that will contribute the most to Nigerian nutrition or revenue when expanded beyond the levels of the optimum solution if that expansion requires the use of arable land.

While the animal industries are not vigorous contenders for expansion if the objective is to provide nutrients that Nigeria needs in the least costly way, this is so largely because they already are providing a very important stock of nutrients. They do this largely with resources that have alternative uses of little or no value. The total carcass weight of the meat output of Nigeria, in this solution, amounts to 756 million pounds, an increase of 9 percent over the FAO estimate of the annual average slaughter for 1959–1962.[35] Beef output, at 418 million pounds, is 2 percent above the FAO estimate. (Our calculations assume that all animals are slaughtered in the areas where they are produced. When slaughter occurs outside that area, carcass weights usually will be lower as a result of the weight lost in transit.)

One may estimate the total value to Nigeria of the animal industries in the optimal solution by valuing the output of each industry at the values per head that are given in Table 23. (For Area I, values must be used that include the use value of the land required. At 2.8s per acre, use value amounts to 1,214s, 33s, and 41s per carcass of output for cattle, goats, and sheep, respectively. Adding the surplus earned per head gives the following total figures: 1,214s, 39s, and 64s, respectively. For commercial cattle in Area VI, one must include the value of the May–June labor required. This brings the total value per carcass in that area to 371s.)

Table 24 gives the aggregate value of animal industry output by industry and area. The figures include the value of the nutrients produced (based on the marginal opportunity cost of obtaining them in some other way) plus the value of cash revenues from the sale of hides and skins. The latter amounts to 233 million shillings, or 16 percent of the aggregate value of the output of the animal industries. Half of this, 118 million shillings, is from goatskins.

The cattle of the Fulani herdsmen (Area I cattle) provide an output worth 1.06 billion shillings (£53 million). This dominates not only Area I, but also the whole animal industry sector. In Area I goats and sheep provide 14 percent of the value of area output and use 11 percent of the pasture available.[36]

In the intermediate savanna the value of cattle output also exceeds that of goats and sheep, but in the remaining four areas of the country the output from goats and sheep is more valuable than that from cattle. In the country as a whole, goats and sheep produce about 20 percent of the total output value of the animal industries. Area I bush cattle alone produce 75 percent of the total; only 5 percent of the total comes from cattle in the other five areas in this solution. Although nothing is to be gained by expanding bush cattle production in Area I beyond the level of this solution, these cattle play a vital role in Nigerian nutrition at that level.

Nigeria has numerous programs designed to increase the output of the animal industries. From a nutritional standpoint, they benefit the well-to-do at the expense of the poor. Traditional methods of animal production are efficient sources of nutrition as long as the resources they consume have few alternative uses. The "modern" methods, however, are inefficient in almost every case, whether in producing beef, pork, or poultry. Except in one case, the nutrients produceable by animal industries using modern methods could have been more than re-

Table 24. *Aggregate Value of Animal Industry Output in the Optimal Solution, in Thousands of Shillings*

Area	Production activity: Cattle, Bush	Cattle, Commercial	Goats	Sheep	Swine, commercial	Chicks, commercial	Total for all industries
I	1,055,000	–	112,200	53,700	0.0	–	1,220,900
II	70,258	0.0	37,400	21,900	0.0	0.0	129,558
III	318	–	12,200	1,900	–	0.0	14,418
IV	160	–	3,600	200	–	–	3,960
V	455	0.0	21,200	4,000	–	0.0	25,655
VI	3,946	447	4,800	10,900	–	0.0	20,093
Total	1,130,137	447	191,400	92,600	0.0	0.0	1,414,581

–: The activity is not available in this area.

placed by using the same resources in other ways. Given the volume of animal protein available from the traditional Nigerian animal industries, supplementation by vegetable sources is more economical than the production of additional animal protein by modern techniques. When cereals that can meet the nutritional needs of the poor directly are converted into animal feed, the resulting animal products will sustain smaller numbers of people than would the original cereals. A certain minimum level of transformation of cereal foods into animal foods may be necessary in order to obtain protein of adequate quality. For the protein levels specified in this study, however, the traditional animal industries can provide sufficient animal protein to maintain quality if supplementary foods are chosen properly.

The protein needs of the country will increase, of course, as population levels grow. Outputs from the traditional animal industries cannot be expected to grow proportionately, so the time may come when alternative methods of animal production become nutritionally efficient. Perhaps research in protein production should be under way now in preparation for that time. The present solution offers at least one important suggestion for such research: It identifies the sulfur-containing amino acids as limiting under Nigerian conditions. If low-cost protein sources are described, trying to improve the availability of the sulfur-containing amino acids would be more efficient than simply seeking increased protein production without concern for the specific amino acids involved.

Resource Earnings

Resource earnings are positive when the resource is insufficient for all of the activities that could make effective use of it, that is, when the optimal level of production would be higher if more of the resource were available.

The model assumes that land and labor are available in quantities 9.5 percent greater than the quantities estimated to have been in use in 1963, except for bush pasture in the dry savanna. The latter is assumed to have decreased by the amount of the increase in arable land. In fact, bush pasture in the dry savanna *has* become scarce as land under cultivation has increased.

There is also one restriction on the use of the increase in arable land. In the eastern moist forest, using any of the increase over 1963 involves a reduction in crop yields.

In the traditional animal industries, except for the dry savanna (Area I), there is more than enough land (bush pasture). The 20 percent expansions that the model permits for individual industries do not begin to exhaust the quantities of bush pasture available outside the dry savanna. Consequently, this resource has no opportunity cost and no use value outside that area. (See Table 25.)

In the dry savanna, however, all the traditional animal industries cannot expand by 20 percent because there is too little bush pasture available. If more were available, animal outputs could increase, so an extra acre of bush pasture has positive use value. In this solution that value amounts to 2.8s per acre (Table 25).

Table 25. ***Revenue Obtainable from an Additional Unit of a Resource, in Shillings***

Resource	*Unit*	*Area*					
		I	*II*	*III*	*IV*	*V*	*VI*
Labor in May and June	man-day	8.46	7.69	0.0	2.07	0.0	3.01
Labor, other	man-day	0.0	0.0	0.0	0.0	0.0	0.0
Land, arable	acre-year	0.0	77	309	262	434	0.0
Land, arable, additional	acre-year	–	–	–	–	0.0	–
Pasture, bush	acre-year	2.76	0.0	0.0	0.0	0.0	0.0

NOTE: This table shows the opportunity-cost valuation of each resource—the potential gain from having one more unit of a specific resource to use, subject to the conditions of the model. Those conditions include maximum limits upon production and consumption activities and constant quantities of all other resources.

–: The resource is not considered in this area.

The labor used for the traditional animal industries usually is not available for other agricultural uses. The nomadic herdsmen of the north normally do not engage in crop production, while the animals owned by settled farmers usually are tended by children or elderly people not well suited for work on cultivated plots. Consequently, the labor used for the traditional animal enterprises is not included in the labor category in this model. That category is restricted to labor available for use in general agricultural activities—for the most part, in the cropping of arable land. There is no possibility in this model for competition for labor from the cropping enterprises to establish a scarcity value for labor used in the traditional animal enterprises. However, the "modern" animal activities that here are called "commercial" cat-

tle and chicken production do use general agricultural labor and/or arable land. Commercial pork production (in two large piggeries in the north) is regarded as using nonagricultural (urban) labor and land.

For cropping activities, either May–June labor or arable land is liable to be a limiting resource. While the model allows cropping activities to rise some 20 percent above their 1963 levels, the quantities of arable land and labor are increased by only 9.5 percent. If the optimal cropping pattern increases labor and land use in the same proportion, there will not be enough land and labor to permit all activities to expand by 20 percent, so some will be kept below their maximum levels. Adding a unit of either resource would allow production to expand, so earnings would be positive for both resources. On the other hand, if the cropping pattern in the optimal solution expands land use in greater proportion than labor use, the available quantity of land will be exhausted before all the labor is employed. In that case, only land need be added to permit production to expand, and only land would have positive resource earnings. The reverse situation would occur if labor use were expanded in greater proportion than land use.

All three situations occur in this solution. In the western and eastern moist forests (Areas III and V), the new pattern increases land use in greater proportion than labor use. Only land has a positive use value in these two areas. (See Table 25.) In contrast, relatively labor-intensive activities dominate the solution in the dry savanna and the forest-savanna mosaic (Areas I and VI), so there only labor has a positive scarcity value. In the other two areas of the country, both land and May–June labor have positive opportunity costs.

In the three moist forest areas, land used in cropping activities can earn from 260s to 430s per acre; in the intermediate savanna it earns 77s per acre. Expanding the land under cultivation would add to Nigerian agricultural income in these four areas if this could be done without reducing the quality of the land employed. In the eastern moist forest the latter condition cannot be met, but elsewhere in the country it might be.

In the western moist forest, an additional acre of land could add 310s to the agricultural revenue of Nigeria, with no change in the quantity of labor available or in the maximum limits imposed upon particular activities. (Because of those maximum limits, the only activities that can be expanded are those that are already below their maxima. These are the least productive of the cropping activities in

the area, but an extra acre of land in the western moist forest could still yield 310s.)

In the central moist forest and the intermediate savanna (Areas IV and II), increases in the land under cultivation would require a reallocation of the labor in use, for the May–June labor available in the model already is fully employed. (See Table 26.) In the western moist forest only 0.2 percent of the May–June labor allowed is still unused in the present solution. As soon as this unused labor is employed, the benefit from adding land will decline.

In the eastern moist forest it is not likely that the amount of land under cultivation could increase without reducing the fallow period and therefore the yields. For this reason the model allows land under

Table 26. *Resources Available and Unused*

Resource and area	*Unit*	*Quantity available*	*Quantity unused*	*Percentage unused*
Labor in May and June	1,000 man-days			
I		449,000	0.0	0.0
II		181,150	0.0	0.0
III		84,290	150	0.2
IV		51,580	0.0	0.0
V		92,140	7,542	8.2
VI		70,000	0.0	0.0
Labor during rest of year	1,000 man-days			
I		1,795,800	915,550	51
II		797,200	489,300	61
III		404,100	117,500	29
IV		247,500	67,900	27
V		442,400	210,800	48
VI		336,200	167,500	50
Land under cultivation	1,000 acres			
I		15,041	624	0.4
II		6,534	0.0	0.0
III		5,188	0.0	0.0
IV		1,260	0.0	0.0
V		3,390	0.0	0.0
VI		2,830	30	1.1
Additions to land under cultivation	1,000 acres			
I		–	–	–
II		–	–	–
III		–	–	–
IV		–	–	–
V		322	322	100
VI		–	–	–

Bush pasture	**One million acres**			
I		429.6	0.0	0.0
II		847.1	821.6	97
III		2.64	1.84	70
IV		2.64	2.15	81
V		10.99	8.68	79
VI		99.55	91.21	92

NOTE: In general, the quantities of arable land and of May–June labor available are 9.5 percent greater than the quantities required, according to our estimates, to carry out the activities in the model at their 1963 levels. In the eastern moist forest the quantity of land available is the 1963 level, with an extra 9.5 percent available under the category of "Additions to land under cultivation." The labor available other than during May and June was estimated by multiplying the May–June quantity by factors that convert from the two-month to a ten-month period and adjusting for differences between the May–June period and the rest of the year in the length of the working day and the number of holidays taken. In the dry savanna the quantity of bush pasture is our estimate of the quantity used at the 1963 levels of the animal industries, less our estimate of the increase in amount of arable land available in that area between 1963 and 1967. In the other areas, the quantities of bush pasture available were set at various multiples of the quantities required to carry on the animal activities at their 1963 levels. (For more detail, see chapter 2.)

—: The resource is not considered in this area.

cultivation in the eastern moist forest to increase above 1963 levels only at the expense of a decrease in yields per acre. If land use were to increase as much as 9.5 percent in this area, the model assumes that yields per acre would decrease by 5 percent. Under this condition it is not optimal to increase the land in use above estimated 1963 levels, even though 8 percent of the May–June labor available is not being used. No part of the 322,000 acres potentially available for use in this area comes into use in the solution. (See Table 26.)

In the dry savanna and the forest-savanna mosaic (Areas I and VI) the optimal cropping pattern leaves small quantities of arable land unused (0.4 and 1.1 percent, respectively). No increase in agricultural revenue would be caused by an increase in the quantity of arable land in these two areas: The alternative opportunity cost of using such land is zero. The amounts of unused land are very small, however, so modest increases in the maximum levels of some of the cropping activities in these areas would be likely to create valuable alternative uses for such land.

One such alternative already exists in the dry savanna—shifting some arable land to use as bush pasture, which earns 2.8s per acre. However, such transfers could not dip very far into the land that is being used in crop production because (as has been seen) most of the cropping activities in use earn far more than 2.8s per acre.[37]

Another alternative consists of relaxing the maximum limits on one or more field crops. Expanding the best of these would yield a product of far more value than can be obtained from expanding any animal industry and probably would use up the excess arable land very quickly.

Except in the eastern and western moist forests, the optimal cropping pattern uses all the May–June labor available. Labor is most scarce (most valuable) in the dry and intermediate savannas, where an extra man-day during the period of peak labor requirements could add some 8s to the value of Nigerian agricultural revenue (Table 25).[38] Additional May–June labor would add nothing to agricultural revenue in the eastern and western moist forests, where labor has zero opportunity costs, as long as land is not increased and individual crops cannot expand beyond the maximum levels set in the model. A small change in some of those levels might create a positive opportunity cost for labor in the western moist forest, however, for only 0.2 percent of the labor there is unused in the present solution.

Wherever May–June labor has a positive value, the optimal cropping pattern is determined partly by the May–June labor requirements for each crop. (No crop will be produced that does not yield as much for its May–June labor as that labor could yield if used for any other crop.) This factor is most important in the dry and intermediate savannas, the areas in which the opportunity cost of labor is the greatest. Indeed, in the dry savanna, May–June labor is the only resource that affects the cropping pattern. (Of the arable land, 0.4 percent remains unused.) In the moist forest areas, where land has a high opportunity cost value, economizing on land use is a major determinant of the cropping pattern. In the eastern and western moist forests, where some labor goes unused, land is the only resource that affects the cropping pattern.

The limits on the labor available in the model are of more descriptive significance than the limits on land. Both figures are based upon the quantities used in 1963, but while there is no reason to doubt that labor was fully employed at that time, the land available often exceeded the land in use. In fact, the quantity of land in use at any given time undoubtedly is determined largely by the quantity that a man and his family are able to cultivate. Therefore, increasing the land under cultivation would be feasible where labor is not fully employed at the peak period of the year. Unfortunately, the amount of unused labor at this period is negligible, except in the eastern moist

forest, where the extra land is not available without serious loss of fertility. Significant expansion in the land under cultivation per man rests upon the use of labor-saving patterns of cropping or the application of labor-saving tools and techniques during the period of peak labor requirements. Rerunning this model with higher land allowances would identify labor-saving cropping patterns.

Summary

To maximize the earnings of Nigerian agriculture while providing nutrients at the levels specified in this problem, a proportional expansion of production from 1963 levels would not be optimal. Most income crops should expand to or beyond the limits set in the model. More than proportional expansion of certain food crops is needed to release resources for use in the production of income while still providing the specified levels of nutrient production. Furthermore, several food crops are so productive of essential nutrients that an extra acre of one of them, beyond solution levels, would release resources worth more in income production than an extra acre of almost any of the income crops. (The only exceptions are tobacco in the savanna areas and oil palm, at prices higher than those prevailing in 1972, in the forest-savanna mosaic.) Where animal production uses resources that do not compete with the rest of agriculture, it is optimal to expand it even beyond the limits allowed in the model. If there is competition for land, however, a number of food crops would yield more from expansion than would any of the animal industries.

Expanding food crops to release resources for income production means an increase in specialization and greater dependence upon the marketing structure. It follows that improvements in the transportation, marketing, and food processing industries, by increasing the opportunities for profitable specialization, also could contribute greatly to expanding agricultural income.

Designing a Development Strategy

The surplus values reported for the various food crops identify those that can provide significant improvements in nutrition for the average farmer with a fixed amount of land to use and that involve the least costly diversion of energy or land from the cultivation of crops that bring money income. Thus, Table 19 shows that in the western moist forest (Area III) the farmer who plants yams, maize,

and cocoyams for his family's food will provide the necessary nutrients with less use of land than would be required if he also had grown okra, bitter cassava, and melon seed. The Area III farmer who increases the proportion of mixed yams and maize above the solution level, at the expense of cocoyams or cassava, also will reduce the quantity of land needed for a given set of nutrients if he does not depart too greatly from the solution level pattern.

If labor, rather than land, were the limiting resource for this farmer, the surplus figures should be expressed in terms of shillings per unit of May–June labor. Quite often the calculations will not need to be made formally. If the farmer is told that the nutrients produced by land in mixed yams and maize are worth about twice as much as the nutrients he could get from land solely in cocoyams, he will have no difficulty in evaluating the return in terms of the labor requirements at his busiest period.[30] His judgment as to how these crops would affect his labor schedule is undoubtedly better than most data on labor requirements possibly could be.

In planning for developmental expenditures, one should look at the acreages already under cultivation as well as the figures of surplus earnings available by expanding beyond the maximum limits set in the model. For example, the solution of the model calls for 889,000 acres of Guinea corn (sorghum) as a sole crop in the intermediate savanna. An expansion of this acreage by one percent (8,890 acres) would contribute total surpluses worth 3,280,000s at 369s per acre. To obtain nutrients worth that much by expanding bush maize as a sole crop at 565s per acre would require fewer acres (5,806), but this is 3 percent of the solution level for bush maize grown alone. Less promotional effort and expense might be required to expand the acreage in Guinea corn as a sole crop by one percent than to expand the sole cropping of maize by 3 percent. Furthermore, while the value of the surplus at the maximum limit might be a satisfactory estimate of the gain per acre for a change in acreage amounting to one percent, it is slightly less likely to be satisfactory for a change of 3 percent. The larger percentage expansion in acreage is less likely to satisfy our assumption that acreage expansion can occur without a decrease in yields.

Another consideration is that sometimes it may be better to focus developmental expenditures on some aspect of the problem other than production. At the yields used in this model, soybeans in the forest-savanna mosaic produce a surplus of 840s per acre in terms of their

nutritional worth, but this nutritional value generally is not accessible to Nigerians because the soybean is not well adapted to traditional methods of cooking. Introducing them into the Nigerian diet is more important than increasing their level of production. Here developmental expenditures well might be directed toward finding ways of preparing soybeans that will fit more readily into Nigerian cookery.

In general, cropping activities earn the most for the resources they employ. While the traditional animal industries often provide some surplus over the opportunity-cost value of the resources they employ, that surplus is comparatively small. Moreover, the opportunity-cost value of the resources they use is itself small, for few of the resources used in the traditional animal industries have significant alternative opportunities. Naturally, the optimal combination of activities for Nigeria includes the traditional animal industries as well as most of the cropping activities. Both are needed. However, most of the cropping activities that are in the solution earn a greater return for the resources they employ than do the animal industries. In an agricultural development program, animal and crop industries are competitive for the time, money, and attention of development and research agencies. If the developmental costs of obtaining comparable expansions of output beyond 120 percent of estimated 1963 levels are the same for both kinds of activities, then expanding crop production—if the right crops are selected—would contribute much more toward improving the income and nutrition of Nigeria than would expansion of the animal industries.

7

Conclusion

Nigerian production techniques in 1963 were adequate to meet the nutritional needs of the 1967 population of 61 million people at the levels prescribed in this model, given the use of efficient patterns of production, trade, and food selection. By meeting the allowances for calories, riboflavin, calcium, and vitamin A in an efficient fashion, all the other nutrient allowances considered in this study were fulfilled, including that for protein. Meeting the calcium and riboflavin allowances was physically difficult, as well as expensive,[1] while meeting the caloric allowance was quite costly.

The levels of the nutrient allowances used in the model, however, were quite modest. They did not allow for the extra nutrient needs that arise because of disease and infestation, for nutrient losses in food preparation, or for the special food needs of the child under five. Neither were allowances made for differences in the seasonal availability of foods or for the fact that nutrients are not distributed within the country in accordance with nutritional needs, either among families or within families. To produce the extra quantities of food required to provide adequate nutrition for all in the face of these additional complications would put much greater pressure on the agricultural system. In particular, the additional nutrient needs are often likely to be especially heavy for protein and certain B-vitamins that

often are found in association with protein. Protein allowances sufficiently high to provide for these extra needs might be difficult to attain. Significantly higher levels of calcium and riboflavin production would have been impossible to achieve with 1963 levels of agricultural technique.

Our analysis indicates that the basic pattern of geographical specialization now followed in Nigeria is wise from the standpoint of nutrition as well as income. Production for export (principally cocoa, palm products, and groundnuts) is most efficiently carried on in the three moist forest areas and the dry savanna. This specialization is attainable while maintaining the specified levels of nutrient availability in each part of Nigeria if the nutritional needs of the exporting areas are partially met by food produced in the two savanna areas and the forest-savanna mosaic. (The dry savanna is important as a producer of both food and income.)

The savanna areas are efficient sources of cereals (especially millet and maize) and of meat animals for the rain forest zones. The forest-savanna mosaic provides a variety of foods for the moist forest.

However, even the savanna areas are not nutritionally self-sufficient in an efficient organization of the Nigerian economy. Both require red palm oil, essential for meeting their needs for vitamin A and helpful in meeting their caloric needs. (While the western moist forest and the forest-savanna mosaic send palm oil and its vitamin A north, at the same time they buy groundnut oil, which provides calories but no vitamin A, from the dry savanna.) At the level set for the calcium allowance, the dry savanna (Area I) also takes cowpeas from the intermediate savanna, but the calcium figure is higher than necessary.

Attaining the goal of least-cost nutrition also implies a modest degree of dependence upon foods obtained from outside Nigerian agriculture—dried freshwater fish with edible bones for all but one area and sugar for the western moist forest. Stockfish, although they constitute a large part of Nigerian food imports, do not appear in the optimum solution of the model. Dried freshwater fish with edible bones are far more economical sources of food energy, riboflavin, and calcium.

The pattern of internal trade reflects both the export opportunities open to the moist forest areas and the opportunity costs of meeting the various nutritional allowances, particularly those for calories, riboflavin (in the rain forest areas), and calcium (in the dry savanna). While the calcium allowance for the dry savanna is unduly high un-

der the circumstances, the riboflavin and calorie allowances are at desirable levels.[2]

Internal movements of foods are important if the allowances are to be met economically. Thus certain trade movements are highly developed in this solution. The flow of millet into the eastern moist forest and the forest-savanna mosaic is huge, while about a billion pounds of maize move into the rain forest areas, and the principal meat-producing areas export *all* the animals produced in the solution. (The needs for riboflavin and calories in the rain forest areas are the principal determinants of the trade.[3]) Releasing resources for income production by expanding food production in the most efficient areas requires increased dependence upon trade and markets and adds to the potential importance of improvements in transportation, marketing, and processing.

The optimal solution of this model has the beef and milk output of the Fulani herdsmen remaining at about the 1963 levels. All the other traditional animal industries expand to their maximum limits. The modern animal activities, however, are at zero level, with the exception of commercial cattle production in the forest-savanna mosaic. None of the other modern animal activities is worth the resources required.

Production of most income crops was below optimal levels in 1963. Income levels can be raised while maintaining adequate supplies of nutrients by expanding most cash crops in greater proportion than the population, even beyond the 20 percent limit set in this model. The income crops are far more promising than the traditional animal activities, except for cotton and rubber, and even these sometimes surpass the latter.

Tobacco, oil palm,[4] and cocoa promise the most gains from expanded acreage, followed by groundnuts and kola nuts. Soybeans surpass all these except tobacco in Area I, but soybeans are a food crop in this solution. Rubber and cotton are poor candidates for expansion.

Most promising of all are the food crops. Expanding many of these beyond the 20 percent limit set in this model would increase income by reducing the proportion of the existing output of exportable produce that must be used for food, or by releasing resources from food production for use in income production. Expansion of the traditional animal industries is desirable as long as they use no resources that have value in alternative uses, but if available resources are required, expanding selected food crops offers the greatest gains. Among the

major crops, yams, cocoyams, and maize are especially efficient sources of nutrients when grown in the proper areas. Their acreage could well expand beyond the levels shown in the model. Although the data are not what one would wish, mixed cropping often appears to be more efficient than sole cropping. The eastern moist forest is the least promising area for expanding food crops.

In the eastern and western moist forests the crop production pattern of the present solution includes proportionately greater representation of activities that are relatively heavy land users than was the case in 1963. In the dry savanna and the forest-savanna mosaic, however, the pattern represents proportionately greater expansion in the more heavily labor-intensive activities.

Additional agricultural labor during the critical months would be the most valuable in the two savanna areas, with their shorter growing seasons. The cultivation of additional land would be most valuable in the three rain forest areas, presumably because of the export opportunities available there.

Two features of the present model have considerable influence upon the results, but are not desirable in a model designed as a basis for policy recommendations. They are the magnitude of the calcium allowance in the dry savanna and the possibility of large consumption of millet in the eastern moist forest. Millet is not widely eaten in the latter, and there is considerable evidence that the calcium allowance essential to health is lower than the one used in the model. These features will be changed in the model to be discussed in Part Two.

In addition, the present model allows all the traditional animal industries to expand by 20 percent outside the dry savanna. This is possible because the quantity of bush pasture available far exceeds the amounts needed, and the labor employed is regarded as consisting of children and the aged who have no other labor uses and are always available in adequate quantity. However, to assume that labor of this type will be adequate for a 20 percent expansion of the activity, especially when the population expands by only 9.5 percent, may be optimistic, so in the revised model animal industry expansion outside the dry savanna will be limited to 9.5 percent.[5]

Finally, some nutritionists would regard the proportion of the sulfur-containing amino acids specified for the fully utilizable protein in this model as lower than is desirable. One might suspect that the finding that protein is not one of the controlling nutrients results from specifying the composition of protein in this way, rather than from

the specific nature of Nigeria's productive powers. This too will be checked by the model to be discussed in Part Two.

In summary, the basic pattern of Nigerian agricultural production is sound. It is not, however, optimal. The major cash crops and numerous food crops appear to have been below optimal levels in 1963. Adjustments in the 1963 pattern of production along the lines indicated here would lower the cost of providing adequate quantities of the nutrients that are economically scarce (calories, riboflavin, calcium, and vitamin A) and increase the levels of income that can be earned from Nigerian agriculture.

The present solution points out desirable directions of change. It does not, and was not intended to, prescribe an optimal pattern. The optimal pattern changes continually as actual changes lead to alterations in the technical coefficients of the various activities, through developing experience with new crops or methods, or with the exhaustion of the supplies of land best suited to particular crops. Furthermore, an optimal pattern in the fullest sense would take account of tastes more than does this model. The most efficient sources of nutrients are not necessarily those that will be chosen by people who eat for pleasure as well as for nourishment.

Part II:

Adequate Nutrition Using Traditional Techniques In the Savanna

8

Introduction: Changes from the Previous Model

The model discussed in Part One was the third in a series designed for the study of Nigerian nutrition and income[1]; it gives a somewhat optimistic estimate of Nigeria's capacity to provide both. Model Four, now to be discussed, is much more conservative, but it confirms the major conclusions concerning the essential nature of the Nigerian nutritional problem that were obtained from the earlier model. In one respect, however, it understates the difficulty of providing an adequate level of nutrition: The use of gathered and collected foods is assumed to be 3 percent higher in this than in the earlier model.

The prior model possessed certain weaknesses. First, the calcium level, which dominated the solution for the dry savanna (Area I), was higher than was nutritionally necessary. Second, the maximum limits imposed upon the consumption of individual foods may have been too high in areas where those foods were relatively unfamiliar. Third, the maximum limits set for the traditional animal industries outside Area I also may have been too high.[2] Most important, however, is the fourth weakness. Many nutritionists would regard the fully utilizable protein used in that model as low in the sulfur-con-

taining amino acids. (Their proportion to the other essential amino acids equalled that of egg protein, but their proportion to the total weight of amino acids in a gram of protein was only about as much as in cow's milk—less than in human milk.[3] Many nutritionists would prefer to use the proportion in human milk as a minimum level.)

It is natural to wonder whether these flaws had significant effects upon the results. Surely the comparative nutritional efficiencies of the various food crops in the dry savanna must have been affected by the fact that reaching the calcium level specified was extremely costly in that area. But were there other effects?

The calcium allowance used in Model Three was only 9 percent below the maximum physically attainable at the riboflavin level specified by the model, while the riboflavin level was only 12 percent below the physically attainable maximum at the specified calcium level, given the conditions of the model. In both cases our requirements pressed hard against the limits of Nigerian capacity. Did this situation result from the level of the calcium allowance in the dry savanna, or did it reflect a more fundamental characteristic of the Nigerian economy?

Protein was not a controlling nutrient in any area. This result may have occurred because the solution permitted large quantities of millet to be consumed in the eastern moist forest and the forest-savanna mosaic, areas in which millet is a relatively unfamiliar food. Perhaps our specifications for fully utilizable protein were too low in the sulfur-containing essential amino acids. A third possibility is that the traditional animal industries were permitted to expand in greater proportion than the labor supply outside the dry savanna.

To solve the problem, when the opportunity arose in 1969 to obtain production data from a new source for the major crops grown in the savanna areas, advantage was taken of the occasion to eliminate the weaknesses from the model and to use the new data. If the important results persisted despite model changes and with the introduction of the new data, our confidence that any earlier peculiarities were not caused by misspecification of the model and that earlier results were descriptive of significant characteristics of the Nigerian economy would be increased.

Consequently, in Model Four the Area I calcium allowance is set at 330 mg daily per capita, not at the 392 mg used previously. For six foods, including millet and sorghum, maximum consumption levels per capita are considerably lower in certain areas. Likewise, new

maximum limits on production levels for the traditional animal industries outside Area I allow those industries to expand by only 9.5 percent above our estimates of their 1963 levels.

Finally, the amount of the sulfur-containing amino acids required in 100 g of fully utilizable protein is nearly 23 percent higher in this model than in the prior one. Instead of 3.424 g of the sulfur-containing amino acids, the present model requires 4.2 g per 100 g of fully utilizable protein. The situation is analogous for methionine: Instead of 1.712 g, the present model requires 2.1 g.

In addition to eliminating these questionable features of Model Three, the new model has another purpose: It represents the consequences of using traditional methods in the savanna areas instead of the more advanced techniques being employed in 1963. For eleven crops of the two savanna areas and the forest-savanna mosaic it uses new data that describe the results obtainable with traditional practices.[4] The results from Model Four, therefore, will not be directly applicable to the policy problems of Nigeria, but will be indicative of the situation that will develop if population growth outstrips the adoption of improved agricultural techniques. Comparison of results between Models Three and Four will enable estimation of the economic and nutritional importance of adopting improved agricultural techniques in the production of food crops. The results also will determine (1) whether errors in the quantitative estimates used in the model are responsible for the important features of the results and (2) which features of the Nigerian situation are so fundamental that they persist despite large changes in the production data used in the problem. One important advantage of the method employed here is that it enables measurement of the effects that alterations in the data have upon the nature of the solution or policy recommendations based upon it.

Most of the data were obtained by Mr. Hossein Yaghoobi and myself during a trip to Nigeria in May 1969. In addition to providing new production information for various activities already in the model, the new data permitted a number of minor changes. The present model includes new consumption activities for soybean and onion in the savanna areas; raises the maximum acreage permitted for mixed cowpea production in the eastern moist forest;[5] eliminates bitter cassava as a crop for the intermediate savanna and adds the acreage allowed it in the previous model to sweet cassava; provides manure for use in onion production in the savanna areas; includes new

data for the amino acid composition of Nigerian maize, kindly provided by Dr. Henry C. Wiggin, Western State Ministry of Agriculture and Natural Resources; and increases the nutrients obtained from gathered and collected foods from 106.33 percent of our estimate of the 1963 level to 109.5 percent of that level.

Table 27 gives the details. Quantitatively, the greatest changes are

Table 27. ***Changes in the Quantitative Specifications of the Models***

Description of data	*Model*		*Unit*
	Four	*Three*	
Nutritional			
Calcium allowance per capita, Area I	330	391.8	milligram
Sulfur-containing amino acid component of fully utilizable protein			percentage by weight
Sulfur-containing amino acids (cystine and methionine)	4.2	3.424	
Methionine	2.1	1.712	
Nutrient composition of foods			grams per kilogram
Maize, whole, white	[a]	[b]	
Lysine	1.63	2.88	
Sulfur-containing amino acids (cystine and methionine)	2.37	3.16	
Methionine	.78	1.86	
Threonine	1.94	3.98	
Tryptophan	.53	.61	
Maximum limits on consumption			million kilograms
Millet			
V	31.4	1,420	
VI	12.56	568	
Sorghum			
V	27.9	1,513	
VI	11.16	605.2	
Potato, Irish			
I	6.48	6.84	
III	4	400	
IV	0.8	80	
V	4	400	
VI	1.6	160	
Potato, sweet			
III	21.6	216	
IV	4.32	43.2	
V	21.6	216	
Groundnut			
II	213	565	
Bean, soya			
I	15.7	–	
II	31.4	–	
VI	12.04	361.2	

Onion			
I	624	–	
II	303	–	
Maximum limits on traditional animal activities			carcasses, output
Area II			
Cattle, bush	336.165	369.7815	1,000
Goats	10.950	12.0450	100,000
Sheep	4.380	4.8180	100,000
Area III			
Cattle, bush	1.095	1.2045	1,000
Goats	2.957	3.2522	100,000
Sheep	.558	.6143	100,000
Area IV			
Cattle, bush	1.095	1.2045	1,000
Goats	2.081	2.2886	100,000
Sheep	.066	.0723	100,000
Area V			
Cattle, bush	3.285	3.6135	1,000
Goats	8.870	9.7565	100,000
Sheep	1.424	1.5659	100,000
Area VI			
Cattle, bush	28.470	31.3170	1,000
Goats	1.752	1.9272	100,000
Sheep	3.395	3.7340	100,000
Maximum limits on other production activities			thousand acres
Area II			
Cassava, sweet			
Sole	939.87135[c]	604.65900	
Mixed	840.42783[c]	760.03950	
Area V			
Cowpea, seed			
Mixed	24[d]	1.2045	
Resource use			
Manure			1,000 long tons
I	3,000	–	
II	1,500	–	
Maximum limit on gathered and collected foods			
Foods fixed in quantity	1,095.000	1,063.333	0.1 percent of 1963 level

–: Not included in this model.

[a] Data obtained from Dr. Henry C. Wiggin, Western State Ministry of Agriculture and Natural Resources, Ibadan, Nigeria.

[b] Data obtained from M.L. Orr and B.K. Watt, *Amino Acid Content of Foods*, Home Economics Research Report no. 4, U.S. Department of Agriculture, Institute of Home Economics (Washington, D.C.: U.S. Government Printing Office, December 1957), Item 182, Table 2, p. 56.

[c] Equals the sum of sweet and bitter cassava acreage in the previous model. Bitter cassava has been eliminated from the present model for Area II. (Our data appear to describe only sweet cassava production.)

[d] Based on an estimate derived from Olatunde A. Ojomo, *Cowpea: Production and Research in Western State of Nigeria* (Ibadan: Research Division, Ministry of Agriculture and Natural Resources, September 1967), p. 15.

in the maximum limits on consumption in a few cases where the Model Three limits failed to reflect the low levels of consumption actually prevailing in particular areas. The most important of these were millet and sorghum. The Model Three values implied per capita consumption levels in the neighborhood of one-half to one-third the levels for the dry savanna, far too high to be realistic in areas where millet and sorghum are eaten only rarely. The new limits imply per capita consumption levels for millet comparable to the intermediate savanna (which still may be very generous for the eastern moist forest and the forest-savanna mosaic). For sorghum the limits imply consumption levels equivalent to those in the western moist forest.

The change in the data for the nutrient composition of maize represents substitution of Nigerian data for a U.S. source. In principle, the Nigerian data should be more representative.

The new model also introduces several new production activities. (See Table 28.) The new data distinguish between upland and swamp rice, which permits replacing the undifferentiated rice activity formerly used in the savanna areas by separate activities for the two types of rice. Data were not obtained on intercrop production of rice, so rice as a mixed crop has been dropped from the model in these two areas. Onion and soybean production have been added in the savanna areas and millet and Guinea corn (sorghum) production in the forest-savanna mosaic. A new intercropping activity that produces cowpea hay as well as seed has been introduced in the dry savanna, with another activity, the production of sheep fed on hay, to make use of the hay produced. There is also explicit treatment of fertilizer purchases, with importing activities for sulphate of ammonia, single superphosphate, and muriate of potash, and transportation (buying) activities that move each of these fertilizers from the port of entry to the area in which it is used. Finally, the present model includes some changes that are more largely matters of form than of substance. These, which are not itemized in Table 28, include: A few exporting activities are made explicit rather than implicit; when a new production activity is introduced, an area may be given a choice between producing what it consumes or buying it; and there are 36 activities, purely technical in function, that provide linear approximations to the six nonlinear protein restraints. The new model contains 638 restraints and 550 activities.

The changes in the production coefficients used in the model are given in Table 29. New data for the traditional production activities

Table 28. ***New Activities Included in Model Four***

Activity	*Area* I	II	III	IV	V	VI	*Nigeria as a whole*
Consumption							
Bean, soya, seed	x	x					
Onion	x	x					
Production							
As a sole crop							
Millet						x	
Rice[a]							
Upland	x	x					
Swamp	x	x					
Sorghum						x	
Bean, soya	x	x					
Onion	x	x					
Sheep, fed on hay	x						
As a mixed crop							
Cowpea, hay and seed	x						
Buying							
From port of entry							
Fertilizer							
Sulphate of ammonia	x	x	x	x	x	x	
Single superphosphate	x	x	x	x	x	x	
Muriate of potash	x	x	x	x	x	x	
Importing							
Fertilizer							
Sulphate of ammonia							x
Single superphosphate							x
Muriate of potash							x

[a] These replace the rice producing activities in Areas I and II in the previous model. That model did not distinguish swamp from upland rice. The present model retains the rice growing activities previously included for Areas IV through VI and regards them as representing swamp rice production. Production of rice as a mixed crop in Areas I and II has been dropped from the present model. The total acreage now allowed for rice in each of Areas I and II is equal to the sum of the sole and mixed acreages for that area in the previous model.

were obtained only for areas that included parts of the former Northern Region (Areas I, II, and VI). For most we are indebted to Mr. Richard B. Woodroofe, Chief Agricultural Officer, Kano State Ministry of Agriculture. He kindly provided information based on results obtained from extension demonstration plots.

The Woodroofe data cover the major crops in the savanna areas (Areas I and II). They do not, however, distribute the total labor usage under traditional cultivation between the May–June period and the remainder of the year. Therefore, when using the new data the previous ratio of May–June to "other" labor has been used to divide the new total figure between the two periods.

The new figure for total labor use per acre is usually lower than the one it replaces. This may reflect nothing more than the fact that the two sets of data came from different sources and thus were based on different definitions of *labor*, different definitions of the length of a man-day, and different conversion factors for translating the work of women and children into man-days. For example, in estimating labor usage with 1963 methods, an estimate of the time spent walking to and from the fields was included with the labor spent on particular crops. This was appropriate for our purposes, but it could not be done for the new data used in the present model. These were based on the work of scientists who were developing improved crops and methods and needed to make comparisons with input requirement and yields under traditional methods for that purpose. Their estimates naturally covered only time spent in the fields.

It is also true, however, that even if the same set of statistical definitions had been used in both cases one still would be likely to find that total labor requirements per acre were less with traditional methods than with the improved methods in use in 1963, as long as those improved methods continued to rely on human labor rather than on machinery or animal power. Note that the changes in techniques being considered are not changes that replace labor by machines or animal power. The higher yields that result from improved methods or varieties require, at the least, more labor for harvesting. Obtaining those higher yields may have involved more thorough soil preparation or better weeding. Still more advanced levels of practice require operations not performed under traditional agriculture, namely, fertilizing or spraying. If fertilizers are used, labor requirements for weeding increase, as any gardener knows.

Furthermore, we are talking about the amount of labor used per unit of land, not the amount used per unit of product. Improved methods of the kinds involved usually raise the ratio of labor use to land use, although they may lower the labor-output ratio. Labor usage rises per unit of land and falls per unit of output if the yield per acre rises sufficiently.

The new material included no information about intercropping. Therefore, in the present model the mixed cropping information is the old data adjusted to bring yields and labor requirements into the same proportions to the new sole cropping data as existed in the previous model. This procedure probably underestimates mixed cropping yields in the new model, for there is reason to believe that in the pre-

Table 29. *Changes in Data for the Production Activities, Areas I, II, and VI*

Activity and coefficient	*Unit*	*Area I Model Four*	*Area I Model Three*	*Area II Model Four*	*Area II Model Three*	*Area VI Model Four*	*Area VI Model Three*
Production as a sole crop							
Maize, bush	1,000 acres						
Yield	1,000,000 pounds	.84	1.2	.54	1.3		
Millet	10,000 acres						
Yield	1,000,000 pounds	4.7	5.8	4.4	6	3.9	–
Labor							
May and June	10,000 man-days	9	20	9	20	9	–
Other	100,000 man-days	1.9	4	1.9	4	1.9	–
Rice, unspecified	10,000 acres						
Yield	1,000,000 pounds	[a]	6	[a]	6.4		
Labor							
May and June	10,000 man-days	[a]	15	[a]	15		
Other	100,000 man-days	[a]	4	[a]	4		
Rice, upland	10,000 acres						
Yield	1,000,000 pounds	8	[b]	8	[b]		
Labor							
May and June	10,000 man-days	18	[b]	18	[b]		
Other	100,000 man-days	3.2	[b]	3.2	[b]		
Rice, swamp	10,000 acres						
Yield	1,000,000 pounds	11	[b]	11	[b]		
Labor							
May and June	10,000 man-days	18	[b]	18	[b]		
Other	100,000 man-days	4.8	[b]	4.8	[b]		
Sorghum	10,000 acres						
Yield	1,000,000 pounds	6.6	8.6	5.6	13.3	3.3	–
Labor							
May and June	10,000 man-days	16	20	16	20	16	–
Other	100,000 man-days	1.9	2.5	1.9	2.5	1.9	–

Table 29—*Continued*

Activity and coefficient	*Unit*	*Area* I *Model* Four	I Model Three	II Model Four	II Model Three	VI Model Four	VI Model Three
Cassava, bitter[c]	1,000 acres						
Yield	10,000,000 pounds			[d]	.315		
Labor							
May and June	10,000 man-days			[d]	1.25		
Other	100,000 man-days			[d]	.125		
Cassava, sweet[c]	1,000 acres						
Yield	1,000,000 pounds	1.75	2.1	1.75	2.2		
Labor							
May and June	10,000 man-days	1.4	1.25	1.4	1.25		
Other	100,000 man-days	.14	.125	.14	.125		
Yam	1,000 acres						
Yield	1,000,000 pounds	2.67	5.99	4.33	7.52		
Labor							
May and June	10,000 man-days	2.1	3.6	2	4		
Other	100,000 man-days	.59	1	.6	1.2		
Cowpea	10,000 acres						
Yield	1,000,000 pounds	2.3	8	2.2	4	1.9	5.7
Labor							
May and June	10,000 man-days	5	20	5	20	0.0	20
Other	100,000 man-days	1.8	2	1.8	2	5	3
Groundnut	10,000 acres						
Yield	1,000,000 pounds	6.7	6	5.6	6	4.5	6.1
Labor							
May and June	10,000 man-days	11	20	11	20	11	24
Other	100,000 man-days	3.4	6	3.4	6	3.4	6
Bean, soya	1,000 acres						
Yield	1,000,000 pounds	.50	–	.39	–	.37	2.1
Labor							
May and June	10,000 man-days	2	–	2	–		
Other	100,000 man-days	.3	–	.3	–		

Table 29—*Continued*

Activity and coefficient	*Unit*	*Area* I *Model* Four	I Model Three	II Model Four	II Model Three	VI Model Four	VI Model Three
Onion	1,000 acres						
Yield	1,000,000 pounds	6.7	–	6.7	–		
Labor							
May and June	10,000 man-days	0.0	–	0.0	–		
Other	100,000 man-days	.5	–	.5	–		
Cotton	1,000 acres						
Yield	1,000,000 pounds	.375	.290[e]	.375	.370[e]		
Labor							
May and June	10,000 man-days	.9	2	.9	2		
Other	100,000 man-days	.28	.6	.28	.6		
Production as a mixed crop[f]							
Maize, bush	10,000 acres						
Yield	1,000,000 pounds	7.4	10.5	5.2	12.5		
Millet	10,000 acres						
Yield	1,000,000 pounds	4.4	5.4	4	5.4		
Labor							
May and June	10,000 man-days	7	15	7	15		
Other	100,000 man-days	1.4	3	1.4	3		
Sorghum	10,000 acrees						
Yield	1,000,000 pounds	4.5	5.9	4.9	6.4		
Labor							
May and June	10,000 man-days	13	17	13	17		
Other	100,000 man-days	1.6	2	1.6	2		
Cassava, bitter[c]	10,000 acres						
Yield	10,000,000 pounds			[d]	2		
Labor							
May and June	10,000 man-days			[d]	10		
Other	100,000 man-days			[d]	.75		

Table 29—*Continued*

Activity and coefficient	*Unit*	*Area* I *Model* Four	I Three	II Four	II Three	VI Four	VI Three
Cassava, sweet[c]	10,000 acres						
Yield	1,000,000 pounds	12	14.5	11.5	14.5		
Labor							
May and June	10,000 man-days	11	10	11	10		
Other	100,000 man-days	.8	.75	.8	.75		
Yam	10,000 acres						
Yield	1,000,000 pounds	31	70	41	71.8		
Labor							
May and June	10,000 man-days	14	24	14	28		
Other	100,000 man-days	3.2	5.4	2.7	5.4		
Cowpea	10,000 acres						
Yield	1,000,000 pounds	1.2	1.4	2	1.6		
Labor							
May and June	10,000 man-days	0.0	12	0.0	12		
Other	100,000 man-days	3.2	2	3.2	2		
Groundnut	10,000 acres						
Yield	1,000,000 pounds	3.5	5.7	3.5	6	3	4.6
Labor							
May and June	10,000 man-days	10	18	10	18	12	22
Other	100,000 man-days	3.1	5.5	3.1	5.5	2.1	4
Cotton	10,000 acres						
Yield	1,000,000 pounds	2.6	2[e]	2.6	2.56[e]	2.6	2.2[e]
Labor							
May and June	10,000 man-days	8	18	8	18	8	22
Other	100,000 man-days	1.9	4	1.9	4	1.9	4

—: The activity was not included in this model.

[a] Replaced by upland and swamp rice.

[b] See "Rice, unspecified."

[c] The figures are for an acre of cassava of which half was planted in the current year. The other half, planted in the previous year, is being harvested during the current year.

[d] The bitter cassava that was included in the previous model has been replaced by sweet cassava in the present model.

[e] In this model the figure did not appear explicitly, for the sale activity was consolidated with the production activity.

[f] Production of rice as a mixed crop was dropped from the model in Areas I and II.

vious model many of the sole crop methods in use were more advanced than their mixed cropping counterparts. As a result, the efficiency of mixed cropping is probably greater than our solution to this model will indicate.

The data on onion production are based upon information received from Mr. J. Green, Institute of Agricultural Research, Samuru.[6] Mr. William M. Steele, Institute of Agricultural Research, Kano station, provided most of the information concerning cowpea production. Valuable assistance with the groundnut data came from Mr. Colin Harkness.[7]

Because the revised production data describe traditional practices, they generally indicate smaller yields than the estimates used in earlier models. Of the 21 changes in yield estimates for sole crops, 16 were decreases.[8] Naturally, the present model provides a less optimistic estimate of the nutritional capability of Nigeria than does its predecessor. The reduction in capability occurs mainly in the savanna areas and the forest-savanna mosaic, for elsewhere the production data were not revised. Of course, the rain forest areas as well as other parts of Nigeria were affected by lower maxima for the traditional animal industries, higher requirements for the sulfur-containing amino acids, lower figures for the essential amino acid content of native white maize, and lower limits on the consumption of certain foods (in the rain forest areas these were millet, sorghum, and Irish and sweet potatoes). The effects of these changes were offset partially by increasing the quantities used of gathered and collected foods (in all of Nigeria) and by allowing more acreage in mixed cowpeas in the eastern moist forest. On balance, these changes introduce a bias against the savanna areas and the forest-savanna mosaic, for traditional production methods in those areas are being compared with the methods in use in 1963 in the rest of Nigeria.

With the present data it becomes impossible to meet the nutritional allowances specified by the model when the level of the gathered and collected foods increases from our estimate for 1963 by only two-thirds as much as the population (as was the case in previous models). Therefore, the present model assumes that foods gathered and collected from bush, field, and roadside, or grown in the compound, increase in the same proportion as the population (by 9.5 percent). (See Table 27.)

9

The Costs of Individual Nutrients: Traditional Techniques

Using traditional production techniques outside the moist forest areas, Nigeria would be capable of providing the nutrient allowances specified for a 1967 population of 61 million people, *if* there were sufficient consumption of gathered and collected foods. If such consumption rises in proportion to population growth, the nutrient allowances can be attained, but if use of these foods lags much behind population growth, it would not be possible under the conditions specified in the model. Attaining the allowances is feasible if the consumption of gathered and collected foods is at 109 percent of our estimate of 1963 levels, but not at 108.99 percent of that estimate. In this model the use of gathered and collected foods is assumed to rise proportionately with population, to 109.5 percent of the 1963 level. Of course, such a rate of increase in the use of collected foods cannot continue indefinitely as population rises. Cultivation must replace collection if a growing population is to feed itself adequately.

Feasibility of the Allowances

Three nutrients are difficult (and therefore costly) to obtai. in adequate amounts even with the assistance of gathered and collected

foods at a level 9 percent above the 1963 consumption levels. These three are riboflavin in the eastern and central moist forests, calories in the intermediate savanna, western moist forest, and forest-savanna mosaic, and vitamin A in the dry savanna.[1] At the limit of feasibility (the lowest level of usage of gathered and collected foods at which all the nutrient allowances are attainable, slightly over 108.99 percent of 1963 levels), an amount of riboflavin equal to the average daily per capita allowance for Nigeria as a whole costs 296,000s when the total quantity available in the eastern moist forest equals the specified allowance for that area.

Lowering the quantity of riboflavin required for the eastern moist forest by the average daily per capita allowance for Nigeria as a whole would reduce the cost of the whole set of allowances (or increase the net revenue from Nigerian agriculture) by this amount. Table 30 shows these costs (the opportunity-costs of providing the nutrients) for each of the nutrients which is economically difficult to obtain in the specified amounts at the limit of feasibility. The costs in resources used are extremely high when the boundary of feasibility is approached. The riboflavin allowance in Area V places the greatest strain on Nigerian productive capacity, but the requirements for riboflavin in Area IV and for calories in Areas II, III, and VI are also very difficult to meet.[2]

Table 30. ***Nutrient Costs at the Limit of Feasibility, Traditional Techniques, in Shillings***

Nutrient	*Area*					
	I	*II*	*III*	*IV*	*V*	*VI*
Calories		190,000	190,000			190,000
Vitamin A	16,700					
Riboflavin				239,000	296,000	

NOTE: These are the least costs of expanding the intake of a single nutrient by one unit, in a single area, subject to all the limits on the levels of production and consumption activities and the constant quantities of resources available. The daily per capita nutrient allowance used as a unit is the average for Nigeria as a whole.

Using lower levels of gathered and collected foods appears infeasible because one or more of these five riboflavin and calorie allowances annot be satisfied. While the gathered and collected foods provided ı the model furnish all kinds of nutrients, the crucially important

contributions at this stage are riboflavin in Areas IV and V and calories in Areas II, III, and VI. The contribution of vitamin A in Area I is much less significant. While the vitamin A requirement in the dry savanna may contribute to the problem of infeasibility, it seems more likely that if adequate quantities of riboflavin and calories were available the Area I allowance for vitamin A could be satisfied within the conditions of the problem, without this level of usage of the gathered and collected foods.

One of the questions concerning Model Three already has been answered. The calcium and riboflavin allowances determined the boundaries of feasibility in that solution. Was that because of some fundamental characteristics of the Nigerian economy or was it simply the result of using an unnecessarily high allowance for calcium in the dry savanna? We now see that calcium was limiting because of the level of this one allowance, but that riboflavin continues to be limiting (in the central and eastern moist forests) when that is changed. Furthermore, we discover that at traditional levels of technique in the savanna areas the food energy (calorie) allowances would have set feasibility boundaries for the 1967 population. Nigeria's capacity to meet the basic nutritional need for food energy is dependent upon its ability to maintain a satisfactory rate of technical progress in agriculture, and the safety margin is not large.

When production outside the moist forest areas is restricted to traditional methods, our nutritional objective is unattainable unless the assumed usage of gathered and collected foods is raised from 106.33 percent to 109 percent of 1963 levels. Note that the higher quality of protein required in the present model plays no part in this, although two other features of the new model may have contributed: lower limits on the consumption of millet and sorghum in the eastern moist forest and lower levels of traditional animal production outside the dry savanna.

In the model to be discussed from now on, the usage of gathered and collected foods is asssumed to have grown in proportion to the growth of population, to 109.5 percent of 1963 levels. This gives a solution slightly inside the boundary of infeasibility, one that extends Nigerian capacity for providing nutrition essentially to its limits, but one not too much affected by the extreme movements in opportunity costs that occur as the limit of feasibility is approached.

Costs of Individual Nutrients

With the use of gathered and collected foods at 109.5 percent of 1963 levels, all the nutrient allowances for a population of 61 million can be met with the production techniques used in the present model. If production is organized with maximum efficiency, five nutrients will be economically scarce in one or another part of the country: riboflavin in the eastern and central moist forests; calories in all six areas; vitamin A in the two savanna areas; iron in the forest-savanna mosaic; and calcium in the dry savanna. If adequate amounts of these nutrients are obtained, the same set of foods will provide adequate amounts of all the others.

A nutrient is economically scarce when the cost of the diet goes up (or the net revenue from agriculture goes down) if the level of the allowance for that nutrient is increased. These are opportunity-cost measures. The net revenue given up when an allowance is increased by one unit is the opportunity for gain that is lost by increasing the allowance. Table 31 shows how much the cost of meeting the whole set of aggregate yearly allowances would rise if the amount of one allowance were increased by the allowance for one person for one day (the per capita allowance calculated over Nigeria as a whole.) By assuming that the use of gathered and collected foods is 109.5 percent of 1963 levels, requirements fall sufficiently inside the boundary of

Table 31. ***Costs of Nutrient Elements in Average Daily per Capita Allowances, Traditional Techniques, in Shillings***

Nutrient	*Area*					
	I	*II*	*III*	*IV*	*V*	*VI*
Calories	.554	6.42	6.42	.870	.664	6.42
Calcium[a]	.057[a]					
Iron						.105
Vitamin A	.526	.008				
Riboflavin				7.14	9.68	
Total cost of average daily allowances for all nutrients	1.14[b]	6.43	6.42	8.01	10.3	6.53

NOTE: These are the least costs of expanding the intake of a single nutrient by one unit, in a single area, subject to all the limits on the levels of production and consumption activities and the constant quantities of resources available. Except when indicated, the daily per capita nutrient allowance used as a unit is the average for Nigeria as a whole.

[a] The unit for all areas is 388.7 mg, although in Area I the actual allowance is much lower, only 330 mg. The cost for 330 mg is .048s.

[b] This figure includes the same amount of calcium (388.7 mg) as in the other areas, although only 330 mg actually were required in Area I.

feasibility[3] to cause a great reduction in the resource costs of meeting the allowances most difficult to satisfy. Nonetheless, with food crop yields generally diminished outside the moist forest areas, the costs of providing nutrients are still, for the most part, much higher than when 1963 techniques were assumed. (Compare Table 8.)

The total cost of the set of allowances is greatest in the eastern moist forest—10.3s per day, or £188 per year. This figure, some six or seven times the GDP per capita, indicates dramatically how difficult feeding the 1967 population would be with only the agricultural techniques used in this model (and how dependent the moist forest is upon the agriculture of the north).

The most notable changes from the situation with 1963 techniques are in the costs of calories in the intermediate savanna, the central moist forest, and the forest-savanna mosaic and of riboflavin in the central and eastern moist forests. In the dry savanna the effect of lowering the calcium allowance is clear: Calories and vitamin A are now the more costly nutrients.

The most difficult allowance to attain in the new model is that for riboflavin in the eastern moist forest. Providing one extra day's per capita allowance requires an expenditure of 9.68s. Part of this cost results from the fact that a large consumption of millet is no longer allowed in this model. At this level of the aggregate riboflavin allowances, small increases in the availability of riboflavin in both Areas IV and V are extremely expensive to bring about, given the production techniques that this model describes. Attaining adequate calorie levels in Areas II, III, and VI is also very expensive, but only about two-thirds as expensive as meeting the riboflavin allowance in Area V.

The principal costs of the most economical adequate diets available for the central and eastern moist forests are the costs of their riboflavin components. In the intermediate savanna, the eastern moist forest, and the forest-savanna mosaic, the cost of the calorie component is almost the whole cost of such a diet.

The cost of calories is almost identical in the latter three areas. (It is identical to the three figures shown in Table 31, but if more figures were shown it would be seen that Area II, a buying area, pays slightly more for its calories than the areas from which it obtains them.) Because the linkage connecting these costs is unusually simple in this case, it may be worthwhile to examine the relationships more carefully.

One source of calories in Areas II, III, and VI is red palm oil. The

only nutrients that palm oil provides are calories (in the form of fat) and vitamin A. In Areas III and VI only the calories matter, as there are extra quantities of vitamin A available, but in Area II both the calories and the vitamin A are of value. Area II obtains its palm oil from Areas III and VI, buying simultaneously from both. While each of the three areas consumes red palm oil, in none of them is this consumption at the maximum level, so the following condition for efficient allocation holds: The value of the nutrients provided by the oil in Area II must equal their value in Area III plus the transportation cost between III and II and also must equal their value in Area VI plus the transportation cost between VI and II. If the value of the calories in palm oil were less in Area VI than in III, and if transportation costs were the same from VI to II as from III to II (as they are assumed to be in the model), Area II could reduce the cost of its palm oil by taking more from VI and less from III. This adjustment would raise the cost of replacing the calories now being sent from VI to II and lower the cost of obtaining calories in III. (The calories cannot be replaced by simply expanding oil palm production, for that is already at the maximum levels permitted in the model in both III and VI.) Only when the value of palm oil (and therefore the cost of replacing the calories it provides) is the same in Area VI as in III will there be no advantage in changing the allocation of Area II purchases between III and VI. Consequently, the value of palm oil, the value of calories, and the cost of providing calories in some alternative way must be the same in Area III as in VI, although the physical means of replacing the calories in palm oil sent to Area II normally will be different in the two areas.

In Area II the same palm oil will be more valuable than in Area III by the amount of the transportation cost incurred in bringing it to Area II. The total value, however, will be divided between the calories and the vitamin A it provides. In this particular case the value of the vitamin A almost exactly balances the cost of transporting the palm oil, so the cost of calories is almost exactly the same in II as in III or VI.[4]

A by-product of this analysis is a partial explanation of the differences between the costs of calories in Areas II, III, and VI, on the one hand, and Areas IV and V, on the other. Red palm oil is consumed in all six areas, but the model provides no route by which it may be transferred from Areas IV and V, where calories are relatively inexpensive, to Areas II, III, and VI, where they are seven to ten times as

valuable. Had such trade routes been included in the model, the costs of calories in Areas IV and V would have been higher, while in Areas II, III, and VI they would have been lower. The net effect would have been less costly nutrition for Nigeria as a whole. The illustration brings out clearly the importance of internal trade for the efficient use of Nigeria's food production capacity. In the previous model, however, adding such trade routes would have been of less value, for the differences among the moist forest areas in the cost of calories were much smaller (Table 8). With the higher level of productivity in the savanna areas that existed in that model, the absence of this one potential source of calories was less important.

If the FAO/WHO recommendation for riboflavin were to be met by using traditional agricultural techniques, even without providing a margin for individual variation, doing so would become the problem of greatest quantitative importance in Areas IV and V. Meeting the caloric allowance in Areas II, III, and VI would be less difficult, but of the same order of magnitude. Lowering the desired riboflavin level would have a significant effect on the quantities of resources diverted from income production to food production, but providing an adequate calorie ration would remain a major problem.

Protein is not one of the costly nutrients. While Nigerian diets are, in fact, often deficient in protein, the production problem is solved without further effort when the riboflavin and calorie allowances set for this problem are fulfilled in the most economical way. More than the specified amount of reference protein is available in each area when these two allowances are satisfied. Not only is protein adequate, but also it is better in quality than in the model discussed in Part One. The minimum quantity of the sulfur-containing amino acids is 23 percent greater in the present model. (In principle, meeting the allowances for calcium, iron, and vitamin A also may contribute to protein output, but their contributions must be minor.) At lower levels of the riboflavin allowances there might not be adequate amounts of protein for the moist forest areas except through the use of additional resources, but at the present level the protein problem is more readily solved than the riboflavin and calorie problems.

To produce adequate amounts of protein on the assumption that each person shares in accordance with his needs, however, may not solve the problem of protein intake. There is a price and income problem involved. If the well-to-do consume more than they need, the

poor will have too little unless production expands beyond the level that would appear adequate if one looked only at averages.

To produce enough so that the poor could have what they need without anyone else reducing his consumption might well require more protein than is being provided simply in the course of satisfying the present calorie and riboflavin allowances (along with those for vitamin A, iron, and calcium). The present solution provides moderate excesses over the existing protein allowances in Areas I to III and in Area VI, a medium large excess in Area V, and a large excess in Area IV. (Note that the largest excesses are in the areas where the riboflavin allowance is controlling.) Major increases in the amount of protein required undoubtedly would make protein one of the economically scarce (costly) nutrients.

The present solution suggests that the limiting essential amino acids in that case would be the sulfur-containing group. In each area it is this group that the present solution provides in the smallest ratio to the specified amount.

In the previous model the absence of protein from the list of costly nutrients might have been caused by several characteristics of the model that made the protein allowance more readily attainable than it should have been. Those characteristics have been corrected in this model: The requirements for the sulfur-containing amino acids and methionine are nearly 23 percent higher here; the amino acid content of native white maize is at a lower level; the consumption limits on millet and sorghum in the eastern moist forest are much lower; and outside the dry savanna the traditional animal industries are restricted to lower levels. While the last two of these changes make the calorie and riboflavin as well as the protein allowances more difficult to attain, the first two affect only protein. Yet protein remains outside the list of costly nutrients, as in the earlier model. Evidently protein belonged outside the list of costly nutrients under 1963 production conditions. Results of the previous model that depended upon that fact were satisfactory.

Given the goals set for calories, riboflavin, and the other nutrients, Nigerian productive capacity was better adapted to meeting the protein goal than those for calories and riboflavin when traditional methods were being used outside the moist forest areas as well as when 1963 methods were in use. Had lower riboflavin goals been set in the moist forest areas, the cost of the diet in the central and eastern moist forests might have been lowered appreciably. At the same time, meet-

ing the calorie allowances in those two areas probably would have become more expensive, and at some stage protein might have become a costly nutrient.

The Most Economical Foods

In order to prevent the diets that appear in the solution from concentrating too much on individual foods that are exceptionally economical sources of nutrients, the model limits the per capita consumption of each food to four times our estimate of the 1963 level. As a consequence, the most economical foods, those that are restrained in their consumption by the maximum limits imposed upon them, commonly provide nutrients that are worth more than the resource costs of the foods. Table 32 lists these surplus nutrient values. If the consumption of one of these foods were permitted to rise by one kilogram, the cost of meeting the whole set of dietary allowances would fall by the amount of the surplus nutrient value obtained from the extra kilogram of food. The "least-cost" diets that this solution develops could be made even less costly by permitting larger quantities of these economical foods to be included. Of course, in general, the more of such a food that is used, the less is to be gained from further increases in its consumption.

The nutrient allowances are most costly to meet in the eastern and central moist forests. In those two areas the most economical foods are (in order) goat meat, mutton, and beef. In Area V goat meat (chevon) provides a surplus nutrient value of 41s per kilogram (at the nutrient costs given in Table 31). The meats are valuable primarily because of the riboflavin they contain; chevon and mutton are more valuable than beef because they provide more riboflavin per kilogram. Their caloric content has some value, of course.[5]

Except for beef in the eastern moist forest, meats were also on the list of most economical foods for these two areas (ranked in the same order) in the model using the more advanced 1963 production techniques outside the moist forest areas (Table 9). (Beef was an economical food in the eastern moist forest in that solution, but it was not consumed at its maximum level.) The potential gains from increasing the amount of meat in the diet are much higher, of course, in the present model, for nutrients are much more costly to obtain when using the techniques of traditional agriculture.

In the present model the next most efficient source of nutrition in these two areas is dried freshwater fish. In Area V millet is close be-

Table 32. ***Potential Gains from Expanding or Contracting Those Consumption Activities Significantly Constrained by Their Maximum or Minimum Levels, Traditional Techniques, in Shillings per Kilogram***

Food	*Area* I	II	III	IV	V	VI
At maximum levels						
Maize						
Local white					2.8[a]	
Yellow					2.8[a]	
Millet					14	9.2
Sorghum					2	.18
Wheat						
Whole		8.5			9.1	8.6
Flour			6.9	4.4		
Potato						
Irish	.054				.36	
Sweet					.14	
Cowpea				1.7	9.9	
Groundnut				10		15
Bean, soya						5.9
Onion		.66				
Oil						
Groundnut	.30	23	23	.76		23
Red palm				.67		
Fish, dried freshwater		3.6	3.2	10	15	3.3
Beef				16	25	
Goat meat (chevon)				30	41	
Mutton				22	32	
Sugar		9.6	9.7			9.7
Beer						
Millet						.81
European-style				2.1	3.3	
At minimum levels						
Beer						
Millet	.047	.55[b]				
European-style		.55[b]	.55			
Kola nut	10	.78				

NOTE: If the maximum level were raised, or the minimum lowered, the revenue provided by the solution would increase.

[a] The maximum limit is satisfied jointly by 197 million kilograms of native white maize and 4 million kilograms of yellow maize.

[b] The minimum limit is satisfied jointly by 1,671 million kilograms of European-style beer and 6 million kilograms of millet beer.

hind, with a surplus nutrient value of 14s per kilogram. Cowpeas and wheat follow, with surpluses of 10s and 9s per kilogram. Again the riboflavin content accounts for most of the value of the food. In the central moist forest groundnuts, yielding a surplus of 10s, are as efficient nutritionally as dried freshwater fish.

European-style beer, because of its riboflavin content, is also an efficient food in both areas. In Area V its surplus of 3.3s per kilogram, although small, is greater than that for either maize or sorghum. (The quantity of beer allowed in the model is, however, limited to the 1963 per capita consumption level for palm wine plus beer in the area, rather than to four times that amount.)

Looking at these data helps explain why solving the riboflavin problem in Areas IV and V also solves the protein problem. Meeting the riboflavin allowance requires expanding a number of protein sources to their maximum levels: meats, fish, cowpeas or groundnuts, and such cereals as millet or wheat.

The nutritional efficiency of a food depends not only upon the nutrient content, but also upon the value of its nutrients in the area where it is consumed. Thus, while many of the most economical foods in Area V are also in that category in Area IV, in the latter area, where riboflavin is less costly to provide, the surplus values are lower. (It is by comparing values in the consuming areas that the computer determines the pattern of internal trade that places each food where its nutritional contribution will be the most significant.)

A lower allowance for riboflavin might have altered the list of efficient foods considerably in Areas IV and V. However, if the riboflavin allowance were much lower, some other nutrient, perhaps protein, probably would become more costly in those areas. If the efficient sources of riboflavin were also efficient sources of protein, such changes in nutrient costs might leave the list of efficient foods relatively unchanged.

A quite different set of foods yields nutritional surpluses in Areas II, III, and VI, where the caloric allowance is the costly one to satisfy. Groundnut oil, yielding a surplus of 23s per kilogram, is the most efficient food in each area. It is evidently a more economical source of calories than red palm oil in these areas.[6] In the forest-savanna mosaic groundnuts themselves are highly efficient, providing a surplus of 15s per kilogram, but in the other two areas they yield no surplus. (In the western moist forest, indeed, they are not efficient enough to enter the diet at all.) Next in line comes white sugar, worth 10s per kilogram more than its cost in each of the three areas.[7] Wheat or wheat flour yields a surplus in each area, as do millet and soybeans in Area VI. Dried freshwater fish yields a modest surplus in each area. In Area VI, but not in the others, millet beer provides a small nutritional surplus.

Wheat (or wheat flour), dried freshwater fish, and groundnut oil appear in the set of most economical foods both where riboflavin is the principal costly nutrient and where calories constitute the principal problem. These foods serve different nutritional purposes in the two situations, but they serve well in both cases.

In general, the areas where nutrients are most expensive are also the areas with the longest lists of foods that yield surpluses in nutrient value. They are, as one might expect, the areas where there is the most to gain from concentrating consumption on foods that are unusually economical sources of the costly nutrients. The dry savanna, where nutrient costs are low, has only two foods that are worth consuming at more than four times the 1963 levels.

Table 32 also identifies those foods that are in the diet only because the model requires them to be present whether or not they are nutritionally efficient. (These are customary items in the diets of the people.)

When more than one method of meeting the requirements is available, the computer chooses the one or more that is most economical. In the dry savanna the beer requirement is met at very small net cost with millet beer. In the intermediate savanna, European-style and millet beer are equally economical as long as almost all of the requirement is met by European-style beer. In the western moist forest, European-style beer is more economical than palm wine.

Even though European-style beer is economical as a means of meeting the requirement for alcoholic beverages in the intermediate savanna and the western moist forest, it still costs .55s more per kilogram than the nutrients it contains are worth. As the price of beer in the model is 1.54s per kilogram, the nutrients it provides are worth only two-thirds the price. In this solution 3,600 million shillings are spent on beer for these two areas. Of this amount, 1,300s represent the cost of satisfying the requirement that the diets contain the customary quantity of beer or palm wine. If these beverages were given up, the cost of the diets could fall immediately, with no loss of nutritive value, as less expensive sources of calories replaced the beer.

On the other hand, it is important to remember that if beer must be provided, no cheaper source exists under the conditions of the problem. The alternatives available for the intermediate savanna are millet beer and Guinea corn (sorghum) beer. The former is as economical as European-style beer (small quantities already are being consumed in the solution), but it is unlikely that large amounts of millet could be

transferred from existing consumption uses without raising the costs of one or more nutrients. To replace small amounts of European-style beer by Guinea corn beer would add .064s per kilogram to the cost of meeting the alcoholic beverage requirement. Large replacements would run into still larger costs as sorghum was pulled out of other consumption uses.

In the western moist forest the alternative means of meeting the alcoholic beverage requirement is palm wine. To replace European-style beer by palm wine would raise the cost of the diet by .57s per kilogram, thus doubling the net cost of satisfying this conventional requirement. The palm products that would have to be given up are worth more than twice as much as the nutrients (calories) that the palm wine would provide in Area III.

European-style beer appears in the consumption pattern in four of the six areas, either at the minimum or the maximum level. It provides a means of obtaining nutrients (principally calories or riboflavin) from outside the Nigerian agricultural sector.

Meeting the conventional requirement for kola nuts costs 10s per kilogram more than the nutrients are worth in the dry savanna, where the opportunity costs of nutrients are very low. The aggregate net cost of meeting this requirement in the dry savanna is 515 million shillings. Eliminating kola nuts from the solution for this area would lower the cost of the diet by this amount. The net cost per kilogram of meeting this conventional requirement is much lower in the intermediate savanna and nothing at all in the western moist forest. There kola nuts provide nutrients just equal in value to their cost. In that area the consumption level is about one-third above the allowable minimum. The model includes no requirement for kola nut consumption in the other three areas.

Restricting agriculture to traditional methods outside the moist forest areas has raised the gains to be made by concentrating consumption on the most efficient foods (compare Table 9) and has nearly doubled the number of foods on the list.[8] All the foods on the list for 1963 techniques remain on the new list. In the central and eastern moist forest meats hold the first rankings on both lists.

When restricted to traditional methods, several foods obtained from outside the Nigerian agricultural sector appear on the list: sugar, wheat and wheat flour for Areas III to VI,[9] dried freshwater fish, and European-style beer. At 1963 levels of production, the only one of these that was on the list of unusually economical foods was dried

freshwater fish (in the dry savanna), and that one was there because the calcium requirement in that model was so difficult to meet in that area. However, dried freshwater fish was consumed in most areas in that solution, although not at its maximum limit. Both dried freshwater fish and sugar were sufficiently economical to be worth purchasing from outside the Nigerian agricultural sector even at 1963 levels of production.[10]

When traditional methods of production are employed in the savanna areas, the nutrient allowances are so much more difficult to attain that exchanging exports for food is much more efficient than it was in the earlier model. Another factor is that, while the changes in production data between the two models involved decreases in yields for most food crops, there were decreases in export crop yields only for groundnuts in Areas II and VI and mixed groundnuts in Area I. (The yield of groundnuts as a sole crop in Area I was increased by 11 percent.) Such a shift in the apparent relative productivity of food and export crops is also conducive to greater purchases of food from outside the agricultural sector.

Effects of Improved Techniques

Changing from the use of traditional techniques outside the moist forest areas to the techniques in use in 1963 did two things. It increased Nigeria's capacity to produce nutrients sufficiently to permit reducing its dependence on gathered and collected foods from 109.5 to 106.33 percent of 1963 levels, and it lowered the marginal opportunity costs of attaining specified nutritional levels to anywhere from 10 to 20 percent of their levels, given the use of traditional techniques (Table 33).[11] The high costs of obtaining small increases in nutrient levels using traditional techniques also make the maximum levels the model imposes upon production activities more significant when yields are at traditional instead of 1963 levels.

The nutrients most difficult to provide in the specified amounts are the same (calories and, in the moist forest areas, riboflavin[12]) at both levels of technique. In both models protein is provided in more than adequate amounts whenever these (and the other costly nutrients—calcium, iron, and vitamin A) are provided at the levels desired.

At both levels of technique meats are highly efficient foods in the central and eastern moist forests. Outside these areas, most foods that provide surpluses of nutrient value when 1963 techniques are used

Table 33. *Comparison of the Costs of the Average Daily Allowances, in Shillings*

Area	*With traditional techniques*	*With 1963 techniques*	*Ratio: 1963 to traditional*
I	1.14	1.35	1.18[a]
II	6.43	.81	.13
III	6.42	1.34	.21
IV	8.01	1.50	.19
V	10.3	.97	.09
VI	6.53	.74	.11

[a] In this area the calcium allowance was unduly high in the model that used 1963 technical levels.

provide larger surpluses or surpluses in more areas when only traditional techniques are used. The scarce nutrients being more costly, the advantage from concentrating consumption on highly efficient foods is larger when productivity is diminished.

The advantage of exporting in exchange for food is also larger in the model in which food productivity is smaller. Sugar, wheat and wheat flour, and European-style beer joined the list of especially economical foods when traditional techniques replaced 1963 techniques outside the moist forest areas.

Conclusion

Even though limited essentially to the use of traditional productive techniques outside the moist forest areas, Nigeria still could provide modestly adequate diets for 61 million people if the food available were distributed in accordance with the nutritional needs of the people rather than in accordance with the ability to pay. To do so, however, would require that the use of gathered and collected foods expand from 1963 levels in proportion to the growth of population and that production and trade be organized with an extraordinary degree of efficiency. The levels of nutrient availability specified for this population are only slightly below the maxima attainable with production limited to traditional techniques.

The nutrient levels most difficult (costly) to attain under these circumstances are those for riboflavin in the eastern and central moist forest and for calories in the intermediate savanna, the western moist forest, and the forest-savanna mosaic. Calories are also economically scarce, and therefore limiting in the problem, in the other three areas. Meeting the vitamin A, iron, or calcium allowance involves some economic sacrifice in at least one area in each case.

At these technical levels, the most economical foods are meats and dried freshwater fish (in the central and eastern moist forests) and the efficient sources of calories, such as groundnut oil, sugar, and wheat in Areas II, III, and VI and groundnuts in Areas IV and VI.

Replacing traditional techniques by 1963 methods outside the moist forest areas reduces dependence upon the use of gathered and collected foods and lowers the marginal opportunity costs of calories and riboflavin by 80 to 90 percent in the areas where these allowances were the most expensive to attain under traditional techniques.

10

Geographical Specialization And Internal Trade: Traditional Techniques

If agriculture were limited essentially to traditional production methods, meeting Nigeria's nutritional needs in the most economical fashion would require significant outside assistance, mainly in the form of purchases of food from outside the agricultural sector. In addition, movements of food within Nigeria require the participation of the transportation sector.

Purchases from Outside Nigerian Agriculture

Food and Fertilizer

Table 34 shows the optimal levels of expenditures in this solution for foods not produced within Nigeria's own agricultural sector. These outside purchases permit food supplies to continue to expand even though food production activities within the sector reach the limits imposed by the acreage maxima set in the model and the stocks of land and labor available.

With one exception, the foods purchased are highly efficient sources of nutrients in most of the areas where they are consumed. They provide nutrients worth more in those areas than the cost of the food. (See Table 32.) The exception is European-style beer,[1] but even this is an efficient food in two of the four areas that purchase it. (In those areas, the central and eastern moist forests, its riboflavin content is very highly valued.)

In the other two areas, the intermediate savanna and the western moist forest, European-style beer is not an efficient food (its nutrients are worth less than the cost of the beer), but it is an efficient means of meeting the requirement that an alcoholic beverage be provided at the same rate per capita as prevailed in 1963. To satisfy the beverage requirements in these areas by palm wine or cereal beer, instead of partially or wholly by European-style beer, would mean giving up palm products and cereals that are more valuable as foods than they would be as beverages.

Table 34. ***Expenditures on Food Not Obtained from Nigerian Agriculture, Traditional Techniques, in Millions of Shillings***

Item	*Area*						*Total*
	I	*II*	*III*	*IV*	*V*	*VI*	
Wheat							
Whole					124	32	156
Flour			177	39			216
Fish, dried freshwater	13	35	746	143	395	119	1,451
Sugar, white		52	242	.36		42	336
Beer, European-style		2,573	1,069	235	786		4,663
Total	13	2,660	2,234	417	1,305	193	6,822
Total per capita, in shillings	.61	256.1	203.1	173	113.2	45.3	111.9

Over half the total expenditure on foods from outside the Nigerian agricultural sector is for European-style beer to meet the requirement for an alcoholic beverage to satisfy customary consumption habits in Areas II and III. Eliminating that requirement in these two areas would eliminate part or all of the 3,600 million shillings spent there on European-style beer and would reduce the cost of the diet to some extent.

The remaining expenditure on foods from outside the agricultural sector, 3,200 million shillings, is for efficient foods, that is, foods that provide nutrients worth at least their full cost. (For the most part,

they provide nutrients worth more than their cost.) This category also includes European-style beer (as its second largest item), but in this case only for Areas IV and V, where it is efficient largely because of the value of its riboflavin content.

The main expenditure on efficient sources of nutrients is for dried freshwater fish, which yield surplus nutrient value in every area but the dry savanna. Half of these fish are taken by the western moist forest, where they constitute 97 percent by weight of the total consumption of meat and fish. This level of consumption occurs because the fish are an economical source of calories for this area, but it undoubtedly explains why no additional expenditure is required in order to meet the riboflavin allowance in this area.

The beer (in Areas IV and V), fish, and wheat, wheat flour, and sugar being purchased from outside Nigerian agriculture are high-value foods that provide nutrients worth more than the costs of the foods in most of the areas for which they are purchased. Expanding the purchases and consumption of these foods would lower the cost of nutrition within Nigeria if the needs of 61 million people had to be met with only traditional productive techniques, as in this model.

The model assumes that purchases of these foods can be expanded indefinitely without affecting their prices; there is no mechanism that drives prices upward toward equality with the nutritional value of these foods. For wheat and white sugar, the assumption corresponds closely to reality, for prices are determined in world markets. With respect to dried freshwater fish the situation is different. Most of the fish comes from within Nigeria or from the waters of neighboring countries.[2] A four-fold expansion of consumption, which the solution of this model envisages, could not occur without driving the price up considerably.

Whether or not they yield surplus values, these foods are being purchased primarily because they provide calories (in Areas II, III, and VI) and riboflavin (in Areas IV and V) more cheaply than any of the alternatives available.[3] The per capita cost of the annual expenditure on them is largest in the intermediate savanna (Table 34),[4] but almost all of this is for European-style beer to satisfy the requirement for customary amounts of an alcoholic beverage. The nutrients provided by beer are worth about two-thirds this amount. In this area they represent about 7 percent of the total value of the nutrients in an average day's allowances.

In the western moist forest the per capita cost of the daily expendi-

ture is .56s. Of this expenditure, 17 percent is to meet the customary requirement for beer consumption. The remainder purchases nutrients and, except for the beer, nutrients that are worth more than they cost in the market. The payment to satisfy the specific requirement for an alcoholic beverage (.095s per capita per day) amounts to 1.5 percent of the total value in Area III of the nutrients in the average daily allowances. The nutrients provided daily by the beer are worth about .17s, or 2.6 percent of the total value in Area III of the nutrients in the average daily allowances.

In the remaining areas, the total outlay for foods obtained from outside Nigerian agriculture is spent on nutrients. The amount ranges downward from .47s per capita per day in the central moist forest and .31s in the eastern moist forest. These expenditures represent approximately 6 and 3 percent, respectively, of the values in those areas of the nutrients in the average daily allowances. The nutrients obtained are worth more than is paid for them. All in all, nutrients obtained from outside Nigerian agriculture represent a significant, but not a large, component in the total supply of nutrients in the country.

Although these nutrients come from outside Nigerian agriculture, they are being purchased, in part, with the earnings of that sector. Agricultural exports (the combined product of the agricultural, transportation, and marketing sectors) earn foreign exchange well in excess of the amounts required for the purchase of nutrients from outside Nigerian agriculture. In this model, agriculture and the associated transportation and marketing services provide 361 million shillings of foreign exchange over and above what is required for purchases of food and fertilizer.

The purchase of dried freshwater fish requires no foreign exchange in this model. Thus it does not depend upon the earnings of agriculture, but may be financed entirely from the earnings of nonagricultural sectors.

Expenditures on fertilizer (see Table 35) represent another type of dependence upon activities outside the agricultural sector. This relationship is necessarily minor in this model, for such expenditures are allowed only for the production of "commercial" maize, in Areas III, V, and VI, and onions, in Areas I and II. All these activities are in the solution, with commercial maize at its maximum production limits and onions in the intermediate savanna at the maximum set by the limit of consumption.

Restricting production outside the moist forest areas to traditional

methods multiplies the desirable level of total expenditure upon foods from outside the Nigerian agricultural sector by a factor of fifteen. (Compare Table 11.) Purchases of dried freshwater fish and white sugar increase by factors of four and three, respectively, while wheat or wheat flour appears as a new commodity worthy of purchase. The main effect, however, is the introduction of massive purchases of European-style beer. This is now an economical way of meeting the conventional requirement for an alcoholic beverage because calories and riboflavin are much more valuable in the present solution. Indeed, they are so valuable that it is no longer wise either to sacrifice potential palm oil production in order to produce palm wine or to convert sufficient millet or Guinea corn into cereal beer to satisfy the requirement in that way. Purchasing European-style beer is a means of obtaining additional calories and riboflavin from outside Nigerian agriculture. This is clearly worthwhile, given the restricted level of Nigerian productivity.

Table 35. ***Expenditures on Fertilizer, Traditional Techniques, in Millions of Shillings***

Item	*Area*						*Total*
	I	*II*	*III*	*IV*	*V*	*VI*	
Sulphate of ammonia	10	5					15
Miscellaneous,[a] for maize, commercial			1.2		.75	1.4	3
Total	10	5	1		1	1	18
Total per capita, in shillings	.47	.48	.11		.065	.33	.30

NOTE: Expenditures include cost of transportation to the area using the fertilizer.
[a] Our data give the amounts spent on fertilizer, but do not specify which kinds are purchased.

Dependence on external sources of food increases in about the same proportion in most areas. The startling exception is the intermediate savanna, which used no outside foods when 1963 production methods were being used, but is now the largest user (in the aggregate and on a per capita basis). In the dry savanna, reducing the calcium allowance has decreased per capita dependence.

Transportation Services

The third type of dependence upon activities outside the agricultural sector is for transportation services. Geographical specialization

in the production of income would be severely limited or impossible if there were no internal movements of food. More important, it is likely that the nutritional allowances in some areas simply could not be met were it not for purchases of food from other parts of the country.

When food moves from one part of the country to another in this solution, it is because the value of the nutrients in the receiving area exceeds their value in the sending area by at least the cost of transportation between areas. Feeding Nigeria in an economical way depends upon the services of the agricultural sector. Table 36 shows what payments for transportation are called for if the nutritional allowances are to be fully met, in each area, in the most economical way that is available when production is confined essentially to traditional methods.

The total payment to the transportation sector in this solution is some 700 million shillings, over 10 percent of the total expenditure on foods from outside Nigerian agriculture. Bringing food from the dry savanna incurs more expenditure, 310 million shillings, than from any other area. Most of this is for rice shipped to the western moist forest. This figure does not include the cost of transporting the meat animals sent from the dry savanna to the rest of Nigeria. Whenever those animals travel on foot the transportation cost is included as a part of the product of the agricultural sector; the entry "0" in the table indicates there was such a movement between the two areas.

The next largest expenditure is for food obtained from the forest-savanna mosaic. The main item here is for shipping yams to the eastern moist forest. There are no other large single expenditures, but payments aggregating some 110 million shillings are called for to transport food from the western moist forest to the two savanna areas, while some 90 million shillings are spent in this solution for shipping foods out of the intermediate savanna area (mainly to the eastern moist forest).

The areas that spend the most on bringing food in from other parts of Nigeria are the eastern moist forest (250 milllion shillings), the western moist forest (200 million shillings), and the intermediate savanna (130 million shillings).

A more significant indication of the importance of transportation expenditures to the people in the area is given by the per capita figures at the bottom of Table 36. The eastern moist forest incurs the highest expenditure per capita (21s per year). The other moist forest areas

Table 36. *Payments for Transportation of Foods Produced by Nigerian Agriculture, Traditional Techniques, in Millions of Shillings*

Activity	*Area* I	II	III	IV	V	VI	*Total*
From Area I							
Millet					23	28	51
Rice			174				174
Wheat, whole		12					12
Groundnut, seed				3.0		35	38
Oil, groundnut		18	8.2	1.9	3.6	7.7	39
Beef cattle[a,b]		0.0		0.0			0.0
Goats[a]		0.0				0.0	0.0
Sheep[a]				0.0		0.0	0.0
Subtotal (Area I)		30	182	5	27	71	314
From Area II							
Maize, local white					27		27
Sorghum					11	1.7	13
Potato							
Irish					2.3		2
Sweet					16		16
Cowpea				21			21
Oil, red palm[c]	12[c]						12
Beef cattle[a]						0.0	0.0
Goats[a]				0.0	0.0		0.0
Sheep[a]						0.0	0.0
Subtotal (Area II)	12			21	56	2	91
From Area III							
Maize, local white				3.5			4
Oil, red palm		43					43
Kola nut	49	20					69
Subtotal (Area III)	49	63		4			116

Table 36—*Continued*

Activity	*I*	*II*	*III*	*Area IV*	*V*	*VI*	*Total*
From Area IV							
Gari			6.2				6
Yams			5.0		54		59
Subtotal (Area IV)			11		54		65
From Area V							
Oil, red palm				7.2			7
Subtotal (Area V)				7			7
From Area VI							
Maize, local white					3.8		4
Yam					105		105
Okra					.049		0.0
Oil, red palm		34					34
Beef cattle[a]					0.0		0.0
Sheep[a]		—			0.0		0.0
Subtotal (Area VI)		34			109		143
Total (Areas I–VI)	61	127	193	37	246	73	736
Total per capita, in shillings							
Shipments to area	2.9	12.2	17.5	15	21.3	17	12.1
Shipments from area	15	8.8	10.5	27	.6	34	12.1

[a] Zero transportation costs for meat animals indicate that the animals are brought in on foot. In these cases, bringing the animals to market is regarded as a part of agricultural production.

[b] The nomadic herds identified as Area I animals in this model actually spend about two-thirds of their time within the geographical boundaries of Area II.

[c] This oil originated in either Area III or Area VI.

and the forest-savanna mosaic incur annual expenditures in this solution that run from 15s to 18s per capita.

The area most dependent upon the transportation industry for outward shipments of its food products is the forest-savanna mosaic, which uses 34s per capita in transportation services each year. Next is the central moist forest, using services worth 27s per capita. Last is the eastern moist forest, which ships only a very small quantity of red palm oil.

The relatively heavy expenditure upon transportation services bringing food into the eastern moist forest, with the almost complete absence of outshipments, reflects the economic burden of attaining adequate nutritional levels in that area. The nutrients in the average daily allowances cost 25 percent more in that area than in the central moist forest, the next most costly area (Table 31).

In the present solution the aggregate expenditure on transportation for food has dropped from 19s per capita (compare Table 12) to 12s, principally because the millet that moved from the dry savanna into the eastern moist forest in the previous model cannot do so here now that the limit on the consumption of millet in Area V has been greatly reduced. The former expenditure of 600 million shillings for this movement of millet is missing from the present solution. This one item is more than sufficient to account for the higher level of aggregate expenditure on food transportation in the earlier model. The effect appears also in the much lower per capita figures for outshipments from Area I and inshipments to Area V in the present model. Effects from changes in the levels of technique employed appear in the numerous changes in detail rather than in the aggregate data.

Revenue Producing Activities

Those agricultural resources that do not produce food for use within Nigeria may be devoted to income producing activities.[5] If 61 million people are to be adequately fed, using only traditional production techniques, most resources must be devoted to food production. Nonetheless, there is some production of cash income as distinct from income in the form of food. There are by-products from food production: hides and skins from slaughtered meat animals, groundnut cake from the production of groundnut oil, and palm kernel from the production of red palm oil. Income crops are produced to exchange for foods produced outside Nigerian agriculture. In this

solution there also is production of income because there are resources left over after the nutritional goals have been met or, conceivably, even if those goals could not be met because the limitations the model places on the acreage in specific food crops may make it impossible to shift all the land from the cash crop to food production.

Using traditional techniques outside the moist forest areas, the Nigerian agricultural sector would be capable of producing an income of 1.3 billion shillings in addition to feeding a population of 61 million. In doing so it would produce net foreign exchange earnings of 360 million shillings.

The principal income producing area in this solution is the western moist forest, which yields an income of 490 million shillings, four-fifths of it from cocoa exports (Table 37). The eastern moist forest, the dry savanna, and the central moist forest are the next most important sources of money income, each one earning between 200 and 300 million shillings. In the eastern moist forest more than half comes from the hides and skins of slaughtered meat animals; the remainder is from exports of palm kernels. In the central moist forest rubber is the principal item.

Practically all of the meat animals are produced in the two savanna areas, most of them in the dry savanna. (In this solution, as in that for Model Three, none of the meat animals produced in the savanna areas is eaten there. They all are sent to other parts of Nigeria where the nutrients they provide, especially the riboflavin, are more desperately needed.) If the earnings from the sale of hides and skins were credited to the dry savanna, as seems reasonable, that area would be the second most important income producing area of Nigeria. The total earnings from exports of hides and skins amount to 224 million shillings. About half of the goats and sheep and two-thirds of the cattle are produced in the dry savanna. Between 20 and 30 percent of the animals of each type originate in the intermediate savanna. Next to hides and skins, the principal income producing activities of the dry savanna are the production of groundnut cake and cotton.

The intermediate savanna, in this solution, produces no income except for the hides and skins that originate there.

Cocoa is the principal commodity exported, followed by palm kernel and its products in the amount of 327 million shillings and hides and skins in the amount of 224 million. The importance of hides and skins in the solution suggests that their potential value as a source of income for the Nigerian economy may not be fully recognized.

Table 37. *Income Producing Activities, Traditional Techniques, in Millions of Shillings*

Activity	*Area* I	II	III	IV	V	VI	*Total*
Export hides and skins[a]							
Beef			.055	17	38	16	71
Goat			4.1	7.9	86	16	114
Sheep			.63	5.0	31	2.5	39
Export cotton	104						104
Export groundnut							
Seed	36						36
Cake	114						114
Sell tobacco	3.6						4
Export							
Cocoa			382	20			402
Rubber				137			137
Export palm kernel							
Whole				17	137	67	221
Oil			74				74
Cake			32				32
Total	258		493	204	292	102	1,348
Net foreign exchange earnings							361
Total income per capita, in shillings	12.1		44.8	84.8	25.3	23.9	22.1

[a] It is assumed that all hides and skins are sold for export.

In summary, the principal export activities in this solution are for cocoa, palm products, and rubber in the moist forest zone, groundnuts and cotton in the dry savanna, and hides and skins from the animals provided by the two savanna areas for the moist forest zone. Aside from these hides and skins the intermediate savanna shows no promise as a producer of nonfood income in this solution.

The most striking difference between the income producing activities in this solution and the pattern in real life is the complete absence of red palm oil from the list of exports and the very small level of export sales of groundnut seed. The nutritional needs of Nigeria require that it use the palm oil and almost all the groundnut seed for food; they cannot be spared for export, given this level of agricultural technique.

The aggregate figures in Table 37 do not reveal how important income earning activities are to the populations of the several areas. The per capita figures show that in this solution the central moist forest, with its rubber exports, produces the most income per capita (85s per year). The western moist forest (mostly cocoa) produces 45s per

capita annually. The dry savanna would be next if it were credited with the hides and skins exported from the areas to which its cattle are sold. On this basis, the forest-savanna mosaic, the eastern moist forest, and the intermediate savanna (with zero earnings) would follow, in that order.

Replacing 1963 techniques by traditional techniques outside the moist forest areas has reduced the income potential of the Nigerian agricultural sector by 50 percent, from 2.6 billion shillings (Table 10) to 1.3 billion shillings in the present solution. Net foreign exchange earnings were reduced still further, to about one-eighth of their level in the previous model, not too surprising a result in view of the fact that lowered yields in food production have increased dependence upon foods purchased from abroad.

Using traditional techniques affected most areas in about the same degree, except for the intermediate savanna, which lost both its income producing activities (cotton and tobacco), and the central moist forest, which lost almost none. The loss in total revenues consisted mainly of reductions of 460 million shillings in exports of groundnut seed and 550 million in cocoa exports and the disappearance of red palm oil exports (220 million shillings). The groundnuts and red palm oil cannot be spared from use as food at the lower levels of agricultural technique, and cocoa production must be reduced in order to release May–June labor for other uses, presumably direct food production.

A summary of all the revenue transactions in the optimal solution is given in Table 38. The total value of the food this solution makes available within Nigeria exceeds the value of the income produced by the agricultural sector by 6.2 billion shillings. (See "Revenues less expenditures" in Table 38.) The food produced within the agricultural sector provides the bulk of the nutrients available within Nigeria, but to provide the full set of nutrients in an efficient manner requires that domestic agricultural food production be augmented by spending 6.8 billion shillings on foods from outside the Nigerian agricultural sector, .7 billion shillings on transporting food within the country, and 18 million shillings on fertilizer. Income producing activities within the agricultural sector yield 1.3 billion shillings, so a net of 6.2 billion shillings would be needed, in addition to the food and income that agriculture can provide, if the necessary nutrients for 61 million people were to be made available using traditional techniques outside the moist forest zone. (Agriculture itself, however, provides enough

Table 38. *Summary of Revenue Transactions, Traditional Techniques*

Transaction	*Area* I	II	III	IV	V	VI	*Total*
			Million shillings				
Revenues from income producing activities	258		493	204	292	102	1,348
Expenditures							
Food not obtained from Nigerian agriculture	13	2,660	2,234	417	1,305	193	6,822
Fertilizer	10	5	1		1	1	18
Transportation of food	61	127	193	37	246	73	736
Revenue less expenditures	174	—2,792	—1,935	—250	—1,260	—165	—6,228

Transaction	*Area* I	II	III	IV	V	VI	*Nigeria as a whole*
			Shillings per capita				
Revenues from income producing activities	12.1		44.8	84.8	25.3	23.9	22.1
Expenditures							
Food not obtained from Nigerian agriculture	.61	256.1	203.1	173.2	113.2	45.3	111.9
Fertilizer	.47	.48	.11		.065	.33	.30
Transportation of food	2.9	12.2	17.5	15.4	21.3	17	12.1
Revenue less expenditures	8.1	—268.8	—175.9	—103.9	—109.3	—38.7	—102.2

foreign exchange to pay for all the food which the model assumes to be purchased from outside the country.[6])

If the nutrients provided within Nigeria are valued at the high marginal costs that prevail for them in this solution, the total comes to 119 billion shillings (£6 billion).[7] Of this sum, 68 billion shillings (57 percent) is the value of the calories provided, while 46 billion (39 percent) is the value of the riboflavin (which has value only in Areas IV and V). Using these marginal valuations one might say that nearly 60 percent by value of the resources devoted to nutrient production in this solution were used to produce calories and 40 percent to produce riboflavin.

Agriculture provides all of this amount by the production of food or of goods to exchange for food, fertilizer, or transportation services, except for the 6.2 billion shillings that must be provided by other sectors of Nigeria. Those 6 billion shillings account for only 5 percent of the total value of adequate diets for 61 million people. A considerable part of the contribution of the agricultural sector, however, consists of the gathered and collected foods that this model assumes are in use. Of the total value of the least cost diets for all of Nigeria, 25 percent consists of the value of nutrients obtained from gathered and collected foods.

The areas showing the greatest excess of expenditures outside the Nigerian agricultural sector over the money incomes earned within that sector are the intermediate savanna and the western and eastern moist forests. As was shown, in the first two of these (Areas II and III) approximately one-third of the excess is attributable to the necessity of satisfying the conventional requirement for the consumption of an alcoholic beverage.

On a per capita basis the rankings remain the same, but the central moist forest requires essentially the same excess of expenditure over agricultural income as the eastern moist forest (about equal to the average for Nigeria as a whole).

Being restricted to traditional production methods outside the moist forest areas forced Nigeria to use the entire output of red palm oil and almost the entire output of groundnut seed as food rather than for export and to reduce the production of cocoa for export by more than half. Gross revenues from income producing activities fell, from 2.6 to 1.3 billion shillings (compare Tables 38 and 13). At the same time, expenditures on foods obtained from outside the Nigerian agricultural sector grew by a factor of fifteen, from 444 million shillings to

6.8 billion shillings. Some 6.2 billion shillings in addition to the total income of the agricultural sector was required in order to provide the nutrient levels specified as our goals.

With the techniques in use in 1963, Nigeria's agricultural sector has the capacity to produce a total income equal to 104 percent of the value of the food provided for Nigeria. Under the restriction to traditional methods, Nigerian agricultural capacity could provide only 95 percent of the total value of the food required. Adopting 1963 techniques in place of traditional techniques was at least equivalent to a 9 percent increase in agricultural capacity or resources.[8]

Internal Trade in Food

The major internal food movements in this solution are the following: (1) yams travel southward from the forest-savanna mosaic and outward to the east and west from the central moist forest; (2) cereals, meats, and groundnuts go southward from the two savanna areas into the rain forest zone; and (3) red palm oil and kola nuts move northward from the western moist forest and the forest-savanna mosaic. The income producing activities within the rain forest zone are being supported by food from the savanna and the forest-savanna mosaic (and, as was seen before, by food from outside Nigerian agriculture), but even if no resources within the rain forest zone were devoted to income activities it appears likely that adequate nutrition for 61 million people would require support from outside the zone. Figure 7 shows the pattern for all shipments of 200 million pounds or more between any two areas.

Table 39 gives a complete statement of the movements of foods produced within Nigeria. Shown in this table are gross shipments. As Areas II and VI both receive and ship the same commodity, Table 40 gives their net contributions.

Within the rain forest, the area most dependent on food from other parts of Nigeria is the eastern moist forest. By weight, yams are the principal purchase of the area: 4,400 million pounds of yams are taken, over three-fourths of them from the forest-savanna mosaic. Maize is the principal cereal purchased, with 300 million pounds coming from the intermediate savanna and 130 million pounds from the forest-savanna mosaic. In addition, 77 million pounds of millet and 77 million pounds of sorghum (Guinea corn) are shipped in. Total purchases of meat equal 440 million pounds. (Two-thirds of all the meat

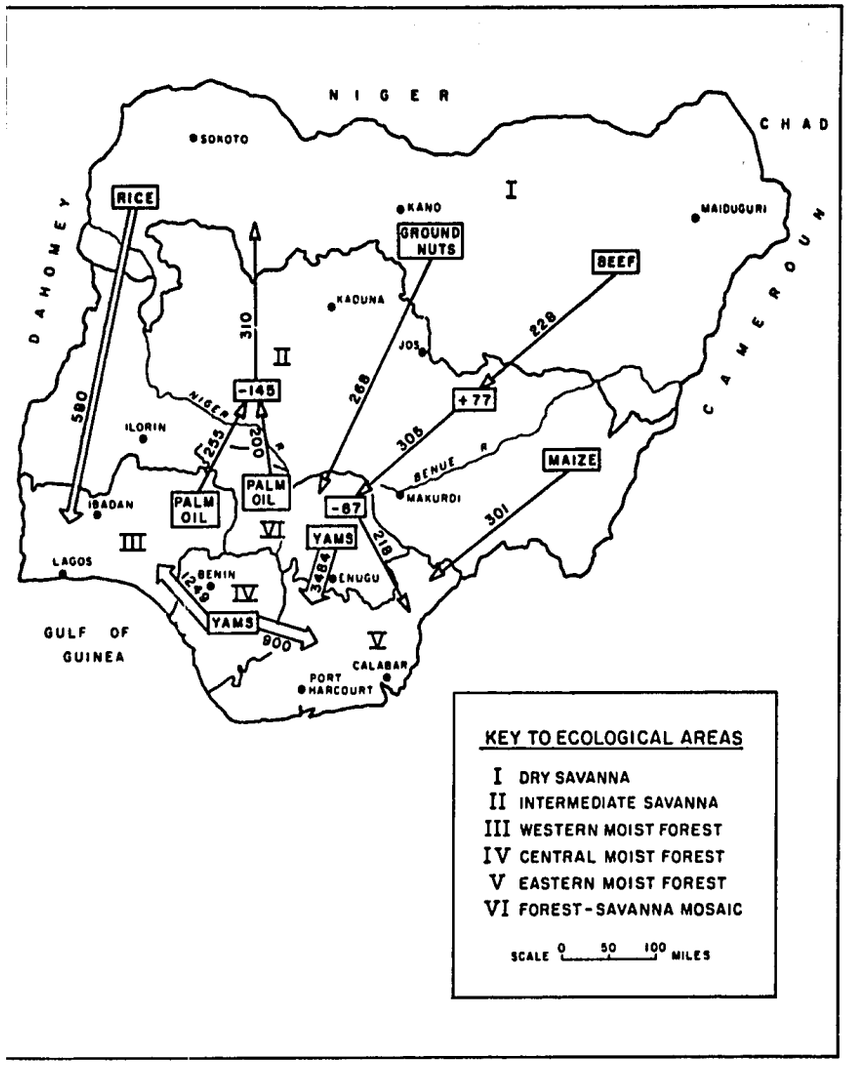


Figure 7. *Major Food Movements, Traditional Techniques*

produced in the savanna areas comes into the eastern moist forest.) Of the total taken by Area V, 200 million pounds are beef, 150 million pounds chevon (goat meat), and 70 million pounds mutton. Most of this comes from the herds of the dry savanna.

Table 39. ***Quantities of Nigerian Foods Transported between Areas, Traditional Techniques, Weight at Farm, in Millions of Pounds***

Item	*Receiving Area* I	II	III	IV	V	VI	*Total sent out*
From Area I							
Millet					77	185	262
Rice			580				580
Wheat, whole		72					72
Groundnut, seed				11		268	279
Oil, groundnut		106	26	5.3	11	37	185
Beef cattle		228		98			326
Goats		117				27	144
Sheep				12		47	59
Total from Area I		523	606	126	88	564	1,907
From Area II							
Maize, local white					301		301
Sorghum					77	29	106
Potato							
Irish					13		13
Sweet					74		74
Cowpea				146			146
Oil, red palm[a]	310[a]						310
Beef cattle						305	305
Goats				12	149		161
Sheep						22	22
Total from Area II	310			158	614	356	1,438
From Area III							
Maize, local white				50			50
Oil, red palm		255					255
Kola nut	114	55					169
Total from Area III	114	310		50			474
From Area IV							
Gari			137				137
Yam			1,249		900		2,149
Total from Area IV			1,386		900		2,286
From Area V							
Oil, red palm				103			103
Total from Area V				103			103
From Area VI							
Maize, local white					126		126
Yam					3,484		3,484
Okra					4.9		5
Oil, red palm		200					200
Beef cattle					218		218
Sheep					74		74
Total from Area VI		200			3,907		4,107
Totals (Areas I–VI)							
Gross purchases	424	1,033	1,992	437	5,509	920	10,315
Purchases net of offsetting sales[b]	424	257	1,992	437	5,509	628	9,247

[a] This originated in Areas III and VI.
[b] Of individual commodities.

Table 40. ***Offsetting Purchases and Sales, Traditional Techniques, in Millions of Pounds***

Item	*Purchases*		*Sales*		*Net sales*
	Origin	*Quantity*	*Destination*	*Quantity*	
Area II					
Beef cattle	I	228	VI	305	+77
Goats	I	117	IV	12	
			V	149	+44
Oil, red palm	III	255	I	310	
	VI	200			—145
Subtotal (Area II)		800		776	—24
Area VI					
Beef cattle	II	305	V	218	—87
Sheep	I	47	V	74	
Sheep	II	22			+5
Subtotal (Area VI)		374		292	—82
Total		1,174		1,068	—106

Area V is almost entirely a food taker. It furnishes other areas nothing but 100 million pounds of red palm oil, sent to the central moist forest.

The heavy inflow of food to the eastern moist forest is an indication of the difficulty of providing an adequate supply of nutrients for the 11,500,000 estimated 1967 population of the area. As was seen in Table 31, the opportunity-cost value in Area V of the nutrients in an average set of daily allowances was 10s. This is one-quarter higher than the value in the next most expensive area, the central moist forest, and more than one-third higher than the value in Areas II, III, and VI. It is no wonder that Areas II, IV, and VI contribute heavily to the provisionment of Area V.

Two nutrients govern the pattern of food movement into the eastern moist forest in this solution: riboflavin and calories. Riboflavin, nearly fifteen times as expensive as calories, dominates. It is largely responsible for the heavy movement of meat and cereal grains into Area V.

Area V would purchase larger quantities of meat, millet, maize, sorghum, and potatoes (both Irish and sweet) if its consumption pattern were not restricted by the conventional requirements that forbid consumption levels more than four times the per capita levels of 1963. As was seen in Table 32, each of these foods provides nutrients that are worth more in Area V than the opportunity-cost of producing the food and transporting it to the area. The largest economies from expanding consumption beyond the limits imposed in the model would be from the meats (which yield surplus nutrient values ranging from

25s to 41s per kilogram) and from millet (with a surplus nutrient value of 14s per kilogram).

The barriers to increasing the quantity of meat in the diet are undoubtedly economic. Meat is well liked, but expensive. The barrier to increasing the consumption of millet is of a different nature. It is an unfamiliar food in the area, so few know how to prepare it except those who have lived for some time in the former Northern Region.

As already noted, the cost of nutrition in the eastern moist forest also could be lowered by increasing the consumption of three foods not obtained from the Nigerian agricultural sector: dried freshwater fish, wheat, and European-style beer. These too are limited by the maximum consumption levels set in the model. (In the case of beer, that level is set equal to the 1963 per capita level.)

Cowpeas also provide nutrients worth more than the opportunity-cost of producing them (by 10s per kilogram), but relaxing the limit on consumption would lead to increased production in Area V rather than to purchases from other areas.

The second most dependent area is the western moist forest, which takes nearly 2 billion pounds of food from other parts of Nigeria. Of this amount, 62 percent consists of yams from the central moist forest and nearly 30 percent of rice from the dry savanna. The search for economical sources of calories organizes the trade for this area.

The major food providers are the forest-savanna mosaic and the central moist forest, both important primarily because of the yams they send to the eastern and western moist forests. Over three-quarters of these go to the eastern moist forest. The forest-savanna mosaic receives 270 million pounds of groundnuts and 185 million pounds of millet from the dry savanna, a net of 90 million pounds of beef from the intermediate savanna, and smaller quantities of other foods from both savanna areas. The principal receipts of the central moist forest are 150 million pounds of cowpeas (from Area II), 100 million pounds of red palm oil (from Area V), and 100 million pounds of beef (from Area I). The central moist forest needs riboflavin and, to a lesser extent, calories; the forest-savanna mosaic needs calories and some iron.

The dry and intermediate savannas are also food providers. From the rest of Nigeria they take 455 million pounds of red palm oil and 170 million pounds of kola nuts, nothing else. The bases for this trade are their needs for calories and vitamin A and the conventional requirements for kola nuts in these areas. The dry savanna also pro-

vides the intermediate savanna with 100 million pounds of groundnut oil and 70 million pounds of wheat.

The most important product of these two areas is the 670 million pounds of meat they send southward. Of this, 530 million pounds (nearly four-fifths) comes from the herds of the dry savanna. Beef constitutes 400 million pounds of the total and goat meat 190 million. In this solution none of the meat produced within the two savanna areas is consumed within their own boundaries.

The meat produced in the savanna areas goes to three destinations. About two-thirds of it (440 million pounds) goes to the eastern moist forest. Of the remainder, 120 million pounds goes to the central moist forest and 110 million pounds to the forest-savanna mosaic. In the two moist forest areas the principal nutritional contribution of the meat is its riboflavin. In the forest-savanna mosaic it is important for its calories and, to a minor extent, iron.

On a per capita basis the central moist forest is the heaviest buyer of meat. Its annual purchases in this solution amount to 51 pounds per person, about one pound per week. The eastern moist forest takes 38 pounds per person and the forest-savanna mosaic 27 pounds per person.[9] The quantities are small, but of vital nutritional importance.

No meat is purchased by the western moist forest, yet its needs for protein, riboflavin, and so forth, are more than adequately met. This area produces and consumes all the traditional animal products that the model permits. Modern poultry production, however, is not an economical source of nutrients. The principal source of protein for the area is the dried freshwater fish purchased from outside the agricultural sector. (Half of the total purchases of Nigeria are consumed here.) These fish, 134 million kilograms of them, provide 97 percent of the total meat and fish consumed in Area III. They are not being purchased for their protein, riboflavin, or calcium, however; they are bought as an economical source of calories, the only costly food element in the western moist forest. For this purpose stockfish would do as well if the price were low enough.[10]

The other major shipments from the dry savanna are 580 million pounds of rice for the western moist forest plus 280 million pounds of groundnut seed and 260 million pounds of millet. Most of the latter two go to the forest-savanna mosaic.

Aside from its meat products, the major shipments from the intermediate savanna consist of 300 million pounds of maize for the eastern moist forest, 150 million pounds of cowpeas for the central

moist forest, and 100 million pounds of Guinea corn (sorghum), three-quarters of which goes to the eastern moist forest. The red palm oil that Table 39 shows going to Area I is oil received from Areas III and VI.

Effects of Improved Techniques

The major determinants of internal food trade in the solution for traditional levels of technique outside the moist forest area are the need for riboflavin for the central and eastern moist forests and calories for the intermediate savanna, the western moist forest, and the forest-savanna mosaic. To meet these needs, meats, groundnuts, and cereals move south from the savanna areas, and yams move into the eastern and western moist forests from Areas IV and VI. Red palm oil goes north to provide vitamin A as well as calories. Large purchases of dried freshwater fish and European-style beer from outside the Nigerian agricultural sector contribute significantly to the nutrient needs of the intermediate savanna and the western and eastern moist forests.

At 1963 levels of technique, the nutritional determinants of trade were basically the same except that there were no large differences among the costs of calories (excluding the dry savanna), and the western moist forest needed riboflavin as well as calories. The total quantities of food purchased from other parts of Nigeria were not too different under the two sets of circumstances: 8 billion pounds when 1963 levels of technique were in use (Table 14) and 9.2 billion pounds with traditional techniques. At 1963 technical levels, however, every area except the eastern moist forest purchased more food from other areas; in that area food purchases were less than half their level when traditional techniques were in use. It is likely, however, that the latter change was caused largely by the necessity of replacing the huge purchases of millet that the model with 1963 techniques allowed, rather than by the changes in techniques employed.

At both technical levels, meats and cereals moved south from the savanna areas, but in the model using 1963 techniques gari moved into the western moist forest from Area VI as well as from IV. There were no large movements of yams into the eastern moist forest in that solution. The reason, in all likelihood, was that two billion pounds of millet were coming in from the dry savanna. The increased importance of yam movements in the model that uses traditional techniques un-

doubtedly is due more to our decision to limit millet consumption to levels tied to customary consumption habits than it is to the changes in production methods between the two models. The larger trade in yams corresponds to trade movements actually occurring within Nigeria.

While the changes in the levels of technique assumed in the two models had no major effects on the volume of internal trade in food, they did have a major effect on the levels of expenditure for foods from outside the Nigerian agricultural sector. Replacing traditional by 1963 techniques outside the moist forest areas reduced that expenditure to one-fifteenth of the level for traditional techniques. It also permitted exporting large quantities of red palm oil and groundnut seed that otherwise would have been required for food and doubling the production of cocoa for export. It doubled Nigeria's income earning potential and increased the net amount of foreign exchange provided (in excess of what was used for food and fertilizer) to 2.8 billion shillings, eight times the level obtained with traditional techniques.

With traditional methods, if used in the most efficient manner, Nigeria's agricultural capacity was sufficient to provide a total product (of food plus income yielding crops) worth 95 percent of the total value of the food required by a population of 61 million. With 1963 production levels, agricultural capacity could provide such a total product worth 104 percent of the value of the food required.

Conclusion

The nutritional allowances for the 1967 Nigerian population could be met with traditional production techniques if the production and trade pattern were organized with a very high degree of efficiency, but an appreciable level of support would be required from foods produced outside the agricultural sector. Even this degree of organization would provide little income for Nigeria other than the food being produced. The value of the food required for 61 million people exceeds by 5 percent the total income produced by the agricultural sector. If Nigeria is to be fed adequately, expenditures are required for food, fertilizer, and transportation that amount to 6.2 billion shillings more than the revenues from the income producing activities of agriculture. Most of these expenditures are for food from outside the agricultural sector, principally European-style beer and dried freshwater fish. (These may be produced within Nigeria, but they are not

regarded here as produced by the agricultural sector.) The agricultural sector, however, can provide the foreign exchange needed for the purchase of food from outside Nigeria, with some to spare.

When limited to traditional techniques, cotton and tobacco are grown as income crops, but almost the whole output of groundnuts is used for food. Cocoa production in the western moist forest has been cut back almost to one-third of the permissible level. No red palm oil is exported, so the income from palm products is limited solely to that from palm kernel and its products. The principal oil palm area (the eastern moist forest) is unable to devote to palm production all the acreage that the model permits. The pressure for adequate food production has restricted the resources available for the production of money income.

In this situation, the most efficient organization of production and trade within the country calls for all the beef, goat meat, and mutton produced in the two savanna areas to be shipped southward. About two-thirds of this goes to the eastern moist forest to help meet the riboflavin requirement. The central moist forest, also with a difficult riboflavin requirement to meet, receives about half the remainder. (On a per capita basis the central moist forest actually receives somewhat more than the eastern forest area.) The other half of the remaining meat goes to the forest-savanna mosaic, where it provides calories and iron.

The dry savanna, where calories are relatively inexpensive, sends rice to the western moist forest and groundnuts to the forest-savanna mosaic, where calories are costly. The intermediate savanna, where calories also are costly, sends maize to the eastern moist forest, where the calories are worth much less but the riboflavin is extremely valuable.

For the north the south provides red palm oil, a source of calories and vitamin A in the two savanna areas.

Within the south the principal commodity movements are of yams from the forest-savanna mosaic into the eastern moist forest and from the central moist forest into the areas both to the east and west of it.

This trade pattern, chosen solely for nutritional efficiency, is essentially consistent with patterns that already exist within Nigeria. Its most startling features are that *all* the beef, goat meat, and mutton produced in the north moves into the rain forest areas and none goes to the western moist forest. (The latter area buys large quantities of dried freshwater fish.) The riboflavin needs of the two savanna areas

are met by the milk from the Fulani herds, plus the cereals available in those areas. The meat goes to the rain forest zone, where its riboflavin is most needed. As a consequence, the protein needs of the rain forest zone are met without further difficulty.

In reality, of course, not all meat goes to the south, and the riboflavin and protein needs of the moist forest zone are not being met. This analysis suggests that measures to facilitate trade in animal products could help greatly in meeting the nutritional problem with no change in production conditions for the animal industries. It must be noted, of course, that the analysis takes no account of the problems raised by the lack of income for the purchase of animal products. The masses of the population cannot solve their nutritional problems by trade unless they have incomes sufficient to buy those products that are only obtainable through trade.

In sum, providing adequate nutrition for 61 million people with traditional techniques in the savanna areas would be a difficult task, although not quite an impossible one. The required geographical pattern of cash and food crop production would be fundamentally the same as the existing pattern, but the volume of resources devoted to income production would be severely restricted, foods from outside Nigerian agriculture would be a significant, probably an essential, component of the total food supply (although not a large one), and it would be necessary to devote the entire production of meat in the savanna areas to providing nutrition for the population outside those areas, particularly the people in the central and eastern moist forests.

The effect of replacing traditional methods outside the moist forest areas by 1963 techniques is to reduce dependence upon foods from outside the agricultural sector, to double the income earning potential of agriculture (largely by expanding exports of red palm oil, groundnuts, and cocoa), and to raise the total value of the potential output of the sector from 95 percent of the value of the food required by a population of 61 million to 104 percent of that value. It is still true, however, that the most efficient allocation of the beef, goat meat, and mutton produced by the savanna areas would be to send all of it southward; none would be consumed in those areas themselves.

11

Production Activities in the Optimal Solution: Traditional Techniques

With only traditional production methods available outside the moist forest areas, feeding 61 million people at an adequate nutritional level requires careful selection of agricultural activities. Those that are most efficient in providing the nutrients that are difficult to acquire may not be the ones most widely engaged in or the ones that are most profitable when judged by the market value of the output. Given sufficient knowledge of and concern for nutritional needs, market values might reflect the nutritional significance of the foods produced (if inequalities in the distribution of income did not weight the nutritional needs and food preferences of the rich far more heavily than the similar needs and preferences of the poor). No such situation exists, or is likely to in the near future, so those who are concerned about the health and strength of the Nigerian people must develop their own evaluations of the nutritional merits of the various agricultural activities. The market may be the most efficient organizing method extant for directing production in accordance with people's

tastes (for any given income distribution), but it cannot be assumed that such an organization always will provide for a well-nourished population. If, however, it can be determined which productive activities would contribute most to the nutritional well-being of the population, developmental efforts devoted to promoting the consumption of those foods and the expansion of those activities can alter consumer preferences and the market price structure in such a way that consumers voluntarily will choose more nutritious diets.

Cash Crop Production

When nutritional needs are given first priority, using traditional techniques outside the moist forest areas instead of 1963 technical levels makes it impossible to maintain export activities at the levels reached in the earlier model. Important export products such as groundnuts and red palm oil have to be used primarily for food (entirely for food in the case of palm oil), and the acreage of income crops such as cotton and tobacco has to be reduced.

All the potential cash crops are at their maximum levels in the dry savanna, but two of them, groundnuts and soybeans, now are used solely for food, not for income (Table 41). (Soybeans are used for food rather than income at both levels of technique.[1])

Outside the dry savanna, however, resources cannnot be spared for cotton and tobacco, the income producing crops.[2] Groundnuts are at their maximum level in Area II, but at zero level in VI, while soybeans are at 60 percent of their maximum level in Area VI, but at zero level in II. The very high cost of reaching the caloric allowance in Areas II and VI requires great selectivity in resource use in those areas.

Resources also are diverted from the tree crops. When 1963 technical levels were in use, all except rubber were at maximum levels in each area (Table 16). With lower levels of food productivity outside the moist forest areas, cocoa production is cut to 40 percent of the permitted level in the principal production area. Rubber survives in the central moist forest on a somewhat smaller scale than in the previous solution, at three-quarters of its permitted level, but it is at zero elsewhere.

Kola nut production stays at its maximum level, but this is a food crop under the definitions of the model. In the western moist forest, indeed, the nutrients in kola nuts are sufficiently valuable to bring

Table 41. *Levels of Cash Crop Activities, Traditional Techniques, in Thousands of Acres*

Crop	Level[a]	Area I	II	III	IV	V	VI
Field Crops							
Groundnut[b]							
Sole	Sol	M	M	–	–	–	0.0
	Max	1,543	220	–	–	–	67
Mixed	Sol	M	M	–	–	–	0.0
	Max	3,416	370	–	–	–	101
Bean, soya[b]							
Sole	Sol	M	0.0	–	–	–	110
	Max	10	10	–	–	–	185
Cotton							
Sole	Sol	M	0.0	–	–	–	–
	Max	248	339	–	–	–	–
Mixed	Sol	M	0.0	–	–	–	0.0
	Max	248	359	–	–	–	52
Tobacco							
Sole	Sol	M	0.0	–	–	–	–
	Max	4	11	–	–	–	–
Tree Crops							
Oil palm[b]	Sol	–	–	M	M	1,792	M
	Max	–	–	1,265	223	2,409	964
Cocoa	Sol	–	–	545	M	–	–
	Max	–	–	1,325	52	–	–
Kola nut[c]	Sol	–	–	M	–	–	–
	Max	–	–	603	–	–	–
Rubber	Sol	–	–	0.0	356	0.0	–
	Max	–	–	24	482	48	–

M: At the maximum level.
–: The activity is not available in this area.
[a] Sol = solution level.
Max = maximum level.
[b] Groundnut, soya bean, and oil palm are food crops as well as cash crops.
[c] The kola nut, although a food crop by the definitions of this model, is included here for comparison with the other tree crops.

consumption above the minimum conventional level. In the two savanna areas, however, consumption is at the minimum levels allowed by the model and only because the model requires it.

Oil palm production in this model is only three-quarters of the maximum allowed for the eastern moist forest. No red palm oil is being produced for export. Production levels undoubtedly would be higher except that the model includes no transportation route that

permits palm oil to be sent from Area V to Areas II, III, and VI, where calories are nearly ten times as expensive. Were such trade possible, the cost of calories (and of the diet) in Areas II, III and VI would be lowered. More economical sources of calories for the western moist forest would permit expansion of cocoa production in that area.

The absence of a trade link for red palm oil between Area V and Areas II, III, and VI was of no great importance in the earlier model, for the differences in the costs of calories among these areas were small at 1963 levels of technique. In addition, Area V was allowed to consume large quantities of millet in that model, so producing red palm oil for export and buying calories and riboflavin in the form of millet was a feasible alternative.

Where a crop is at its maximum level, expanding beyond that level usually increases the income obtainable from the agricultural sector. The gains possible from such modifications in the production pattern of this solution are given in Table 42. The largest gains are from oil palm expansion in Areas III and VI. The oil palm yields a surplus of 4,500s per acre in the western moist forest and 4,600s per acre in the forest-savanna mosaic.[3] Calories are expensive in these areas as well as in the intermediate savanna, which buys palm oil from both these areas. Export income would increase if oil palm production expanded, even though all palm oil was used as food. Sales of palm kernel and kernel products, valuable by-products of palm oil production, would increase. Their value has been included in the value of the surplus from oil palm production as given in Table 42.[4]

The kola nut yields a respectable surplus of 1,300s per acre in the western moist forest. However, this sum partially reflects the value attributed to the nuts because they are required to meet conventional consumption requirements in the two savanna areas. In those areas the value assigned to the nuts exceeds the worth of the nutrients they provide.

Among the field crops that yield income or the alternative of food or income, the most promising opportunity is the expansion of groundnut production, either sole or mixed, in the intermediate savanna. An extra acre could add 1,300s to 1,500s to Nigeria's agricultural income, largely because the calories thus provided are so costly in Area II.

Table 42. *Additions to Revenue Possible if a Single Cash Crop Activity Were Expanded, Traditional Techniques, in Shillings per Acre per Year*

Activity	*Area* I	II	III	IV	V	VI
For food or income						
Groundnut[a]						
Sole	139	1,538	–	–	–	0.0
Mixed	92	1,255	–	–	–	0.0
Bean, soya[a]						
Sole	3.6	0.0	–	–	–	0.0
Cotton						
Sole	71	0.0	–	–	–	–
Mixed	99	0.0	–	–	–	0.0
Tobacco						
Sole	722	0.0	–	–	–	–
Tree crops						
Oil palm[a]	–	–	4,470	250	0.0	4,574
Cocoa	–	–	0.0	8	–	–
Kola nut[b]	–	–	1,282	–	–	–
Rubber	–	–	0.0	0.0	0.0	–

NOTE: The entries show the gain possible from expanding a single activity by one acre, with no increases in the total quantities of land or labor available, and with unchanged limits on other production and consumption activities.
–: The activity is not available in this area.
[a] Groundnut, soya bean, and oil palm are food crops as well as cash crops.
[b] The kola nut, although a food crop by the definitions of this model, is included here for comparison with the other tree crops.

Efficient Food Crops

The food crops that are most efficient as producers of nutrients tend to expand until they are stopped by the maximum limits that the model sets, namely, 20 percent above the 1963 levels of the individual production activities. The model also places limits upon the extent to which customary consumption levels may change, but these limits are much wider than those imposed on production patterns. The consumption of a particular food may increase by 300 percent, so as far as the consumption side of the model is concerned a great deal of leeway is allowed in food choices. The consumption limits cannot by themselves confine production activities to the customary pattern.[5]

If each individual crop is permitted to expand by 20 percent above the 1963 level, but the total quantities of land and labor available are only 9.5 percent above that level, pushing production to the maximum limits for those crops that are most productive of nutrition or income necessarily requires cutting the production of other crops below 1963

levels. The least productive activities will be cut to zero. Activities that can earn only enough to pay for the resources they require, at the opportunity-cost values of those resources, will be carried on at levels between zero and the maxima permitted by the model. Activities that are at their maxima usually will be earning more than the opportunity-cost value of the resources they require. The amount of the surplus an acre of such an activity earns in this solution is the amount by which the total income from Nigerian agriculture would expand if the maximum limit on that activity were to be relaxed so that one additional acre could be produced (with no increases in the total quantities of land or labor available for use by all activities).

Table 43 shows the levels of food crop activities in the optimal solution. Surprisingly, for those who think of protein production as the major nutritional problem, the principal food crop to drop out of the production pattern entirely in the dry savanna is the cowpea. To introduce cowpeas into the cropping pattern as a sole crop would reduce agricultural income by 110s per acre of cowpeas added. If intercropped, the sacrifice would be much less, only 38s per acre. Cowpeas grown for seed and hay in an intercropping arrangement would involve a sacrifice of 45s per year.[6]

In the dry savanna the allowances for calories and vitamin A pose the major nutritional problems. When these (and the reduced calcium allowance) are satisfied in the most economical way available in the model, more than enough protein is available.

Vitamin A is expensive in this area because it is obtained in part by buying red palm oil from the intermediate savanna, where the oil is worth 26s per kilogram. Palm oil, in turn, is valuable because of the scarcity of calories in the intermediate savanna and in Areas III and VI. Thus the cost of vitamin A in Area I reflects the scarcity of calories in Areas II, III, and VI.

The model does not provide the dry savanna with the option of selling cowpeas to other parts of the country. Perhaps if this option were available the crop would appear more promising, but this is not likely, for in no area do cowpeas appear in the solution at the maximum level permitted by the model. It must be remembered, moreover, that if cowpea production expands, something else must contract. Those activities that are at their maxima can be there only because other land-using activities have given way for them. In this area the principal sources of the extra land required for activities that have expanded more than the average have been the disappearance of

Table 43. ***Levels of Food Crop Activities, Traditional Techniques, in Thousands of Acres***

Crop	*Level*[a]	*Area* *I*	*II*	*III*	*IV*	*V*	*VI*
Maize, bush							
Sole	Sol	M	M	M	M	–	M
	Max	9.3	190	691	1.8	–	16
Mixed	Sol	M	M	M	M	M	M
	Max	28	440	646	66	437	425
Maize, commercial							
Sole	Sol	–	–	M	–	M	M
	Max	–	–	11	–	7	13
Millet							
Sole	Sol	1,705	M	–	–	–	0.0
	Max	2,309	20	–	–	–	5
Mixed	Sol	M	M	–	–	–	–
	Max	8,224	20	–	–	–	–
Rice, upland							
Sole	Sol	M	M	–	–	–	–
	Max	140	25	–	–	–	–
Rice, swamp							
Sole	Sol	M	M	–	M	M	M
	Max	426	74	–	13	101	78
Mixed	Sol	–	–	–	M	M	M
	Max	–	–	–	26	7	4.1
Sorghum							
Sole	Sol	M	M	–	–	–	M
	Max	2,002	889	–	–	–	5
Mixed	Sol	M	M	–	–	–	–
	Max	6,260	2,629	–	–	–	–
Wheat							
Sole	Sol	M	–	–	–	–	–
	Max	73	–	–	–	–	–
Cassava, bitter[b]							
Sole	Sol	–	–	M	M	M	M
	Max	–	–	512	164	188	293
Mixed	Sol	–	–	M	M	M	M
	Max	–	–	640	133	595	647
Cassava, sweet[b]							
Sole	Sol	M	M	–	–	–	–
	Max	317	940	–	–	–	–
Mixed	Sol	M	M	–	–	–	–
	Max	317	840	–	–	–	–
Potato, Irish							
Sole	Sol	5.2	M	–	–	–	–
	Max	9.7	84	–	–	–	–
Mixed	Sol	0.0	M	–	–	–	–
	Max	4.2	8.4	–	–	–	–

Potato, sweet							
Sole	Sol	M	M	–	–	–	–
	Max	6	12	–	–	–	–
Mixed	Sol	M	M	–	–	–	–
	Max	18	36	–	–	–	–
Cocoyam	Sol	–	–	M	M	M	–
Sole	Max	–	–	25	5	62	–
	Sol	–	–	M	M	M	–
Mixed	Max	–	–	136	75	248	–
Yam							
Sole	Sol	M	M	M	M	M	M
	Max	455	449	470	39	277	240
Mixed	Sol	M	M	M	M	M	M
	Max	241	269	235	394	917	504
Cowpea, seed							
Sole	Sol	0.0	0.0	–	–	–	0.0
	Max	15	20	–	–	–	1.4
Mixed	Sol	0.0	3,628	–	–	4	729
	Max	3,020	4,325	–	–	24	884
Cowpeea, seed and hay							
Mixed	Sol	0.0	–	–	–	–	–
	Max	3,020	–	–	–	–	–
Melon seed							
Sole	Sol	M	M	M	M	M	M
	Max	19	53	75	3.2	1.8	7.7
Mixed	Sol	M	M	M	M	M	M
	Max	39	78	85	133	316	96
Okra							
Sole	Sol	–	–	–	–	–	M
	Max	–	–	–	–	–	9.6
Mixed	Sol	–	–	0.0	M	M	M
	Max	–	–	264	89	60	30
Onion							
Sole	Sol	300	150	–	–	–	–
	Max	350	175	–	–	–	–

NOTE: The kola nut and crops that may be used either for food or income are listed in Table 41.
M: Present in the solution at the maximum level.
–: The activity is not available in this area.
[a] Sol = solution level.
Max = maximum level.
[b] The figures are for an acre of cassava of which half has been planted in the current year. The other half, planted in the previous year, is being harvested during the current year.

mixed cowpeas from the solution and the restriction of the production of millet as a sole crop below its maximum level. Given the nutritional situation that exists, cowpea production is less efficient than the production of a number of other crops grown in the dry savanna.

Furthermore, although the intermediate savanna is allowed to ship cowpeas to other parts of the country (and does so), cowpeas are among the less productive crops even in that area. As was seen in Table 32, cowpeas have marked nutritional advantages in the central and eastern moist forest, but their consumption is limited by the customary habits of the people. If the consumption levels for cowpeas in those areas were to expand well beyond what is permitted in this model, particularly in the eastern moist forest, cowpea production might become reasonably attractive as a source of nutrients. Under the conditions of this problem, however, cowpea production by traditional methods is not an efficient source of nutrition in the dry savanna, and only passably efficient elsewhere.

The only other crop production activity that drops to zero level in the dry savanna is growing Irish potatoes as a mixed crop. (As a sole crop their level is less than the maximum allowed.) Irish potato production in this area, however, is limited by the customary limit on consumption (Table 32). Somewhat larger levels of production would be nutritionally efficient if people were willing to consume such quantities.

Onion production is below its maximum acreage limit, but is kept there by the limitation on the quantity of manure available, not by any deficiency as a source of nutrients. An extra ton of manure would be worth 11.5s in this area. It has this value because it would permit onion production to expand by one-tenth of an acre. An extra acre of onions produces a product worth 115s more than the value of the land and fertilizer employed if the manure is regarded as costless. The extra value is attributed to the manure required because, if a ton less of manure were available, 11.5s would be cut off from Nigerian agricultural revenue.

In the intermediate savanna the standard for holding a place in the optimal production pattern is much higher than in the dry savanna. Land in Area II can earn 1,400s a year in its least profitable uses.[7] The value of the nutrients provided by mixed cowpea production is just sufficient to meet this standard; sole cowpeas disappear from the solution. The land set free for other crops to use has come primarily from the disappearance of cotton from the production pattern and the restriction of mixed cowpeas to less than their maximum level. Soybeans are at zero level, and onions are below their maximum, but neither situation releases any significant amount of land.[8]

In the western moist forest, all but one field crop activity is at its

maximum limit. This is possible because cocoa production is less than half its maximum level. Okra production drops to zero in the optimal solution.

In the central moist forest, where nutrients are very expensive, every field crop activity is at its maximum limit. Only one activity using arable land, rubber production, is restricted in order to make room for others to expand to their full limits.

In the eastern moist forest nutrients are even more costly than in Area IV. Here mixed cowpeas are the only field crop to be produced at less than their maximum limit. Their output has been restricted by the maximum limit on the consumption of cowpeas in this area. Land has been made available for field crop production at this level by the reduction of rubber production to zero and by holding oil palm production to three-fourths of its maximum level.

In the forest-savanna mosaic, the land required for the expansion of crops used only for food has come principally from the disappearance of groundnuts and cotton from the production pattern plus holding cowpeas and soybeans below their maximum levels. Millet and sole cowpeas are also at zero levels, as is "modern" beef cattle production. Groundnut, millet, and soybean production might be at higher levels if consumption in this area were not restricted by the conventional limits. (See Table 32.)

Almost all the food crops are at their maximum levels in this solution. A summary view of the adjustments from the 1963 pattern of production reveals that outside Areas I and VI land has been made available for food crops largely by reductions in the level of income crops. Of the major export crops, only the groundnut has been able to hold its own with food crops in all the areas where it is an important crop. However, the groundnut *is* mainly a food crop in this solution; the level of export income from groundnut products is very low. The oil palm is now entirely a food crop, except that the by-products, palm kernel and its products, are exported. Oil palm production is at the maximum level permitted in three of the four areas that grow it, but in the principal production area (Area V) the acreage is only three-fourths of the permitted level.

Surpluses Earned

Not all the activities at their maximum limits in this solution are equally productive of nutrients or income for Nigeria. Table 44 shows how the value of the product of one acre of each activity exceeds the

opportunity-cost value of the resources that it requires. Many of these surpluses are very large because the limiting nutrients have very high values in this solution. To provide for the nutritional needs of 61 million people with production techniques limited essentially to traditional methods means that the opportunity costs of the most limiting nutrients will be large. It also means that it becomes important to identify the activities that produce large amounts of the most costly nutrients in comparison with the quantities of the scarce resources that they require. Table 44 provides this information.

In the dry savanna the most productive activities are upland and swamp rice production. Raising the maximum limit on upland rice production by one acre in this area would allow agricultural income to rise by 2,100s with no increase in the total quantity of arable land employed in the area. The increase would come by adjusting the production pattern, by shifting land into rice from less efficient production activities. The total quantity of labor used in the area could rise or fall because there is unused labor available. If labor as well as land were limiting, the adjustments would be made in such a way as to hold the total quantities constant for both labor and land.

Encouraging swamp rice production to expand would be even more advantageous, for an extra acre of swamp rice would add 3,000s to the total agricultural income of Nigeria.

However, rice would not be an attractive crop if it were being grown for Area I consumption, for the nutrients it provides are not particularly valuable in that area. In this solution, no rice is consumed within the dry savanna. Rice is an important crop for Area I because

Table 44. *Additions to Revenue Possible if a Single Food Crop Activity Were Expanded, Traditional Techniques, in Shillings per Acre per Year*

Activity	*Area*					
	I	*II*	*III*	*IV*	*V*	*VI*
Maize, bush						
Sole	64	384	2,354	5,847	–	3,532
Mixed	139	1,130	2,331	2,529	1,245	1,597
Maize, commercial						
Sole	–	–	4,741	–	5,376	3,957
Millet						
Sole	0.0	468	–	–	–	0.0
Mixed	93	1,111	–	–	–	–
Rice, upland						
Sole	2,137	1,176	–	–	–	–

Rice, swamp						
Sole	3,004	2,135	–	1,069	1,343	2,780
Mixed	–	–	–	1,857	1,100	1,031
Sorghum						
Sole	41	662	–	–	–	630
Mixed	76	1,218	–	–	–	–
Wheat						
Sole	335	–	–	–	–	–
Cassava, bitter[a]						
Sole	–	–	665	1,528	436	711
Mixed	–	–	706	1,746	91	402
Cassava, sweet[a]						
Sole	30	725	–	–	–	–
Mixed	69	815	–	–	–	–
Potato, Irish						
Sole	0.0	1,572	–	–	–	–
Mixed	0.0	416	–	–	–	–
Potato, sweet						
Sole	706	4,259	–	–	–	–
Mixed	406	3,379	–	–	–	–
Cocoyam						
Sole	–	–	2,570	2,801	2,689	–
Mixed	–	–	631	2,531	2,361	–
Yam						
Sole	36	2,098	923	5,355	3,475	4,071
Mixed	174	2,725	2,818	3,621	3,418	3,702
Cowpea, seed						
Sole	0.0	0.0	–	–	–	0.0
Mixed	0.0	0.0	–	–	0.0	0.0
Cowpea, seed and hay						
Mixed	0.0	–	–	–	–	–
Melon seed						
Sole	72	1,060	1,377	1,304	425	1,622
Mixed	111	2,024	920	1,205	260	1,474
Okra						
Sole	–	–	–	–	–	137
Mixed	–	–	0.0	101	143	99
Onion						
Sole	0.0	0.0	–	–	–	–

NOTE: The kola nut and crops that may be used for either food or income are listed in Table 42. The entries here show the gain possible from expanding a single activity by one acre, with no increases in the total quantities of land or labor available, and with unchanged limits on other production and consumption activities.

–: The activity is not available in this area.

[a] The figures are for an acre of cassava, half of which was planted in the current year. The other half, planted in the previous year, is being harvested during the current year.

it is sent to the western moist forest where its nutrients are badly needed. Encouraging its expansion in Area I is a contribution to the nutritional problem of the western moist forest and, by providing a marketable product, to the income problem of the dry savanna.

If the cost of bringing about a given acreage expansion is the same for each crop, it is evident that the crops most worth promoting in any given area are those that show the largest surpluses in Table 44. In the dry savanna the crops to promote under the conditions of this problem are swamp and upland rice production.

As the output of any crop expands beyond the limits imposed in this model, there will come a point at which the value of the surplus it produces declines. These results indicate directions of expansion that would be advantageous, but do not reveal how large the optimal expansion would be. The model could be used to estimate the effects of expansions of different magnitude, but that has not been done to date.

In the intermediate savanna the crops most advantageous to expand are sweet potatoes, both sole and mixed, and yams. Sole sweet potatoes yield a surplus of 4,300s per acre. Intercropped yams have a net value of 2,700s per acre harvested in addition to what may be earned from the other crops grown on the land. Swamp rice and sole yams follow, yielding about 2,000s per acre. Melon seed as a mixed crop yields 2,000s per acre plus the surpluses from whatever else is grown on the land. While yams are not the most valuable of these crops, they are the only crop already being produced on a large scale. It is probable that the development cost of expanding yam production by 2,000 acres would be much less than the cost of expanding any other of these crops by that amount. In the solution, 2,000 acres of mixed yams are less than .75 percent of the acreage (Table 43); expanding sole sweet potato production by 2,000 acres would represent a 17 percent change in output.

Most advantageous to expand in the western moist forest are mixed yams and maize, yielding a combined surplus of 5,100s per acre. Next most promising is commercial maize (included in the model, although it does not represent production by traditional techniques). The surplus obtainable from this method of production is 4,700s per acre. Next are sole cocoyams and bush maize, yielding 2,600s and 2,400s per acre. All these crops are efficient sources of the calories that are so costly to obtain in this area. Expanding these activities to a significant extent could lower the cost of providing the calories required.

Outstanding in the central moist forest are mixed bush maize and yams, with a combined surplus of over 6,000s per acre. Cocoyams and cassava yield large surpluses (2,500s and 1,700s, respectively) as components of mixed cropping combinations.

The leaders among the sole cropping activities are bush maize (5,800s per acre), yams (5,400s per acre), and cocoyams (2,800s per acre). The high surpluses from yam production reflect the importance of this area as a provider of yams to the areas east and west of it.

Commercial maize, yams, and cocoyams are the most productive food crops in the eastern moist forest. Commercial maize yields a surplus nutrient value of 5,400s per acre. Mixed bush maize and yams together yield a surplus of 4,700s.

In the forest-savanna mosaic, yams and maize are the most productive crops. Bush maize mixed with yams yields 5,300s per acre. Sole yams yield 4,100s, while sole maize yields 4,000s using commercial techniques and 3,500s with "bush" techniques. Swamp rice as a sole crop can earn 2,800s an acre. The nutritive significance of yams and maize in this area derives from their sales to the eastern moist forest as well as from local use. Expanding their production in Area VI will help reduce the cost of nutrition in Area V, where meeting the nutrient allowances is most difficult.

The inhabitant of any given area should be interested in the nutritional productivity of the crops in his area. The information just given serves this purpose. From the standpoint of the country as a whole, however, it is wise to make comparisons across areas. The most economical way of satisfying the nutritional needs of any one area is likely to involve expanding the production of crops in some other part of the country.

Table 45 lists the 27 activities with the largest surpluses, in descending order, for the country as a whole. Sole and mixed crops are listed separately. The total surplus from an acre of land in mixed cropping is the sum of the surpluses from the several crops grown on the land,[9] so suitable combinations of mixed crops frequently will be superior to any sole crop available in the area. It should be remembered, however, that the data for mixed cropping are less accurate than the sole crop data.

From the national standpoint the most efficient way to increase either nutrient production or the income obtainable from given quantities of land and labor would be to increase the levels of production of certain food crops beyond those that prevail in this solution. The

Table 45. ***The Twenty-Seven Field Crop Activities with the Largest Surpluses, Traditional Techniques***

Activity	*Surplus, shillings per acre harvested*	*Area* I	II	III	IV	V	VI	*Rank*
Sole crops								
Maize, bush	5,847				IV			1
Maize, commercial	5,376					V		2
Yam	5,355				IV			3
Maize, commercial	4,741			III				4
Potato, sweet	4,259		II					5
Yam	4,071						VI	6
Maize, commercial	3,957						VI	7
Maize, bush	3,532						VI	8
Yam	3,475					V		9
Rice, swamp	3,004	I						10
Cocoyam	2,801				IV			11
Rice, swamp	2,780						VI	12
Cocoyam	2,689					V		13
Cocoyam	2,570			III				14
Maize, bush	2,354			III				15
Rice, upland	2,137	I						16
Rice, swamp	2,135		II					17
Mixed crops								
Yam	3,702						VI	1
Yam	3,621				IV			2
Yam	3,418					V		3
Potato, sweet	3,379		II					4
Yam	2,818			III				5
Yam	2,725		II					6
Cocoyam	2,531				IV			7
Maize, bush	2,529				IV			8
Cocoyam	2,361					V		9
Maize, bush	2,331			III				10

crops to be increased should be selected in accordance with the information in Table 45 on the assumption that the quantities of arable land available in each area cannot be changed. Maize, yams, and cocoyams appear most often on the two lists, which probably is the reason they play major roles in the traditional farming systems. For the most part, expenditures intended to increase food production should be going into the rain forest zone and the forest-savanna mosaic.

The oil palm surpluses, shown in Table 42, should be added to this list, for those amounted to 4,500s and 4,600s in Areas III and VI. Expanding palm oil production beyond the limits imposed by the model

in those areas would be more desirable in terms of nutrition or income than any one of the last 13 activities in the sole crop section of Table 45. Only four sole cropping activities offer greater opportunity. Given that the present model lacks a marketing route for palm oil from Area V to Areas III and VI, it is possible that gains equally as great could be attained by expanding the solution levels in Area V, although Table 42 does not indicate this. The model as it stands simply does not answer this question, although it could, of course, be modified to do so.

The benefits of increased production of food crops may be taken either in the form of nutrient output that exceeds the levels specified in the statement of the problem or in the form of levels of money income exceeding that attainable in this solution. Every time an acre of land is shifted from the production of a food crop that yields no surplus value to one that yields a surplus of 3,000s, resources worth 3,000s that are devoted to nutrient production in this solution are set free for use in the production of income. One obvious mechanism is the release of groundnuts and red palm oil from use as food so that they may be sold as export products. If people must be fed adequately before resources are devoted to income production, the most effective way to increase income is to concentrate on expanding the production of the most efficient food crops. Income production then will increase by itself.

Effects of Improved Techniques

At either level of production technique, the principal task, from the nutritional point of view, is to provide sufficient calories and riboflavin, the latter being difficult to supply only in the moist forest areas. When traditional techniques are used outside the moist forest areas, iron is a scarce (costly) nutrient in the forest-savanna mosaic. Calcium and vitamin A are costly in certain areas at either technical level, but in the present model, where the calcium allowance for the dry savanna has been reduced to 330 mg daily per capita, calcium loses almost all its importance. Outside the dry savanna, meeting the unchanged allowance involves no cost, and in the dry savanna the cost is only about 4 percent of the total cost of the daily diet. Before the dry savanna allowance was changed, calcium accounted for almost the whole cost of the diet in that area.

When the calorie and riboflavin allowances are satsified, along with the other three where those nutrients are scarce (costly), more than

enough is provided of protein and each of the other food elements with which the models are concerned. Economical sources of calories provide incidental amounts of protein, while riboflavin may be serving as a proxy for protein in the areas where protein is likely to be scarce.

The general improvement in yields associated with replacing traditional techniques by 1963 methods outside the moist forest areas markedly reduces the level of dependence upon food from outside Nigerian agriculture and increases the quantity of resources devoted to producing income rather than food. Large quantities of red palm oil and groundnuts must be used for food when traditional techniques are used, but these can be exported when 1963 methods are employed. Likewise, with 1963 methods the acreage that can be spared for cocoa production more than doubles. At both technical levels the gains from expanding food crops are superior to those from income crops, but the difference is much less when 1963 techniques are in use. (The surpluses listed in Table 17 are roughly of the same order of magnitude as those in Table 19, but in Table 42 the only surpluses comparable in magnitude with most of those listed in Table 44 are for crops that could be sold for income but are in fact going for food.)

The improvements to 1963 levels take place outside the moist forest areas. Within the latter areas 1963 methods are in use in both models. Naturally the differential change in techniques has differential effects upon the various areas. When the moist forest areas use 1963 methods, but the rest of the country does not, the moist forest areas could be expected to be the best places for expanding food production. This is the case: Each of these areas has five or six crops in the list of field crop activities with the largest surpluses (Table 45).[10] The forest-savanna mosaic is surprising, however; although it has some activities using traditional methods, it has four of the 17 leading sole crops, in addition to oil palm, and one of the 10 leading mixed crops. (Each of its leading crops uses 1963 techniques, of course.)

When the whole country uses 1963 methods, the savanna areas and the forest-savanna mosaic could be expected to become more profitable places for expanding food production. This is true for the two savanna areas. Each then has four or five of the 17 leading sole crops and two or three of the 10 leading mixed crops (Table 20). The forest-savanna mosaic, in contrast, becomes less promising as the savanna moves forward. It now has only two crops in the list of 17 leading sole crops and none among the leading mixed crops. Still, the

most surprising change in position is that of the eastern moist forest. It has *no* crops in the list of activities with large surpluses, either sole or mixed, when the whole country is using 1963 techniques. The latter two changes, however, cannot be attributed entirely to the effects of improved techniques. The model with traditional methods allows very little millet consumption in Areas V and VI, but the one that uses 1963 techniques for the whole country sets the consumption maxima at levels 45 times greater (Table 27). The increased opportunity to draw upon the dry savanna for food is alone sufficient to make Areas V and VI less promising places in which to expand food production.

At either level of technique, maize and yams appear most frequently in the arrays by surpluses, although the Area I and II activities drop out when traditional methods are used in those areas.[11] Except for tobacco, the Area I crops in the list for 1963 methods are there largely because they provide a high ratio of calcium to calories. These rankings should be ignored, for the calcium allowance is unduly high in that model. Swamp rice and bush maize, the leading Area I crops with traditional methods, are more appropriate candidates for expansion in that area.

In the moist forest areas, where the production data were the same in both models, maize, cocoyams, and yams are the most advantageous of the sole crops to expand at either level of technique, but in Area V not even these are as advantageous as various activities in other parts of the country when 1963 techniques are available in all of Nigeria.

At yields of 2,100 pounds per acre soybeans become a leading candidate for expansion in the forest-savanna mosaic, along with bush maize, although at traditional yields for soybeans (370 pounds) they are worth cultivating only at about 60 percent of the maximum level allowed in the model. Yams and swamp rice join the group of leading sole crops in the model that uses traditional methods.

At 1963 yields, bush maize, sorghum, and yams are advantageous sole food crops to expand in the intermediate savanna, but not at traditional yields (for which see Table 29). Sweet potatoes, with their yield at 1963 levels in both cases (6,000 pounds per acre), are advantageous to expand in both models.

The Animal Industries

With crop production techniques at traditional levels outside the moist forest areas, the optimal pattern for the animal industries is to

carry on all the traditional activities at their maximum levels except the production of cattle from the migrant herds of the Fulani. Neither hay-fed sheep nor any of the modern modes of animal production is an economical means of providing nutrition for Nigeria.[12] (See Table 46.)

Some animal production in the dry savanna has to be contracted in this solution because the quantity of pasture available is less than is required to support the 1963 levels of animal production.[13] Given the data of this problem, goats and sheep are more efficient producers of nutrition than cattle in this area, so the quantity of bush cattle is restricted to make possible the maximum production of goats and sheep.[14] The bush cattle production of 870,000 carcasses is 81 percent of the maximum allowed by the model. This is slightly below our estimate for 1963 production: 890,000 carcasses.

Further expansion of bush cattle production under this limitation on the amount of pasture available would be disadvantageous for Nigeria. It would require contracting the output of goats or sheep, but goats yield a product worth 5s per acre in addition to the value of the land they use, and sheep yield 6s. (See Table 47.) Expanding bush cattle production would yield only the value of the land used: 4.4s per acre (Table 48).

If more bush pasture were available, cattle production would expand. (Sheep and goat production can expand no more in this solution because the model imposes limits on maximum output.) To expand cattle production by transferring land from crop use to pasture would be extremely wasteful, however. Arable land in the dry savanna can earn 180s per year in its least advantageous use (Table 48). To convert an acre of land into pasture that yields a product worth only 4.4s per acre would be to lose nutrients worth more than 170s per year. At traditional levels of technique in crop production, expanding field crops in the dry savanna offers Nigeria far more nutritional benefit than expanding the production of animal products.

In other parts of Nigeria the traditional animal industries can expand without drawing land from crop production, for there is an abundance of unused bush pasture. As long as the extra labor required can be obtained without withdrawing labor from crop production, such expansion would be advantageous for Nigeria. Small amounts of unused May–June labor exist in the central moist forest and the forest-savanna mosaic, and there are large quantities of unused labor in the intermediate savanna (Table 49). The potential gains from such ex-

Table 46. *Levels of the Animal Industries, Traditional Techniques Employed in Cropping Activities*

Activity	*Unit*	*Level*[a]	*Area*					
			I	*II*	*III*	*IV*	*V*	*VI*
Cattle, bush	1,000 head—output	Sol	869	M	M	M	M	M
		Max	1072	336	1.1	1.1	3.3	28
Cattle, commercial	1,000 head—output	Sol	—	0.0	—	—	0.0	0.0
		Max	—	11	—	—	6	1.2
Goats	100,000 head—output	Sol	M	M	M	M	M	M
		Max	29	11	3	2.1	9	1.8
Sheep, bush	100,000 head—output	Sol	M	M	M	M	M	M
		Max	8	4.4	.56	.07	1.4	3.4
Sheep, hay-fed	100,000 head—output	Sol	0.0	—	—	—	—	—
		Max	[b]	—	—	—	—	—
Swine, commercial	1,000 head—output	Sol	0.0	0.0	—	—	—	—
		Max	29	7.2	—	—	—	—
Chickens, commercial	100,000 chicks—input	Sol	—	0.0	0.0	—	0.0	0.0
		Max	—	5.3	7.9	—	[c]	[c]

M: Present in the solution at the maximum level.
—: The activity is not available in this area.
[a] Sol = solution level.
Max = maximum level.
[b] Limited by the production of cowpea hay.
[c] Limited by the feed production of the Ministry of Agriculture.

Table 47. *Additions to Revenue Obtainable by Expanding a Single Animal Industry, Traditional Techniques Employed in Cropping Activities*

Activity	*Unit*	*Shillings per unit of activity per year in Area*						*Shillings per acre of pasture per year in Area*					
		I	*II*	*III*	*IV*	*V*	*VI*	*I*	*II*	*III*	*IV*	*V*	*VI*
Cattle, bush	head—output	0.0	581	692	416	386	386	0.0	19.4	28.8	33.3	16.1	2.8
Cattle, commercial[a]	head—output	—	0.0	—	—	0.0	0.0	—	0.0	—	—	0.0	0.0
Goats	head—output	58.93	89.60	60.40	44.80	62.72	71.68	4.91	11.20	33.56	22.40	34.84	14.34
Sheep, bush	head—output	86.80	109.39	58.93	66.81	61.26	70.01	5.79	10.94	19.64	22.27	20.42	8.75
Sheep, hay-fed	head—output	[b]	—	—	—	—	—	[c]	—	—	—	—	—
Swine, commercial	head—output	0.0	0.0	—	—	—	—	[c]	[c]	—	—	—	—
Chickens, commercial	100 chicks—input	—	0.0	0.0	—	[b]	[b]	—	[c]	[c]	—	[c]	[c]

NOTE: These are the gains made possible by expanding any one activity by a small amount, given that the quantities of resources available and the limits upon other production and consumption activities remain unchanged.

—: The activity is not available in this area.

[a] The pasture for commercial cattle makes use of arable land.

[b] The model imposes no direct limit on this activity.

[c] Not a pasture-using activity.

Table 48. *Additions to Revenue Obtainable from an Additional Unit of a Resource, Traditional Techniques in the Savanna Areas, in Shillings*

Resource	*Unit*	*Nigeria as a whole*	*Area* I	II	III	IV	V	VI
Gathered and collected foods	One percent of estimated 1963 level	269 million	—	—	—	—	—	—
Labor	man-day							
May and June		—	0.0	0.0	69.98	0.0	8.78	0.0
Other		—	0.0	0.0	0.0	0.0	0.0	0.0
Land	acre-year							
Arable		—	177	1,380	0.0	386	515	593
Additional arable		—	—	—	—	—	0.0	—
Pasture, bush	acre-year	—	4.42	0.0	0.0	0.0	0.0	0.0
Manure	long ton	—	11.5	0.0	—	—	—	—

NOTE: Each value given here is the opportunity-cost valuation of the resource, the potential gain from having one more unit of a specific resource to use, subject to the conditions of the model. These conditions include maximum limits upon production and consumption activities and constant quantities of all other resources.

—: The resource is not considered in this area.

pansion, measured as earnings per acre of pasture used, are shown in Table 47. They do not exceed 33s per acre in these three areas.[15]

As soon as labor is fully employed, as it already is in the western and eastern moist forests, the gains from expanding the animal industries will be less than are shown in Table 47, for crop production activities would have to be contracted in order to provide the extra labor. (The calculations in Table 47 assume that labor is available without this alternative cost.) The cost of diverting labor from cropping activities undoubtedly would be very high. In four of the six areas, cropping activities are able to earn 400s per acre and more for the land they use (1,400s in the intermediate savanna), whereas earnings of the best of the animal activities do not exceed 35s per acre.[16] In the western moist forest May–June labor already can earn 70s per man-day; it is unlikely that any of the animal industries would be more productive than this.

In sum, no animal industry expansion is advisable in the dry savanna if economical nutrition for all Nigerians is the objective. Outside the dry savanna, expansions that would not prevent the use of labor in more productive activities would be advantageous. However, the gains from such expansions are modest, not at all comparable with the gains to be made from analogous expansions of cropping activities.

The optimal production pattern for the animal industries is the same at both levels of technique, except that when traditional techniques are employed outside the moist forest areas commercial beef cattle production in the forest-savanna mosaic becomes uneconomical. The pressure on resources that is imposed in order to meet the calorie allowance when using traditional cropping methods is so great that land in Area VI no longer can be spared for cattle production.

When 1963 techniques were employed, gains of 2.8s per acre could be made in the dry savanna by transferring unused arable land to cattle production. At the same time, expanding a number of crop production activities beyond the limits set in the model could give much larger gains and would be preferable if there were not enough land for both. Using traditional techniques means generally lower yields from cropping activities in the savanna areas and the forest-savanna mosaic, but it has the effect of increasing the advantage that cropping activities have over the animal industries in the dry savanna. The lower yields (and the moderately lower maximum limits used in this model for the traditional animal industries outside the dry savanna)

Table 49. ***Resources Available and Unused, Traditional Techniques***

Resource and area	*Unit*	*Quantity available*	*Quantity unused*	*Percentage unused*
Gathered and collected foods, Nigeria	One percent of estimated 1963 level	109.5	0.0	0.0
Labor: May and June	1,000 man-days			
I		449,000	173,000	38.5
II		181,150	77,200	42.6
III		84,290	0.0	0.0
IV		51,580	2,400	4.7
V		92,140	0.0	0.0
VI		70,000	1,030	1.5
Labor: other	1,000 man-days			
I		1,795,800	1,250,000	69.6
II		797,200	520,000	65.2
III		404,100	145,000	35.9
IV		247,500	79,600	32.2
V		442,400	212,000	47.9
VI		336,200	164,000	48.8
Land: arable	1,000 acres			
I		15,041	0.0	0.0
II		6,534	0.0	0.0
III		5,188	238	4.6
IV		1,260	0.0	0.0
V		3,390	0.0	0.0
VI		2,830	0.0	0.0
Land: additional arable[a]	1,000 acres			
V		322	320.6	99.6
Pasture: bush	1 million acres			
I		429.6	0.0	0.0
II		847.1	823.9	97.3
III		2.64	1.91	72.3
IV		2.64	2.19	83
V		10.99	8.89	80.9
VI		99.55	91.97	92.4
Manure[a]	1,000 long tons			
I		3,000	0.0	0.0
II		1,500	3.1	0.2

[a] This resource appears in the model only in the areas listed.

make nutrients much more expensive to obtain. This increases the value of the animal activities in general, but it increases the value of efficient cropping activities even more. Animal activities in the dry savanna can earn 4.4s per acre for the bush pasture they use (in addi-

tion to the surpluses that goats and sheep will yield), but field crops can earn 180s per acre (in addition to their surpluses). Using traditional methods there is *no* unused arable land in Area I, and no transfer of land from crops to animals would be advisable. Expanding the animal industries in the dry savanna requires the adoption of improved crop production methods if Nigerians are to be fed both adequately and economically.

Outside the dry savanna each of the traditional animal activities is worth expanding if it employs no resources that have an alternative use, whichever level of technique is employed in crop production activities. If a choice must be made between the animal activities and crop production, however, at either technical level, in every area there are cropping activities that yield much larger surpluses than any of the animal activities. Limiting production techniques for most crops to traditional methods outside the moist forest areas raises the surpluses from the traditional animal activities, but not nearly as much as it raises the surpluses from most of the cropping activities. In general, using traditional techniques triples the surplus per acre of pasture for bush cattle and for goats, outside the dry savanna, and multiplies the surplus from sheep by two or two and one-half times. In the western moist forest, however, the surpluses rise by smaller amounts, probably because the large purchases of dried freshwater fish provide an effective alternative to obtaining the needed nutrients (calories, in this case) from meat products.

Resource Earnings

Of the resources usually considered in discussions of agricultural production, this study takes explicit consideration of only land and labor. Labor includes that available during May and June, generally the months of greatest labor needs, and that available during the remainder of the year. Physical capital is not considered explicitly in these models, except for the manure or fertilizer used by a few of the activities considered. For the most part, at the technical levels considered, physical capital consists of seed, simple tools, and homemade storage facilities. It is assumed that these resources are provided by labor applied during the off-peak months or, in the case of seed, by the previous year's productive activity. The essential assumption is that these resources do not limit the volume of output in any activity.

In meeting its nutritional needs Nigeria makes use of another

resource not normally considered in production studies but certainly of great significance in any study of nutrition. Its existence and importance must be recognized. This is especially true because this resource will disappear as Nigeria continues to grow and develop. One of the problems for agricultural development is to discover means of replacing the nutritional contributions now being provided from this source.

The resource in question is the bush, the forest and the roadside, plus those edible products of the compound and the field that often go unnoticed, even when they are by-products of the principal products under cultivation. In Nigeria, gathered and collected foods—animals, insects, leaves, fruits, and so forth—provide a significant portion of the total diet. One percent of the amount we estimate to have been consumed in 1963 provides nutrients equal in value to 269 million shillings in this solution. (See Table 48.) It is assumed that the usage of such foods has increased from 1963 levels by 9.5 percent, that is, in proportion to the growth of population. Thus the aggregate value of the gathered and collected foods used in this solution comes to 29,500 million shillings (25 percent of the total value of the nutrients required for Nigeria). Important as it is, this resource plays no active part in the solution. It is not allocated among competing uses for greater efficiency, but simply accepted gratefully as a major contributor to the nutrition of the Nigerian people.

The resources more commonly considered—land and labor—do enter actively into the economizing process. They must be allocated among competing enterprises in an efficient fashion if Nigeria is to feed itself adequately and at the least sacrifice of its income earning potential.

To be efficient a production activity must earn at least as much, in income or in the value of the nutrients it produces, as each of the resources that it employs could earn if used for some other activity. Thus a land-using activity must earn at least as much for the land it uses as the least worthwhile land-using activity in that area. If all the efficient activities taken together in one area can use more land than is available, each unit of land will have a positive annual use-value, for expanding one activity will force the contraction of another and, therefore, some loss of valuable output from the contracting activity. If, on the other hand, there is more land than all activities use, no activity need reduce its use of land when another expands, no loss of income occurs, and land will have a zero annual use-value.

In the optimal production pattern, when traditional methods are

used outside the moist forest areas, arable land has a positive annual use-value in five of the six areas (Table 48). The model assumes that the quantity of land that can be used is determined ultimately by the size of the population. A population 9.5 percent larger than that of 1963 will be able to make use of 9.5 percent more land. In the western moist forest this is more land than can be used by the optimal combination of activities, so land has a zero use-value, but in all other areas an increase of only 9.5 percent in the land available for use leaves land a scarce factor, with a positive use-value. That value is least in the dry savanna, where an acre of land in field crops can earn 180s a year, and most in the intermediate savanna, where it can earn 1,400s. In the central and eastern moist forests and the forest-savanna mosaic an acre of arable land can earn 400s to 600s per year.

The eastern moist forest is a special case. There it was assumed that *any* increase above 1963 levels in the quantity of arable land in use would have to be accompanied by a lengthening of the fallow period and a consequent reduction in yields. The 9.5 percent increase in arable land that is allowed in the model can be used only at the expense of a reduction in yields on all land used in the area.[17] As Table 49 shows, the consequence is that only 1,400 acres (.04 percent of the 1963 acreage) of the potential increase in the quantity of land available is put to use in the eastern moist forest. The 3,400,000 acres of arable land estimated to have been in use in 1963 have a use-value of 515s per acre. The 1,400 additional acres employed in this solution have no use-value.

In four of the six areas land has a use-value in this solution, but labor does not. In the savanna areas and the forest-savanna mosaic this can be explained in part by the fact that our data for traditional production methods normally report a lower level of labor use per acre than our data for 1963 methods. In this situation, expanding all cropping activities, but maintaining their 1963 proportions, would exhaust the stock of land available before all of the May–June labor provided in the model could be used, so land would have a positive use-value and labor a zero value. (Both May–June labor and arable land are provided in this model in quantities 9.5 percent greater than their levels in 1963, but labor use would not be expanding as rapidly as land use.)

Another possible reason for finding land used to capacity while some labor is idle would be that the optimal production pattern for this model has shifted away from the actual 1963 production pattern

to one that uses land in greater proportion than it does May–June labor. This mechanism can operate in all areas and apparently has operated everywhere except in the eastern and western moist forests. Elsewhere the optimal combination of activities uses land to the fullest, but leaves some labor unemployed, given that land and labor are available in the proportions estimated to have been used in 1963.

In the eastern moist forest land usage has increased by only .04 percent above 1963 levels, but labor use has increased by the full 9.5 percent allowed in the model. In this area, however, any increase above 1963 levels of land use is accompanied in the model by a reduction in yields traceable to a shorter fallow period. Both factors have positive use-value, for all the land available without shortening the fallow period is fully used as well as the full stock of labor available in the model.

In the western moist forest also the most profitable production pattern has shifted in favor of activities that use a greater proportion of May–June labor to land than was the case in 1963. Labor, the only limiting resource in this area, has a very high use-value (70s per day) during the period of peak agricultural need. The factor that limits food production under these conditions is the availability of labor during the busiest period.

In the eastern and western moist forests it is necessary, when traditional methods are used outside the moist forest areas, to shift some land from oil palm (in the eastern forest) and cocoa (in the western forest) to food production. Most food crops use more May–June labor per acre than do cocoa or oil palm, so the ratio of labor-use to land-use rises in these areas. The same mechanism may be operating with rubber production in the central moist forest, but it is quantitatively less important there.

Table 48 includes two other factors that have use-value in the optimal solution, both of them related to the dry savanna. These are bush pasture, which earns 4.4s per acre, and manure (which has been regarded as given in quantity), with a scarcity-value of 11.5s per long ton. If more bush pasture were available, cattle production would expand in Area I, and if more manure were available, onion production would expand. (The bush pasture available in the dry savanna is less than that used in 1963 because the increase in arable land between 1963 and 1967 has been taken from the bush pasture.)

Outside the dry savanna neither bush pasture nor manure has a scarcity-value. Onion production in the intermediate savanna is lim-

ited by the restriction on consumption to a level that leaves some manure unused, while the maximum limits on traditional animal activities outside the dry savanna leave 70 percent or more of the bush pasture unused in those areas (Table 49).

When land is the only scarce factor, as in Areas II, IV, and VI (and in Area I for all cropping activities except onion production), efficient production consists of producing the set of activities that maximizes the value of the product per acre of land. The pattern would be to engage in the activity that yields the most valuable product per acre, to the limit allowed in the model, then to pursue the activity with the next most valuable product, and so forth, until the stock of available land is exhausted. The value of the product of an acre of the last activity for which there is land is the value attributable to an acre of land in any activity. Subtracting this figure from the total value product of an acre of any activity gives the surplus yielded by that activity.

If labor is the only scarce factor, as May–June labor is in the western moist forest, efficient production calls for arranging the activities in the order of their value product per man-day. To determine this, select the activities that yield the largest of these values and pursue each to the limit allowed by the model until the stock of labor available is exhausted. At this point, the value of the product per man-day in the least productive activity will be the value of one man-day in any activity.

If one knew in advance which of the factors would be limiting, this procedure could be used to determine the optimal production pattern. However, it is not possible, in general, to know beforehand whether labor or land will be limiting, or whether, indeed, both labor and land are limiting. It is only after the set of most profitable activities has been chosen that one can know which are the limiting factors.

The set of activities that maximizes the value of the product from the land available will not, in general, be the set that maximizes the product from the labor available. If both labor and land are limiting there will be still another set that yields a larger total value product than either of the first two.

Where both labor and land are limiting, maximizing the total value obtainable means maximizing the aggregate surpluses from the several activities employed, after subtracting the opportunity-cost value of each of the limiting factors from the total value of the product of an activity. Efficient production means using every activity that yields a positive surplus. In addition, each activity that yields a

zero surplus is pursued to the extent that the stocks of resources available will allow. Engage in no activity unless it produces a product worth at least as much as the services of the resources it employs.

In principle, this statement provides a means of selecting the optimal combination of activities when any number of factors is limiting, but to apply it one must know the opportunity-cost values of the several factors, and these cannot be known until the optimal combination of activities has been determined. The problem is one of general equilibrium, in which all variables must be determined simultaneously. While opportunity-cost values can be calculated on the basis of many different combinations of activities, only those sets of values are satisfactory that leave no activity unused that has a positive surplus after factor stocks are exploited fully.[18] The resource values in Table 48 are opportunity-cost values that meet the necessary conditions. They are appropriate for determining an optimal production pattern.

Just as the surpluses the various crops can earn (Table 45) show how existing stocks of land could be used more effectively by expanding the acreage in the most productive crops, the use-values of the several resources show how the income potential of Nigerian agriculture could be increased if the quantities of resources available could be changed. Factors have use-value because they are scarce; they limit the quantity of output attainable. The amount of the use-value of a given factor is the value of the additional output that could be obtained if one additional unit of that factor were to become available.

In five of the six areas the aggregate income from Nigerian agriculture would increase if more land could be put into use, even with the existing limits on the levels of individual activities. In four of those areas some unused labor is available. Some of the added land, to be sure, is not likely to be equal in quality to the land already in use, but if land now in use can earn 600s per acre per year, even land of lower quality can earn appreciable amounts. In some parts of Nigeria, however, adding to the land under cultivation might require reducing the length of the fallow period. Where this is necessary the benefits to be gained from expanding cultivation can be reduced considerably, as will be seen.

Efforts to bring more land under cultivation would have most effect on Nigerian income in the intermediate savanna. Additional land in that area can contribute more than twice as much as in the other areas where land services have high value. Table 49 shows that over 40

percent of the available May–June labor in the intermediate savanna is unused in this solution, so the average farmer there could handle a considerable quantity of extra land.

The pattern of production in this solution has also left much excess May–June labor in the dry savanna. Nearly 40 percent of the labor available there is unused with this cropping pattern.

In the central moist forest and the forest-savanna mosaic, however, bringing additional land under cultivation would quickly exhaust the stock of unused labor during May and June. The excess labor in those areas is less than 5 percent of the total quantities available.

Increases in the quantities of land available beyond the point where all May–June labor is employed would require a rearrangement of the production pattern in favor of activities using a smaller ratio of labor to land. Thus the net gains from adding land would begin to decline. The increases still would add to income over some range, but the gains would become smaller and smaller. At the same time the opportunity-cost value of labor would begin to rise.

In this solution increases in land in the western moist forest would be of no value since labor is the scarce factor there. The optimal production program leaves nearly 5 percent of the available land unused.

For different reasons, increases in land-use in the eastern moist forest also would be of no value, despite the scarcity of nutrients there. An additional acre of land would be worth 500s if it could be had without shortening the fallow period, but this is not possible. Any land added shortens the fallow period and thus reduces yields on all land in cultivation. The pressure for production is so severe in this area that 1,400 acres have been added to 1963 levels of cultivation, even under this condition. This is, however, only .4 percent of the land that could have been added in this model. Adding more land under this condition would add nothing to Nigerian agricultural income. (See Table 48.)

In the western moist forest an additional man during May and June could add 70s a day to the value of the output, so hiring temporary labor during these two months could be very advantageous. Nearly 5 percent of the arable land available in this area is unused in this solution (Table 49), so an appreciable number of laborers could be employed before land scarcities began to reduce the amount an additional man could earn. If the maximum limits on the most promising crops were relaxed at the same time, additional opportunities for profitable employment would be created during this period of the year.

During most of the year, however, there are large surpluses of agricultural labor, ranging from 32 percent (in the central moist forest) to 70 percent (in the dry savanna). These reflect the strong seasonal pattern of Nigerian rainfall.

Bush pasture outside the dry savanna also is available in quantities far in excess of the need for it (Table 49). The excesses range from 72 to 97 percent of the estimated quantities available. This is, of course, the source from which increases in arable land will come as Nigerian agriculture expands in its effort to meet the requirements of an increasing population.

When data for traditional instead of 1963 techniques are used for the principal crops in the savanna areas and for five activities in the forest-savanna mosaic,[19] the change generally reduces both yields and labor requirements per acre of land. The consequences are much as one would expect. In the dry savanna and the forest-savanna mosaic, May–June labor was the only factor limiting cropping activities under 1963 techniques, but land is the only limiting factor when traditional techniques are used. In the intermediate savanna and the central moist forest, both land and May–June labor were limiting with 1963 techniques, but land again becomes the only limiting factor. Moreover, approximately 40 percent of May–June labor goes unused in the two savanna areas when traditional techniques are employed.

In the eastern moist forest, land is a scarce (limiting) factor at either level of technique, but May–June labor also becomes somewhat limiting when traditional techniques are used outside the moist forest areas. There is a small increase in the amount of arable land in use in this area, even at the expense of generally reduced yields, when traditional techniques reduce the productivity of land in the savanna areas.

Reduced land productivity outside the moist forest areas has the peculiar effect in the western moist forest of shifting the production pattern from one in which land is the sole limiting factor to one in which labor is the sole limiting factor. As has been seen, this is because food crops generally use more May–June labor per acre of land than does cocoa.

Efficient Nutrient Production

The 1963 production pattern would not be adequate to meet the nutritional goals set for a population of 61 million if traditional tech-

niques were being employed in the savanna areas. Examining the adjustments that would have to be made to meet those goals gives insight into the kinds of adjustments that will be necessary and the sacrifices that will have to be made even with those adjustments if the continuing growth of population outruns the rate at which improved production techniques are adopted by the Nigerian farmer.

The major adjustment, of course, would be to shift the overall production pattern toward the production of more food at the expense of the production of income. In the present solution, almost all food production activities expand to the maximum levels allowed in the model. (For most of them it would be efficient to expand even beyond those levels if this could be done without adversely affecting yields or factor requirements.)

As the quantities of May–June labor and arable land available to provide for 61 million people are assumed to be only 9.5 percent more than were in use in 1963, expanding most food crops to 20 percent above their 1963 levels requires withdrawing the additional resources needed from other uses. The principal activities that decrease or disappear in order to free these resources are the production of cowpeas and millet in the dry savanna, cotton in the intermediate savanna, cocoa in the western moist forest, oil palm in the eastern moist forest, and a miscellany of activities in the forest-savanna mosaic that includes production of groundnuts, soybeans, cotton, and beef cattle by modern methods. These are the activities most readily spared under these difficult conditions.

More concentration on the production of crops of high nutritional value is needed under these less productive technical conditions than was the case in the actual 1963 pattern. Some crops yield nutrients worth much more than the resources they require. These crops are especially common in the rain forest zone and the forest-savanna mosaic, but every area has at least two crops that yield large surpluses—in excess of 2,100s per acre. Improving the nutritional efficiency of production means specializing more heavily in these crops.[20]

Identifying the crops that are especially efficient sources of nutrition is of particular importance for those concerned with the nutrition of the average farm family. The farmer with limited land could improve his family's nutrition simply by increasing the fraction of his acreage devoted to crops that are high in nutritional efficiency. In the process he also might release resources that can be used to increase the income production of his farm.

Among the unusually efficient crops, the combination of yams and bush maize as mixed crops is the most promising in the central and western moist forests and the forest-savanna mosaic, and it stands high on the list in the eastern moist forest and the intermediate savanna. Among the sole crops, the greatest gains in productivity would come from expanding the production of yams in the central moist forest, bush maize in the central moist forest and commercial maize in the eastern and western moist forests,[21] and oil palm in the western moist forest and the forest-savanna mosaic.[22] Sweet potatoes in the intermediate savanna and yams and maize in the forest-savanna mosaic are very productive, while cocoyams and rice are also on the list of especially efficient food crops.

It is comforting to note that most of these crops are already important components of actual production patterns. It must be noted, however, that other important components of customary production patterns are much less efficient sources of nutrition at these technical levels—millet, sorghum, and cassava, for example—and that at least one major crop, cowpeas in the dry savanna, does not appear at all in the optimal solution when traditional methods are employed in the savanna areas. The opportunity-costs of the various nutrients are reflected in a particular crop's nutritional efficiency, which therefore will change as changing technical conditions alter the relative costs of producing the several nutrients.

Adjusting to the need for greater food crop production in the south may alter the proportions in which factors are used. In the western moist forest the shift from cocoa to food crops means that labor becomes a limiting factor in the Model Four solution. Optimal crop selection turns on the value productivity per unit of labor. In all other areas the quantity of arable land allowed in the model is limiting, and in four of these areas it is the only limiting resource for general crop production. In the two savanna areas large quantities of May–June labor go unused in the optimal solution.

In the intermediate savanna an extra acre of land could earn 1,400s using these technical levels, even with all the restrictions that the model imposes upon the maximum levels of the various productive activities. Therefore, expanding the amount of land under cultivation in this area would be an appropriate means of increasing the income from Nigerian agriculture under these conditions. Smaller but significant gains also could be made by increasing the quantity of land under cultivation in the central moist forest and the forest-savanna mo-

saic. Additional land in the eastern moist forest would be valuable, but it is not available on any large scale without reducing the fallow period. It seems unlikely that this would be advisable, and only a very small expansion of this sort occurs in the present solution.

Simultaneously increasing the quantities of land under cultivation in Areas II, IV, and VI and expanding the production of high-surplus activities in these areas beyond the maxima set in the model would provide the gains from both these sources. In the intermediate savanna, for example, if an acre of extra land were devoted to sweet potatoes, the total gain would be 1,380s from the land plus 4,259s as the sweet potato surplus, for a total of 5,639s (Tables 48 and 44). Where extra land can be put into use, the combined data from Tables 48 and 44 are to be used in planning a development program.

Of course, gains of the magnitudes shown in these tables would not persist indefinitely in the face of continuing changes in the production pattern and/or increases in the total quantity of land in use. As more and more land is brought into cultivation, or as larger and larger acreages of given crops are planted, the benefits from further increases eventually must diminish.

With cropping activities carried on in the savanna areas by traditional methods, the animal activities would not be promising candidates for expansion, although they are carried on at maximum levels in this solution, except for cattle production in the dry savanna. There cattle production has been cut back slightly from 1963 levels in order to permit goat and sheep production to expand fully. If one seeks to provide 1.02 mg of riboflavin daily per capita, goats or sheep are more efficient sources of nutrition than cattle in the dry savanna, as in some other areas (Table 47). No modern animal production activity is nutritionally efficient at any level.

To expand animal production activities by transferring land or labor from cropping activities would be wasteful of resources, for the surpluses available from animal activities are very small compared with those to be had from crop production. Large quantities of bush pasture go unused outside the dry savanna, but a much greater contribution to the nutrition and income of Nigeria would accrue if some of this land were added to the stock of arable land under cultivation than if it were devoted to an expansion of the animal industries.

Increasing nutrient production by shifting resources to the crops with the largest surpluses or by putting additional land into use would reduce the cost of meeting the nutrition allowances specified

for this problem and provide resources for use in the production of income crops. The result would be an increase in the total income that Nigerian agriculture could earn at these technical levels. Without such shifts in the production pattern the level of money income attainable without sacrificing nutritional needs would be small indeed.

12

Efficient Nutrition with Traditional Techniques

It would be possible for Nigeria to feed a population of 61 million while using traditional techniques for the principal crops in the two savanna areas and for some crops in the forest-savanna mosaic, but it would not be easy. To do so efficiently (with the least sacrifice of income earning capacity) would require spending 6.8 billion shillings on food from outside the agricultural sector and .7 billion shillings on transporting food within the country.

The foods to be purchased would be European-style beer, dried freshwater fish, wheat and wheat flour, and white sugar. Two-thirds of the expenditure would be for European-style beer, a relatively economical means of satisfying the minimum requirement for alcoholic beverages in the intermediate savanna and the western moist forest and a source of riboflavin in the central and eastern moist forests. One-fifth of the expenditure would be for dried freshwater fish, half of which is consumed in the western moist forest as an economical source of calories under the circumstances.

Both the beer and the fish are regarded in the model as produced within Nigeria, but outside the agricultural sector. A small amount of

foreign exchange is required to pay for imported materials needed for beer production. The agricultural exports in this solution are more than sufficient to provide the foreign exchange needed for imported materials, food, and fertilizers.

Of the total value of the nutrients provided in adequate least-cost diets for 61 million people, 25 percent represents those supplied by gathered and collected foods and 70 percent those supplied by the agricultural sector narrowly defined (either directly by the production of food or indirectly by the production of goods to be exchanged for food obtained from outside the sector). The nonagricultural sector would have to provide nutrients worth an additional 5 percent of the total by exchanging goods and services for them. (This sector, of course, also would produce goods and services to exchange with the agricultural sector for the food and other products that the latter furnishes the nonagricultural sector.)

From the standpoint of production, the principal nutritional problem is to provide enough calories. Food energy is scarce (costly) in every area, but especially in the intermediate savanna, the western moist forest, and the forest-savanna mosaic. Meeting the riboflavin standard set in the model (1.02 mg daily per capita) is difficult only in the central and eastern moist forests, but there it can be as much as 50 percent more costly than the calorie requirement at its most expensive. When the calorie and riboflavin requirements are met satisfactorily, along with the allowances for vitamin A in the two savanna areas, iron in the forest-savanna mosaic, and calcium in the dry savanna (none of the latter three being very expensive to meet), the diet provides more than the specified quantities of each of the other nutrients considered by the model. In particular, there is protein enough in each area, and it is more than adequate in quality.

The cost of the diet could be lowered somewhat if the riboflavin allowances were lowered in the central and eastern moist forest areas. How great a saving would be possible in this way is questionable, for riboflavin may be serving as a proxy variable for protein. The riboflavin allowances are being met in those areas with the assistance of purchases of meats, maize, cowpeas, sorghum, and millet from other parts of Nigeria (mainly the two savanna areas). If less riboflavin were specified, it is likely that very much the same trade pattern would be needed in order to satisfy the protein requirement.

Efficient solution of Nigeria's nutritional problem calls for extensive internal trade in food. Some 9 billion pounds are moved between ar-

eas in this solution, 5.5 billion pounds of it coming into the eastern moist forest. The forest-savanna mosaic sends large quantities of yams into the eastern moist forest, while the central moist forest sends yams both east and west. Rice, groundnuts, maize, and meat animals flow from the two savanna areas into the rain forest and the forest-savanna mosaic, while red palm oil moves north from the western moist forest and the forest-savanna mosaic and from the eastern into the central moist forest.

Two-thirds of all the meat produced in the savanna areas is consumed in the eastern moist forest. The remaining third is divided almost equally between the forest-savanna mosaic and the central moist forest. In the two moist forest areas the meat is important primarily for the riboflavin it provides; in the forest-savanna mosaic for its calories and, to a minor extent, its iron. No meat is sent into the western moist forest. The protein and riboflavin needs of this area are more than adequately satisfied, largely by the dried freshwater fish that it purchases from outside the agricultural sector. The fish are purchased as an economical source of calories, however, not for their protein and riboflavin.

With productivity outside the moist forest areas at the levels of traditional techniques, not many agricultural resources can be spared for the production of income, even with the expansion of individual food crops limited to 20 percent of their 1963 levels. All the red palm oil produced, and almost all the groundnuts, must be used for consumption. In addition, oil palm production in the eastern moist forest must be held to only three-fourths of the maximum allowed for the area, and cocoa in the western moist forest must be held to 40 percent of its allowable maximum.[1] Rubber in the central moist forest is at three-fourths of its permitted level, but at zero level elsewhere. Cotton production drops to zero in the intermediate savanna and the forest-savanna mosaic.

Nonetheless, some income production occurs. The income from cocoa, rubber, cotton, groundnuts, and tobacco comes to 683 million shillings, while by-products of the food production activities (palm kernel and palm kernel products, hides and skins, and groundnut cake) provide an income of 665 million shillings. Net foreign exchange earnings in this solution are 361 million shillings.

The production pattern that meets nutritional needs efficiently has nearly all food crop activities at the maximum levels allowed in the model. To make this possible, resources are released by reducing in-

come production activities, as just stated, and by reducing or eliminating the production of cowpeas and millet in the dry savanna and groundnuts, soybeans, and beef cattle by modern methods in the forest-savanna mosaic, along with certain minor activities.

The traditional animal industries should be carried on at maximum levels, except for cattle production in the dry savanna. There the expanded acreage allowed for crop production has come from bush pasture, leaving too little to support all three traditional animal activities at their maximum levels. Maximum efficiency under the conditions of this model calls for goats and sheep to be at their maximum levels and cattle to be slightly below the levels of 1963.

The total product of the agricultural sector could be increased significantly if more land than this model allows were cultivated in the intermediate savanna, the central moist forest, and the forest-savanna mosaic. In the intermediate savanna some 40 percent of the May–June labor is unused in the present solution, so a considerable expansion of land under cultivation should be possible. In the other two areas May–June labor is nearly exhausted by the present solution, so continuing increases in land under cultivation would soon require readjustments in the cropping pattern to economize on labor as well as on land. This would cause the gains from adding to the land under cultivation to diminish, but it is not likely that they would drop immediately to zero.

While the country as a whole can benefit by encouraging increases in farm sizes or the amount of land under cultivation in the areas where additional land could contribute significantly to Nigeria's nutrition or income, this option may not be open to the individual farmer. The total product of the agricultural sector also could be increased above the levels shown in this solution without change in the quantities of labor or land available by expanding cultivation of the most efficient crops beyond the levels to which they are limited in this model. Mixed yams and bush maize are a highly efficient combination in the moist forests, the forest-savanna mosaic, and the intermediate savanna. Among the sole crops, such expansion would be highly advantageous for yams in the central moist forest, bush maize in the central moist forest and commercial maize in the eastern and western moist forests (if yields of 1,700 to 1,900 pounds per acre can be obtained), and oil palm in the western moist forest and the forest-savanna mosaic. Sweet potatoes in the intermediate savanna and yams and maize in the forest-savanna mosaic are also very productive.

Knowledge of these most efficient sources of nutrition is important, not only to development planners, but also to the individual farmer. The average farmer with limited land area can improve his family's nutrition simply by increasing the proportion of these highly efficient crops in his own plantings, perhaps also releasing resources that he can use for the production of income.

Efficiency with given techniques is obtained by selecting patterns of production, consumption, and trade that enable Nigeria to meet the nutritional needs of each area by combining production within the area with exchange for nutrients more efficiently produced in other areas. With such efficiency, Nigeria can provide the nutrients needed by a population of 61 million, even using the techniques of traditional agriculture outside the moist forest areas. Nigeria, however, is very near the limit of its capacity to provide adequate nutrition. It will be impossible to continue to do this as population continues to grow unless there are great changes in consumption patterns, disproportionate increases in the amount of land under cultivation, or significant improvements in agricultural techniques. Fortunately, as was seen in Part One, farmers are adopting improved techniques at a rate that already has greatly increased the capacity to provide nutrition and income for the population.

Part III:

Summary and Recommendations

13

Persistent Characteristics Of the Nutritional Problem

The model described in Part Two was developed for two reasons: (1) to correct certain features of the earlier model that might have had adverse effects upon its usefulness as a basis for policy formation and (2) to determine the consequences of using traditional methods in the savanna areas instead of the techniques actually being employed in 1963. Comparison of the results from Models Three and Four will indicate the quantitative importance of the flaws detected in Model Three, identify those features of the Nigerian nutritional situation that are fundamental (in the sense that they persist despite large changes in the production data used in the problem), and provide an estimate of the economic and nutritional importance of adopting improved agricultural techniques.

Results from the earlier model were described in Part One. However, certain defects in the model might have been thought responsible for important features of those results. For example, the calorie and riboflavin allowances were more difficult to meet than the protein allowance. Indeed, when the allowances for the controlling nutrients (calories, riboflavin, calcium, and vitamin A) were met in an econom-

ical way, the solution provided more than enough protein in each area of Nigeria. When the production problem was solved for calories, riboflavin, calcium, and vitamin A, it also was solved for protein.

Did this result describe the true nature of the production problem for nutrients, or did it occur because the model required that the sulfur-containing amino acids constitute only 3.4 percent by weight of the fully utilizable protein? (The 1957 FAO provisional pattern suggested that 4.2 percent of the weight of reference protein should consist of the sulfur-containing amino acids. See chapter 3 above.) Or did this result occur because the model allowed the traditional animal industries outside the dry savanna to expand by 20 percent when their supply of free labor expanded by only 9.5 percent? Or because the solution called for the eastern moist forest to consume perhaps 26 times as much millet as was customary in that area? Model Four, described in Part Two, provided answers for these questions.

Likewise, in the earlier model the traditional animal industries provided almost the entire meat output of the country. (Modern beef production accounted for only 1,200 head of output, about .0003 percent of the total value of the animal industry output in the solution. (See Tables 22 and 24.) Was this the result of allowing the traditional animal industries outside Area I to expand by 20 percent rather than 9.5 percent?

The earlier model also showed that meeting the calcium allowance was the dominant problem in the production of nutrients for the dry savanna, that calories were not costly there (indeed, that increasing the caloric allowance alone would *lower* the cost of the diet), and that consuming dried freshwater fish provided nutrients worth 98s per kilogram more than the cost of the fish in that area. Do these results describe the nutritional situation with which policy makers must deal, or was the calcium allowance (392 mg per capita per day in Area I) set at an unreasonably high level, given the production situation in that area?

The Model Using 1963 Techniques

Of the four features of the model that changed in going from Model Three to Model Four, only one had a major effect upon the results. Reducing the daily calcium allowance in the dry savanna to 330 mg per person rendered that allowance of minor importance and lowered the cost of nutrition there. The dry savanna diet, instead of

being one of the three most expensive, became the least expensive of the six, now costing only about one-sixth as much as the next most economical diet. Calories, along with vitamin A, became one of the costly nutrients in the area, and dried freshwater fish ceased to yield a surplus nutrient value there. While the calcium content of the fish was still important enough to make it an efficient food,[1] it was now consumed only in modest amounts and had no advantage over many other foods consumed in the area.

It is clear that the calcium allowance in Model Three had significant effects on the results for the dry savanna. Because the allowance was generous, attaining it fully represented a goal of little nutritional importance, but it could only be reached in the dry savanna at great economic sacrifice. To base policy conclusions on a model using this allowance would risk diverting attention from the more significant nutritional problem of providing sufficient calories for the people of this area. Therefore, only the results from Model Four should be used for the dry savanna area.

Lowering the permissible levels for the consumption of millet in Areas V and VI had a dramatic effect in reducing purchases from the dry savanna.[2] The fact that the cost of meeting the riboflavin allowance in Area V rose from Model Three to Model Four by more than twice as much as in Area IV also must be attributed at least partially to reduced millet purchases by the eastern moist forest. There also must have been various readjustments in consumption and trade patterns to replace the nutrients the millet provided in Model Three. While this alteration in the model had significant effects, these did not include making protein a costly nutrient in Area V.

With respect to these changes in maximum consumption levels, the results of both models are valuable for policy purposes, but they must be used in different ways. The model that assumes 1963 technical levels identifies a highly economical consumption pattern and suggests that encouraging the consumption of millet is sound nutritional policy. It may not, however, be effective in the short run. If the consumption of millet is resisted in Area V, because of its relative unfamiliarity, the results of Model Four, although based in part on traditional production techniques, will be more useful guides to low-cost nutritional patterns for the time being.

Restricting the traditional animal industries to 109.5 rather than 120 percent of 1963 levels did not enhance the part played by the modern animal industries in Nigerian meat production. Indeed, not even the

small Area VI commercial beef activity that was included in the Model Three solution proved efficient enough to earn a place in the Model Four solution. If there were any beneficial effects on commercial meat production as a result of the restriction of traditional animal activities, they were more than wiped out by the reductions in field crop yields that occurred when 1963 agricultural techniques were replaced by traditional methods outside the moist forest areas.

Perhaps the most important reason for revising Model Three was to find whether the absence of protein from the list of controlling nutrients was caused by faults in the model or whether this simply reflected the true nature of the nutrient production problem in Nigeria. We now know that it was not the fault of the model. In Model Four the sulfur-containing amino acids must constitute 4.2 percent of the weight of fully utilizable protein, the consumption of millet in the eastern moist forest is severely restricted, and the maximum levels of the traditional animal industries have been cut back outside the dry savanna, but still protein is not among the controlling nutrients. When the allowances for calories and riboflavin are fully met, along with those for calcium, vitamin A, and iron, there is more than enough protein for each part of Nigeria at the levels of protein use specified by the model.

In short, outside the dry savanna the Model Three results are satisfactory for use in policy formation. The production data used there describe the techniques actually in use in 1963 with reasonable accuracy, and such flaws as the model possesses do not seriously disturb the results obtained with its use. Model Four, while preferable in some respects, assumes that traditional production methods are used generally outside the moist forest areas. Its results not only are more pessimistic, but also, to the extent that their detail is influenced by the assumption of traditional techniques, less representative of the situation that now prevails in Nigeria.

Persistent Characteristics of the Nutritional Problem

Despite the changes made between Model Three and Model Four, and despite the replacement of 1963 methods by traditional methods for the principal crops in the two savanna areas and for several crops in the forest-savanna mosaic, the most important features of the solutions of the two models remain the same. These features represent fundamental characteristics of the nutritional problem of Nigeria, that

is, characteristics of the production situation that show through even when specific features of the model are changed or when a significant general change occurs in the level of agricultural productivity in a large part of the country.

Basic to the whole nutritional problem is the nature of Nigeria's production capability for nutrients. Both models show that the nutrients that are economically scarce for reasons of production (difficult or costly to produce in adequate quantities) are primarily calories and, in the rain forest areas, riboflavin. Providing adequate amounts of vitamin A, iron, and calcium requires moderate sacrifices of income or resources in some areas, but providing a daily average of 2,266 k calories per capita is a major economic problem everywhere. The modest riboflavin allowance of 1.02 mg per person per day requires no necessary economic sacrifice outside the moist forest areas, but in those areas it may be even more costly to attain than the calorie allowance.

When these two allowances are attained economically, along with the relatively unburdensome allowances for vitamin A, calcium, and iron, the daily reference protein allowance (34.4 g per person) is more than adequately satisfied, and without extra cost. From a production point of view the allowances for calories and riboflavin are definitely more difficult to satisfy than the allowance for protein.

Some nutritionists may regard even 1.02 mg of riboflavin per day as more than should be sought for Nigeria, given the magnitude of the economic sacrifice that this requires in the rain forest areas. Such a judgment could be defended, for lowering the riboflavin allowance in the rain forest areas will lower the cost of the diet there and perhaps elsewhere as well. However, riboflavin appears to have served as a proxy for protein in these areas, so lowering the riboflavin allowance will also lower the amount of protein provided. At some point the quantity of protein in the diet will reach the level of one or more of the protein allowances. From that point on, further reductions in the riboflavin allowance will have less and less effect on the cost of the diet, and protein will become a more and more costly nutrient. As the relative importance of the production problem for riboflavin is reduced, the protein problem begins to appear.

Even though providing sufficient protein to meet the allowances specified is not one of the dominant production problems when the riboflavin and other allowances are at the levels used here, it is clear from both models that the quantities of protein being provided are

limited by the quantities of the sulfur-containing amino acids. These acids, whether at their higher or lower ratio to the total weight of fully utilizable protein, limit the quantities of protein being provided. Should Nigeria desire larger quantities of protein of good nutritional quality (perhaps to offset inequalities in distribution or the extra needs caused by disease or stress), efficient programs to provide the extra protein must increase the quantities of the sulfur-containing amino acids. Simply increasing protein in general is not an efficient way to solve the problem.

From both models it appears that Nigeria can produce the protein needed if the protein produced is used with the maximum nutritional efficiency. As it stands, however, many Nigerians cannot afford enough protein to meet their nutritional needs. Consequently, protein is not being used with maximum nutritional efficiency from the standpoint of the country as a whole. If the problem of protein deficiency in consumption is to be solved, either more economical sources of protein or higher incomes for the masses of the people will be required.

The problem of providing economical protein is inseparable from the problem of providing all the nutrients in an economical fashion. The solution requires economical production patterns, effective use of trade, both within and outside the agricultural sector, improved methods of food preservation and transportation, and wise choices concerning food consumption patterns. With protein, however, it may be necessary to produce considerably larger quantities than would be needed if protein foods were distributed equally among the people, for the animal proteins are favored foods. They will be driven up in price by the consumption of the well-to-do unless they are produced in such quantity that there will be enough left over for the poor after the well-to-do have bought all they want.[3]

Finding economical sources of protein, as of calories and riboflavin, requires making effective use of trade. In both models it is more economical to purchase dried freshwater fish and white sugar than to produce all food within the Nigerian agricultural sector.

In both models meeting the riboflavin (and protein) needs of the rain forest areas is heavily dependent upon purchases of meats from the savanna areas. In the most efficient allocation of meat production from the activities included in this model, all the output of the two savanna areas goes to the rain forests or to the forest-savanna mosaic. Some meat is consumed within the savanna in these solutions, but it consists of domestic poultry, pigs, and bush meat, items that represent

important parts of the Nigerian diet, but are not represented by specific production activities in these models. The two savanna areas also consume the milk and milk products from the nomadic cattle herds, thus obtaining significant quantities of calories, riboflavin, calcium, and protein.

Grains from the north are important sources of calories and riboflavin for the moist forest areas in both models. Maize and rice are major trade items, not to mention enormous quantities of millet in Model Three, where millet consumption in Areas V and VI was allowed on a large scale.

Making effective use of internal trade is also esssential to the provision of higher incomes for the great mass of agricultural workers. Internal movements of yams or gari within the moist forest areas and the forest-savanna mosaic provide calories that permit the areas best suited to export production to expand their exports to levels that otherwise would not be nutritionally satisfactory. Red palm oil for the north provides economical vitamin A and calories, in both models, with groundnut oil from the savanna in turn providing calories for the intermediate savanna.

In general, higher incomes for agricultural workers require more effective use of agricultural land and labor, elimination of the obstacles marketing board policies have erected to expanding the production of export crops, and encouragement of a nutritionally efficient pattern of food production in general. An efficient organization of agriculture to meet nutritional needs simultaneously lowers the cost of adequate nutrition for the Nigerian people and increases their ability to buy the nutrients they need by releasing resources that can be used to expand export production.

The cost of adequate nutrition for Nigerians can be lowered by increasing the levels of those production activities that are most efficient producers of nutrition. Both models agree that these activities are generally to be found among the field crops, with yams, maize, and cocoyams appearing frequently in the lists of the most efficient crops for the various areas.[4] The animal industries are efficient sources of nutrition as long as they do not employ resources that have alternative uses. However, it would be nutritionally inefficient to expand the animal industries if to do so meant using land or labor that could have been employed in most of the food crop industries.

Increasing the land devoted to the most efficient food crops beyond 120 percent of 1963 levels can contribute to income at the same time

as it lowers the cost of an adequate diet. Increasing the levels of the most efficient nutrient producing activities can increase income from the export crops, either by reducing the quantities of groundnuts and red palm oil that must be eaten rather than exported, or by freeing land and labor for use in expanding the acreage of cocoa, groundnuts, or palm products. If we refuse to expand income production at the expense of the nutritional well-being of Nigerians, both models agree that the best way to bring about an increase in the aggregate income from agriculture is to expand the acreage of the most efficient food crops beyond 120 percent of 1963 levels. This would allow greater income expansion than would most direct increases in cash crop acreage that would be possible without the enabling adjustment in the production of food crops.

14

The Effects of Technical Improvement

Model Four assumes that traditional peasant techniques are employed for the principal crops outside the moist forest areas. In two respects the nutritional levels sought are more easily attained with this model than with its predecessor: The daily calcium allowance in the dry savanna is only 330 mg per capita instead of 392 mg, and the consumption of gathered and collected foods is assumed to be at 109.5 percent of 1963 levels rather than at 106.33 percent. In most other respects the desired nutritional levels are more difficult to attain: The maximum consumption limits for millet, sorghum, and four other foods are lower in certain areas; there are lower maximum production limits for the traditional animal industries outside the dry savanna; the amount of the sulfur-containing amino acids required in 100 g of fully utilizable protein is 4.2 rather than 3.424 g; the amino acid content ascribed to native white maize is lower; and, of course, yields from traditional methods are generally lower than those obtained with 1963 methods.

Of all these differences, the one that most affects the results obtained is the use of data representing traditional production methods for some crops in Model Four where data representative of 1963

methods were used in Model Three. Ten crops are affected: Seven of these are food crops, two (soybeans and groundnuts) are crops that can be used either for food or for export, and one is an income crop (cotton). In addition, Model Four introduces a new crop, the onion, grown by traditional methods in Areas I and II. The two crops that can be used either for food or export are, in fact, used almost entirely for food when the traditional methods are assumed to be in use.

Model Three shows larger yields in 13 food production activities involving the following five sole crops: bush maize, sorghum, sweet cassava, yams, and cowpeas. In addition, yields increase in three instances for the two crops that can be used either for food or export: soybeans and groundnuts. The 1963 data specify lower yields only for rice and cotton in the two savanna areas and for groundnuts in the dry savanna.[1] Table 29 has the details.

For mixed crops, the use of 1963 methods provides 11 instances of increased yields from six food crops: bush maize, millet, sorghum, sweet cassava, yams, and cowpeas. Groundnut yields rise in all three areas where they are grown. Decreases in yields appear only for cowpeas in the intermediate savanna and for cotton.

For both sole and mixed crops the data for 1963 methods usually involve higher labor usage per acre of land. This is because the 1963 data included time spent travelling to and from the fields as labor time and because producing and harvesting the larger outputs usually required that more labor be applied to a unit of land.

Nigerian Productive Capacity

The changes in yields associated with these adoptions of 1963 techniques have a dramatic effect upon Nigeria's capacity to feed its people adequately, even though the changes are assumed to have occurred only outside the moist forest areas. (As no data on traditional methods were available within the moist forest areas, Model Four assumes that 1963 methods are employed there.) While other differences between the models have some effects, those effects are dominated thoroughly by the changes in productive methods, except for the specific instances discussed in the last chapter.

Without the use of 1963 techniques for these ten crops,[2] it would have been physically impossible to meet the allowances specified for a population of 61 million at the level of use of gathered and collected foods that was assumed in Model Three. In several areas the desired

quantities of calories and riboflavin were simply unattainable under the conditions of the model. Only when the consumption of gathered and collected foods rises from 106.33 to essentially 109 percent of 1963 levels does it become possible to provide the nutrient amounts specified without the use of 1963 techniques outside the moist forest areas.

Assuming that gathered and collected foods are consumed at 109.5 percent of 1963 levels makes it feasible to retain the specified allowance levels while using traditional methods in these activities. Under these circumstances an efficient organization of Nigeria's agriculture could provide 95 percent (by value) of the nutrients needed by a rural and urban population of 61 million. The direct production of food would provide most of these nutrients, but some would be obtained by exchanging agricultural output for food produced outside the Nigerian agricultural sector. With 1963 methods, the agricultural sector could produce a total income equal to 104 percent of the value of the food needed for Nigeria. The progress already made by 1963 in adopting improved methods for these ten crops, and only outside the moist forest areas, was equivalent to at least a 9 percent increase in agricultural capacity or resources.

The total cost of food for Nigeria can be regarded as consisting of a physical component (the land and labor devoted to food production) and a monetary component (expenditures for food transportation services rendered within Nigeria, for fertilizers, and for food purchased from outside the agricultural sector of Nigeria). The physical component is equal to the whole of the land and labor resources of the agricultural sector, after adjustment for the monetary value of the revenues earned from the portion of those resources devoted to income producing activities. The physical component unquestionably represents the major part of the food cost.

The physical resources devoted to agriculture remain essentially the same in both models, except that Model Four assumes the use of about 3 percent more resources in the form of gathered and collected foods. However, the fraction of total physical resources devoted to food production diminishes with the adoption of improved methods, as a larger volume of the total stock of resources is devoted to income producing activities rather than to the production of food. The monetary component of the cost of food is affected directly by changes in expenditures on food from outside the agricultural sector, on fertilizers, or on transportation for food within Nigeria.

If R stands for the total quantity of resources devoted to Nigerian agriculture, and if this is regarded as constant between the two models, the total necessary cost of the food needed for 61 million people can be stated as $R + 6.23$ billion shillings when traditional techniques are used outside the moist forest areas and as $R - 1.01$ billion shillings when 1963 techniques are used everywhere (Table 50). The improved methods that already had been adopted by 1963 for these ten crops lowered the aggregate necessary cost of Nigeria's food requirements by 7.24 billion shillings,[3] or 119s per capita.

Table 50. *Aggregate Cost of Food, in Millions of Shillings*

Components	*Using some traditional methods*	*Using 1963 methods entirely*
Physical component	R	R
Monetary component		
Food purchased from outside Nigerian agriculture	6,822	444
Transportation of food produced within Nigeria	736	1,162
Fertilizers	18	3
Less:		
Revenues earned from income producing activities (adjustment to physical component)	—1,348	—2,622
Aggregate cost of food	$R + 6{,}231$[a]	$R - 1{,}012$[a]

[a] Discrepancy between sum and parts caused by rounding error.

The principal saving was in the cost of food purchased from outside the Nigerian agricultural sector. This declined by 6.4 billion shillings (93.5 percent), to only 444 million shillings. With the improved methods it was no longer efficient to buy wheat, wheat flour, and European-style beer in order to help meet the requirements for calories, riboflavin, and the customary consumption level for alcoholic beverages. Instead of 112s per capita spent on foods from outside the Nigerian agricultural sector, 7s sufficed.

Table 50 shows a 60 percent increase in expenditures for the internal transportation of food grown within Nigeria when the new methods were adopted, but this is more than accounted for by the cost of the extraordinary volume of millet shipments that this model permitted. The increase cannot be attributed to changes in the production methods employed.

The second important factor reducing the cost of food for Nigeria was the reduction in the quantity of agricultural resources that had to be used for food production. The aggregate income that Nigeria can earn without sacrificing the population's nutritional well-being depends heavily on the techniques employed in food production. When traditional methods were employed outside the moist forest areas for these ten crops, the income producing activities of Nigerian agriculture could gross only 1.348 billion shillings. When 1963 methods were used everywhere, those income producing activities could earn twice as much: 2.622 billion shillings. That is, the value of the resources *not* devoted to food production had doubled.

Because part of the income earned by agriculture may be exchanged for food, fertilizers, or transportation services produced outside the Nigerian agricultural sector, in order to determine the net portion of *R* that can be devoted to income production without sacrificing nutritional well-being one must subtract expenditures for fertilizers, transportation, and food purchased from outside the agricultural sector from the total gross revenues earned from income producing activities. This done, Table 50 shows that the resources of the agricultural sector must be supplemented by a net expenditure of 6.23 billion shillings if people are to be fed adequately when traditional methods are being used outside the moist forest areas, but resources worth a net of 1.01 billion shillings annually can be spared for the production of income when 1963 methods are used. Thus the aggregate cost of food is 6.2 billion shillings *more* than the value of all agricultural resources when some traditional methods are being used, but with 1963 methods the amount is reduced to 1.0 billion shillings *less* than the value of all agricultural resources.

Costs of Individual Nutrients

When traditional methods are used for the principal crops outside the most forest areas the (marginal) costs are very high for the nutrients that are most scarce economically.[4] At these low levels of nutrient productivity the resources that must be given up in order to add one person's average daily calorie allowance to the total quantity of calories available in the area have an earning power of 6.4s in Areas II, III, and VI, while the resources that must be sacrificed to add one person's average daily riboflavin allowance in Areas IV and V have an earning power of 7.1s and 9.7s, respectively (Table 31). Adopting

1963 techniques lowers the costs to between one-seventh and one-twentieth of these levels (Table 8). In all areas but the dry savanna the minimum costs of the average daily allowances for all nutrients fall to between 10 and 20 percent of what their levels were when some traditional methods were employed (Table 33).[5]

Adopting 1963 techniques does not, however, alter the basic nutritional situation. Reaching the calorie allowances remains costly in every area,[6] and reaching the riboflavin allowances is costly in the rain forest areas.[7] Iron, which involves a moderate cost in the forest-savanna mosaic when traditional methods are being used, ceases to be scarce when 1963 methods are adopted. Vitamin A and calcium involve moderate cost in one or more areas at either level of production technique.

At either technical level more than enough protein is provided in each area whenever the solution provides the specified quantities of calories and riboflavin, as well as the other scarce nutrients, vitamin A, calcium, and iron.

With the scarce nutrients as costly as they are when traditional methods are in use, those foods that provide nutrients worth more than the cost of the food often provide quite large surpluses (Table 32). Adopting 1963 levels of productivity reduces the advantage from concentrating consumption on foods that provide nutrients of extra value. (See Table 9.)

At lower levels of food productivity it is much more important (indeed, perhaps necessary) to obtain food from outside the agricultural sector. Five of the items on the list of foods having superior nutritional efficiency (sugar, wheat, wheat flour, European-style beer, and dried freshwater fish) are obtained from outside the sector. With the adoption of 1963 techniques these disappear from the list.[8]

At both levels of technique the foods yielding the largest nutritional surpluses are meats in the central and eastern moist forests.

Internal Trade

The major difference between the optimal food transportation patterns at different levels of productivity is the result of a specific change in the model that does not relate to differences in production techniques. Two billion pounds of millet that move into the eastern moist forest in the solution representing 1963 technical levels cannot do so in the solution using traditional methods because the latter limits millet consumption in Area V to about 2 percent of the maximum allowed when 1963 methods were employed.

The total volume of internal trade in food is not very different at the two technical levels; adopting 1963 methods reduces the figure from 9.2 to 8 billion pounds. The relatively stable total conceals a marked internal restructuring, however, for with the adoption of 1963 techniques outside the moist forest areas food purchases increase in every area except the eastern moist forest, while food purchases there are more than halved, decreasing from 5.5 to 2.5 billion pounds. (Compare Tables 39 and 14.) When the savanna areas use traditional techniques, the eastern moist forest buys 4.8 billion pounds of yams from Areas IV and VI; when the savanna areas use 1963 techniques, Area V buys 2 billion pounds of millet from the dry savanna, but no yams. It may be that this change reflects primarily the high level of millet consumption allowed in the model that uses 1963 techniques. (A pound of millet provides over three times as much food energy and over five times as much riboflavin as a pound of yams.)

With traditional methods employed outside the moist forest areas, the major determinants of internal trade in food are the need for riboflavin for the central and eastern moist forests and calories for the intermediate savanna, the western moist forest, and the forest-savanna mosaic. In addition, the two savanna areas require vitamin A. With the adoption of 1963 methods, large differences among the costs of calories disappear, and riboflavin becomes significant in all three of the moist forest areas. At both technical levels the major movements are of meats and cereals southward from the savanna areas, red palm oil northward from the moist forest areas,[9] and yams or gari from Areas VI and IV into Area III and, when traditional methods are being employed in the north, into Area V. None of the meat produced by the activities within the model is consumed within the two savanna areas at either level of productivity. When traditional methods are used in the north, groundnuts for food also move south in significant quantity. With the adoption of improved methods this trade nearly disappears, although the southward movement of groundnut oil persists at about the same level. At the higher levels of food productivity implied by 1963 methods, few groundnuts need be used for food in the south, so they are available for export.

Cash Crop Production

An agriculture that can produce only 1.3 billion shillings of income when traditional techniques are used for the principal crops outside the moist forest areas can double that by improving its techniques to the levels in use in 1963. In the process it can expand its net foreign

exchange earnings nearly eight-fold, from 360 million to 2.8 billion shillings. (Compare Tables 37 and 10.) Adopting improved methods approximately doubles the income earned by the dry savanna and the western and eastern moist forests and permits the intermediate savanna, which produces no income crops when traditional methods are employed, to earn more than 100 million shillings.

It is primarily increased productivity in food production that makes these gains possible, not improved yields in cash crop production. The only income crops for which there were data on changes in methods are groundnuts, soybeans, and cotton, and those data showed the yields of cotton everywhere and of sole groundnuts in the dry savanna to have *decreased* when 1963 methods were adopted. The change in income earned is accounted for almost entirely by the facts that with increased food crop productivity red palm oil and groundnuts can be exported that formerly had to be used for food, oil palm production in the eastern moist forest can expand by one-third, and cocoa production in the western moist forest can expand to more than double the acreage that could be allowed when nutritional needs were harder to satisfy.[10] The same mechanism makes the intermediate savanna an income producing area. Resources can be spared for cotton and tobacco production (even though cotton yields are lower, according to the data available) when food crop methods are improved.

When improved methods are used in food production, sufficient resources can be spared for income production to permit almost every cash crop production activity to be at its maximum level. The only exceptions are cotton grown as a mixed crop in the two savanna areas and rubber in the central and eastern moist forests. When traditional methods are in use, the resources available after nutritional needs are satisfied permit no cash crop except the kola nut to be at its maximum level in every area in which that crop can be produced. In no area is rubber at its maximum limit. Cocoa and the oil palm are below their maxima in the major production areas. (See Table 41.) Furthermore, the acreage devoted to oil palm, groundnuts, and soybeans is as large as it is only because these crops are being used primarily for food rather than income.

Efficient Food Production Activities

With given resources and a given technical level, increasing agricultural income without sacrificing Nigerian nutritional well-being re-

quires either (1) shifting resources from less productive to more productive income activities, so that the same resources can yield more income, or (2) shifting resources from less efficient to more efficient food production activities, so that some resources can be added to those already in use for income production. This study compares the two approaches by measuring the gains to be had by expanding a specific activity beyond 120 percent of its level in 1963.

At both technical levels it is true that greater gains generally are to be had by expanding any of a number of food crops beyond 120 percent of the 1963 level than by expanding the income crops. Oil palm in Areas VI and III may appear to be an exception when traditional methods are being used, but under these circumstances all red palm oil is being used for food. When 1963 methods are employed, expanding oil palm in Area VI or tobacco would yield greater gains than most food crops, but even these are surpassed by two of the food crops. However, because adopting 1963 methods increases food productivity generally, use of these methods drastically reduces the margin of superiority for expanding food crops instead of income activities.

Adopting improved methods in the two savanna areas increases the number of crops in those areas that will yield large surpluses if expanded beyond 120 percent of their 1963 levels (compare Tables 20 and 45). This is to be expected. In the eastern moist forests, however, the improvements in the savanna have the opposite effect. Instead of having five cropping activities on the list of activities with large surpluses, this area has none when 1963 methods are in use everywhere. This change, however, cannot be attributed wholly to increased productivity in the savanna areas. In the model that used 1963 techniques everywhere, the eastern moist forest was allowed to consume large quantities of millet from the dry savanna. It may be this special consumption opportunity rather than differences in productivity that makes the eastern moist forest so unpromising an area in which to expand food production when 1963 techniques are in use everywhere.

A similar phenomenon occurs in the forest-savanna mosaic, which is somewhat surprising. This area has five cropping activities among the 27 with the largest surpluses when traditional techniques are being employed for some of its activities and only two when 1963 techniques are in use for all activities. Here, as in the eastern moist forest, the model that uses 1963 methods entirely also provides the opportunity to consume unusually large quantities of millet from the dry

savanna. This alternative reduces the attractiveness of food production within the forest-savanna mosaic.

This same reduced attractiveness of food production in Area VI brings about a small reduction in the quantity of arable land in use there. The result is that land-use in the area no longer has a scarcity-value. This, in turn, makes commercial beef production an efficient enterprise (although not as profitable an enterprise as most of the field crops grown in the area). Without the improved access to nutrients from field crops, none of the modern animal activities would have been nutritionally efficient.

Adopting 1963 methods outside the moist forest areas has no major effect on the kinds of crops that are especially efficient producers of nutrients within the moist forest areas. The number of crops appearing in the list of the 27 yielding nutrients with the largest surplus value diminishes as crops from the savanna areas move into the list, but the crops continue to be maize, yams, and cocoyams, except that mixed rice is added in the central moist forest.

In the intermediate savanna, adopting 1963 methods adds five entries to the list of crops providing nutrients with the largest surplus values. These are maize, sorghum, and yams as sole crops and maize and melon seed as mixed crops. Nothing can be said about the effect of improved techniques in the dry savanna, for the unnecessarily high calcium requirement included with the model based on 1963 techniques is sufficient to dominate the influence of changes in productivity.

Resource Use

The data generally record higher labor input per acre when 1963 rather than traditional techniques are employed. This is so partly because the data available regarding traditional methods do not include an allowance for the time spent travelling between field and home or field and field, while the data for 1963 methods do include such an allowance. In addition, greater yields require more labor at harvest time, and obtaining greater yields may require more careful land preparation, better weeding, and other labor-using practices associated with insect and disease control or with the application of fertilizers. The improved practices in use in 1963 generally were not practices that substituted animal or machine power for labor, although they did include the use of improved varieties.[11]

Given that the data showed higher labor inputs per acre, it is not surprising that the total quantity of May–June labor employed rises in the two savanna areas and the forest-savanna mosaic when 1963 methods are adopted there. Whether the new set of activities was in fact more labor intensive cannot be determined with these data. In the central moist forest, however, where the same phenomenon occurs, the data did not change, so the only factor operating is a shift in the production pattern.

In the eastern and western moist forests there is a shift to less labor-intensive activities. Labor use in May and June diminishes when 1963 methods are adopted outside the moist forest areas. Greater food productivity outside the forest areas means that more land in the eastern and western areas can be devoted to oil palm and cocoa. These tree crops use relatively less May–June labor per acre than do most food crops.

These shifts in labor usage are associated with changes in the pattern of resource earnings for land and May–June labor. Rather than land being the only one of these two factors with positive resource earnings, as was the case in Areas I, II, IV, and VI when traditional methods were in use outside the moist forest areas, May–June labor becomes the only factor with positive resource earnings in Areas I and VI when 1963 methods are used everywhere; both factors have positive resource earnings in Areas II and IV. In Areas III and V, however, land is the only factor with positive resource earnings when 1963 methods are used everywhere, although labor had positive resource earnings in both areas when traditional methods were being used in the savanna areas, and in Area III it was the only factor receiving positive resource earnings.

Summary

The improvements in production technique already adopted by 1963 for ten crops outside the moist forest areas were equivalent to reducing the least aggregate cost of feeding 61 million people by 7.24 billion shillings, or 119s per capita. Most of this saving took the form of a reduction in dependence upon sources outside the Nigerian agricultural sector. Optimal expenditures for food from outside decreased by 6.4 billion shillings.

Adoption of these improved techniques increased the total productive capacity of Nigerian agriculture by 9 percent. With the methods

in use in 1963, a total agricultural income equal to 104 percent of the value of the nutrients needed for 61 million people could be produced; when traditional methods were employed for these ten crops the maximum agricultural output attainable under the conditions of the model amounted to only 95 percent of the value of those nutrients.

A 9 percent increase in total agricultural capacity may not seem startling, but remember that the Nigerian population was being equally well fed in the two situations, so the whole of the increase in capacity translates into an increase in income production, that is, production for export or for sale for nonfood purposes within Nigeria. The potential for production of income crops doubled as a result of the adoption of the improved methods, increasing from 1.3 to 2.6 billion shillings. Foreign exchange earnings increased nearly eightfold, from 360 million to 2.8 billion shillings. Increased productivity in food-growing made this possible. With additional quantities of food available from other crops, red palm oil and groundnuts could be exported that formerly had to be used as food, oil palm production in the eastern moist forest could expand by one-third, and cocoa production in the western moist forest could more than double. The income producing capacity of a country that wishes its people to be adequately fed depends very closely upon the agricultural productivity of its food growing activities.

15

Policy Recommendations

This volume studies the optimal organization of a production system operating at given technical levels. It determines a pattern of resource use capable of providing specified levels of nutrition for the Nigerian population in an efficient manner, a pattern that maximizes the income that can be earned by the agricultural sector without sacrificing the nutritional well-being of the Nigerian people. Significant gains in income or nutritional status are possible, with no changes in production techniques, if Nigeria makes a more effective selection of the productive activities employed.

Additional possibilities for growth in income or in nutritional capability are created when production techniques improve. A secondary purpose of this volume, therefore, is to study the effects of changes in the techniques employed in a part of the productive system upon productive capacity and the optimal organization of that system. Only by efficient adaptation of production and consumption patterns can improvements in production methods have their full effects on aggregate production capacity.

This study has identified the nutrients that are economically scarce or "costly" in Nigeria (nutrients that only can be provided in adequate quantities by giving up opportunities for earning cash income), the activities that are particularly efficient in the production of these

costly nutrients, and patterns of trade that contribute to the provision of these nutrients in an efficient way. Analysis of the results suggest numerous policies that can improve the level of Nigerian nutrition or increase the income earned from agriculture.

One warning is needed, however. To the extent that the efficient production patterns obtained in this solution depend upon an increased volume of internal trade, moving toward such patterns may mean moving away from a subsistence economy, which the farmer understands, to a market economy, which he does not. While such a transition will come (and must come, if incomes are to reach their potential levels), attempts to hasten the process should be undertaken only with full awareness of the risks involved.

Summary of Results

The basic pattern of geographical specialization now followed in Nigeria is sound either from the standpoint of nutrition or of income. The three moist forest areas and the dry savanna are efficient sources of production for export, but they need assistance with their nutritional needs from the intermediate savanna and the forest-savanna mosaic. The dry savanna plays a dual role, partly as producer of cash crops and partly as producer of food for the rain forest zone.

The traditional agricultural activities of Nigeria are generally efficient sources of income and/or nutrition. Such major crops as groundnuts from the dry savanna in the north, cocoa from the western moist forest, and palm products from the eastern moist forest appear as leading sources of food or income in the optimal solutions obtained from the models used in this study. The traditional animal industries are efficient sources of nutrition as long as they use resources that have little value in alternative employments. Carried on at the levels at which they appear in these solutions, these industries provide, in conjunction with other foods, more than sufficient protein to meet the levels of allowances specified in this analysis. The quality of the protein in the diet as a whole is satisfactory.

The traditional animal industries appear at the maximum levels permitted in the problem. In the dry savanna they are limited by the amount of pasture available. Elsewhere, only the individual output limits specified in the model restrict their expansion. Further expansion, however, would be much less productive in terms of either income or nutrition than would expansion of any of a large number of

food crops. Given this volume of output from the traditional sector, the modern "commercial" animal industries are inefficient users of resources and are not worth carrying on at any level, with the exception of commercial beef production in the forest-savanna mosaic.

In crop production, however, modern methods can do much to improve nutritional productivity. Food crop activities with yields in the range that represents the use of improved practices are prominent among the activities that provide nutrients having the greatest excess of value per acre over the value of the resources they require.[1]

The Nutritional Problem

The principal nutritional problems in Nigeria appear to be protein-calorie malnutrition, riboflavin deficiencies, anemia, low or borderline intakes of thiamin and calcium, and blindness from vitamin A deficiency. Nutritional deficiencies may exist because of problems in production, distribution (either physical distribution or distribution of the means of paying for food), or consumption. A country may be physically incapable of producing or otherwise obtaining enough of a nutrient to meet the needs of the people, no matter how efficiently they use what is produced. Even if physical production capacity is large enough, the nutrient may be too costly, so a population with low incomes may not choose to consume it in adequate quantities. In still other cases a particular nutrient may not be costly to produce in amounts that would be adequate if it were used efficiently, but it may be made costly because the well-to-do purchase more than is required for their nutritional needs, driving up the price for all.

In the first two cases the nutritional deficiency stems from production problems; in the latter case from income distribution problems. Deficiencies also may appear because of storage and transportation difficulties: The food that is produced cannot be placed in the hands of the consumers who need it at the right place or the right time. Additional problems may appear in the realm of consumption. The housewife may not know how to choose a satisfactory diet from the foods available; her family may not be willing to eat what is nutritionally sound; her cooking methods may destroy a large portion of the nutrients in the food. Finally, nutritional deficiencies may occur because diseases, parasitic infestations, and stress increase the needs for particular nutrients above normal levels.

This study is concerned primarily with those aspects of the nutri-

tional problem that exist because of limitations on productive capacity. Its purpose is to remove the production problem as a cause of dificiency, to the extent possible. (Of course, deficiencies still will exist that originate outside the sphere of production.) This study asks whether Nigeria has the capacity to produce the per capita quantities of the various nutrients that are commonly recommended. If the capacity exists, how must agricultural production be organized in order to provide those allowances in the most economical way? Only by so doing can nutrients be made available to the maximum number of the poor. Providing nutrients in the most economical way also means providing them in the most economical amounts, for if agriculture is asked to supply more than is necessary of one or more nutrients, the cost of providing that nutrient may rise for all consumers.

In concentrating on the production problem the assumption is made that consumers eat those familiar foods that are most efficient as sources of nutrients (subject to the habitual consumption limits imposed in the model). Thus our solutions provide an efficient pattern of consumption as well as of production and internal trade. It is assumed, moreover, that food is distributed in accordance with the nutritional needs of the population, that there is no loss of nutrients in cooking, that wastes from food cooked but not eaten can be neglected, and that diseases, parasites, and stress do not increase nutrient needs above normal levels. In short, important aspects of the larger nutritional problem, including the important problem of the distribution of income, lie outside the scope of the study.

Also outside that scope is the question of whether those who need food will be able to pay for it, even when adequate quantities of food have been produced. Given the existing distribution of income within Nigeria, as in any of the developing countries, a considerable fraction of the population is likely to be unable to afford an adequate diet. Nor is there any apparent reason to believe that adopting an agricultural production pattern that is more efficient in the production of nutrients would lead to a distinctively different distribution of income, although it might improve the nutritional well-being of that portion of the population that grows most of its own food. However, whatever the income barriers may be, their effect is minimized when least-cost patterns of production and consumption are employed. Moreover, the production patterns obtained in these solutions maximize the income that can be earned from the agricultural resources available without sacrificing the nutritional well-being of the population. The larger the

income that can be earned after nutritional needs have been met, the less likely it is that needs or desires for housing, clothing, education, or other nonfood items of consumption will create a situation in which people feel that they cannot afford adequate nutrition.

Finally, in the Nigerian economy most food still is grown by the family that consumes it. To the extent that nutritional needs are met by subsistence farming, there can be no shortage of the power to purchase (consume) that which is produced, but there can be the decision to produce less food than the family needs in order to produce larger quantities of the income crops, where other forms of income are preferred to adequate nutrition. The production patterns suggested in these solutions enable the farmer to improve the nutritional levels attainable from a given set of resources, where those levels have been inadequate, and to earn the maximum amount available from the production of income crops with whatever resources are left over. The purchase of food from other producers is called for only where nutrients can be obtained more efficiently in this way than by direct production.

The Scarce Nutrients—and Protein

Of the fourteen nutrients considered in this study, the allowances for four are more difficult to attain than those for any of the others. For two of the nutrients, under the conditions of the model it is beyond the physical capacity of the country to produce the quantities that originally were specified by the allowances. Even assuming the most efficient use of nutrients possible, the limitations of Nigerian productive capacity make commonly recommended levels of these two allowances impossible to attain.[2]

The allowances used here for these two nutrients, 1.02 mg of riboflavin daily per capita and 389 mg of calcium, are near the upper boundary of the attainable range for Nigeria, with the agricultural techniques in use in 1963. For the calcium allowance, even this level is unduly high for the dry savanna. It can be attained, but only at considerable sacrifice of potential income and some risk of unnecessary distortion of the production pattern in the area. To meet this calcium allowance there it is necessary to select food crops primarily on the basis of a high ratio of calcium to calories. As there is little or no evidence that calcium deficiency is in fact a problem in Nigeria, in Model Four this allowance was lowered to 330 mg daily per capita (but only

in the dry savanna). At this level the allowance is met quite easily. Indeed, in Model Four calcium remains costly only in the dry savanna, and there its cost is low.

Two food elements other than riboflavin and calcium are more difficult to provide in commonly recommended amounts than any of the others. These are calories and vitamin A. The scarce nutrients, therefore, under Nigerian conditions, are these four: calories, riboflavin, calcium, and vitamin A. Of these the calorie allowance is in general the most costly to meet. Even with the most efficient utilization of Nigeria's food supplies, satisfying these four allowances requires that resources be diverted to food production that otherwise could be used for the production of income. These nutrients can be provided in the amounts specified by the present levels of these allowances, but they are economically scarce, that is, costly. The production component of the nutritional problem is the problem of how to produce adequate quantities of these four nutrients efficiently. Solving this problem solves the production problem for all the other nutrients, for the organization of production that efficiently provides adequate quantities of these four also provides more than enough of each of the other nutrients.

It is noteworthy that protein is not one of the critical nutrients.[3] No extra cost need be incurred to meet the protein allowances when the riboflavin, calorie, and calcium allowances for the moist forest areas are satisfied in an economical way. The foods that provide these three nutrients also provide sufficient animal and vegetable protein to make a diet that is sufficient in protein quantity and adequate in protein quality, given the level of efficiency in consumption that is assumed here. To obtain this result, however, all of the beef, goat meat, and mutton produced in the two savanna areas moves southward, to be consumed where it is most needed.

With only four economically scarce nutrients (and not more than three in any given area—see Table 8), Idusogie has suggested that nutritional planners may find that they need to look at only two or three food elements in developing adequate low-cost diets for any given area. Calories will be one, with riboflavin another in the moist forest areas. Providing adequate quantities of these two will go a long way toward meeting the desired goals for the others. An efficient strategy for manual diet planning in the moist forest areas, for example, could be to provide the quantity of riboflavin needed and then add the re-

maining calories required, before checking with respect to any of the other nutrients to be considered.

Calories

At the allowance levels now being used, Nigeria's most serious production problem is how to provide sufficient food energy at low cost. The most costly allowance to satisfy, in most parts of Nigeria, is that for calories. Meeting it accounts for between 50 and 98 percent of the total cost of the least-cost diet in most areas.

Fortunately, agricultural research and development expenditures already are devoted to a large extent to efforts to obtain more economical sources of calories, although they usually are not explained in those terms. Almost any successful activity directed toward increasing the yields of food crops lowers the cost of providing calories.

These activities should be supplemented by encouraging expanded production in each area of the crops that this study has shown to be outstanding in nutritional efficiency in that area. These will be economical sources of calories as well as of the other nutrients that are costly in that area. Similarly, the consumption of nutritionally efficient foods should be encouraged, especially those above the minimum level of nutritional efficiency (those that provide nutrients worth more than the cost of the food).

Improvements in storage, processing, transportation, and marketing would improve the caloric situation in all parts of Nigeria, but especially in the food-importing moist forest areas.

Seeking economical sources of calories is somewhat more important in the western moist forest and the intermediate savanna areas than in the others. It is in those two that the allowance is most costly to obtain, so the benefits from improved sources of calories will be greatest.

Expanding the production of efficient sources of calories means, among other things, encouraging the production of crops like maize, yams, cocoyams, and sweet potatoes in the appropriate areas.[4] It may not be possible, however, to make effective use of expanded maize production in the south until solutions are found for the difficult storage problems that now limit its use.

Encouraging the production of yams, cocoyams, and sweet potatoes may seem unwise to some, for the incidence of kwashiorkor often has been related to the excessive consumption of yams and cocoyams. Gurney has pointed out that yams, cocoyams, and sweet potatoes contain less than 2 percent protein by weight and more than 61 percent

water. For infants and young children the consumption of these foods is so limited by their bulk that they may contribute to malnutrition. Gurney fears that increasing the production of yams, cocoyams, and sweet potatoes in Nigeria may increase protein-calorie malnutrition among young children.[5] Certainly the young child should not have too many of these tubers. For that matter, they are efficient for adults only up to certain levels of consumption. Gurney's warnings illustrate the dangers that can arise from misuse of these recommendations.

The recommendations concern the diets of Nigerians as a group, that is, an average family or hypothetical average Nigerian, presumably an adult or teenager. They assert that for the average family the cost of attaining the nutrient levels specified could have been lowered in certain areas by consuming more yams, cocoyams, or sweet potatoes than were eaten in 1963. Obviously this does not mean consuming only yams, cocoyams, or sweet potatoes, nor does it mean consuming them in quantities that will provide more calories than are called for in the diet.

It was not the purpose of this study to provide recommendations concerning diets for the very young. Nor were restrictions imposed upon the diet for the family as a whole that would make that diet suitable for infants and young children. To have done so would have raised the cost quite unreasonably.[6] The consumption patterns developed herein are appropriate for an average family as a whole, but individuals within the family need not—indeed, should not—consume exactly the same things. Adults, by consuming relatively low-quality sources of protein, can release the more concentrated ones for the use of the young child.[7]

The more fundamental question concerns the proper role of fleshy tubers in the family diet. To say that yams, cocoyams, and sweet potatoes are efficient sources of nutrients is not to say that diets should be composed wholly of these foods. They are efficient *in combination* with other foods; those combinations, which this study determines, provide the protein needed without providing too many calories, even though these particular foods are high in calories. It is the *diet* that must be properly balanced, not individual foods.

Yams, cocoyams, and sweet potatoes are economical primarily *because* they are low-cost sources of calories. In Nigeria, as in much of the world, providing calories is a major part of the nutritional problem. Low caloric intake even can be the cause of protein deficiency, although protein intake itself otherwise would be satisfactory. As P.

V. Sukhatme has said: "Emphasis on increasing consumption of protein regardless of energy content of the diet may not go far toward the solution of the protein problem. For even when the diet provides an adequate amount of protein, symptoms of protein deficiency may still arise if it does not also provide adequate calories, since under these circumstances protein is utilized at reduced efficiency."[8]

In India, Sukhatme provides evidence that a significant fraction of protein deficiency cases results indirectly from low caloric intake.[9] The same mechanism could operate in Nigeria if too much emphasis on protein production were to lead to neglect of the economical sources of calories.

Reducing yam and cocoyam production in favor of crops that provide relatively more protein would mean that an acreage just sufficient to feed a family at the levels specified in this model no longer would suffice. The nutrients that a half-acre of land would produce if used for yams would require more land if some other crops were grown. If the farmer's land and labor had been just sufficient to provide the nutrients needed by his family, replacing some of his yams by a crop yielding nutrients of less net value per acre would mean that some of the nutrients he formerly could afford now would be out of reach. His new crop mix might provide a diet with a higher *ratio* of protein to calories, but there would not be enough calories and perhaps not enough protein either. The new diet might contain "nutritionally superior" foods, yet the family would go hungry. How much better is a "better" food if there is not enough of it?

The judgment that the starchy tubers are nutritionally inferior foods is correct in one context, but quite incorrect in another. Whether or not a food is inferior depends upon the problem to be solved. If adequate diets must be found where labor or land limit the quantities of food that can be produced, two fallacies must be avoided: (1) seeking the necessary balance among the nutrients in a particular food rather than in the diet as a whole and (2) seeking highly nutritious *foods* when what is needed are highly nutritious *uses of land or labor.* What must be achieved is a high nutrient yield per unit of land (labor). This objective may be attainable by producing high-yielding crops of moderate nutritional value as foods when it cannot be attained by producing crops that have high nutrient value per pound, but low yields.

Yams are a high-yielding crop in terms of calories (even though they also provide a great deal of water). The calories are essential to

the diet and must be obtained from somewhere. If they are not obtained from the cheapest sources, resources must be used for the production or purchase of calories that otherwise could have been used for other purposes, including the production or purchase of protein. In all probability, the starchy tubers became staples in West African diets because they were economical sources of nutrients—perhaps not of all nutrients, but of essential nutrients without which people could not survive.

Such tubers need supplementation, but efficient dietary adaptation will not be obtained by denying the proper role that the fleshy tubers can play. Underusing them can divert income into calorie production that would have been more wisely used in adding protein to the diet. If part of the caloric content of the diet comes from yams and cocoyams, there may be enough resources left over to produce something that can be traded for meat, fish, or millet.

Where limitations on income or production capacity contribute to malnutrition, problems of interpretation arise that may be unfamiliar to nutritionists. The problem is one of economizing as well as one of nutrition. From the viewpoint of the nutritionist, whether a food is nutritious is a physiological matter; it has nothing to do with market prices or production costs. On the other hand, whether a food is economically efficient as a source of nutrients involves both the physiological attributes of the food and questions of market price or production cost. The nutritionist's evaluation of the food, in its pure form, applies to a world in which all foods are free. When costs must be taken into account, different action programs may be needed. Some nutritionists may feel that the production of yams, cocoyams, and so forth, should not be encouraged because depending too heavily on them would mean a diet deficient in protein. In fact, for low-income people use of these tubers should be encouraged, *in proper combination with other foods*, because eating enough of them makes it possible, even with a low income, to provide all the calories one needs and still be able to afford the protein and other nutrients required.

Riboflavin

The riboflavin allowance used in this study is a modest one. The figure of 1.02 mg daily per capita is 20 percent below the intake recommended by the 1965 Joint FAO/WHO Expert Group.[10] The recommended intake, .55 mg per 1,000 calories, works out to 1.246 mg per

day for the average caloric level used in this study (2,266 k calories). It is intended to provide sufficient riboflavin for the maintenance of health in nearly all people.[11] Our level corresponds to the .44 mg per 1,000 calories (.997 mg per day at the caloric level used here) that the Expert Group considered adequate for the needs of an average adult, without allowance for individual variation. At intake levels much below .44 mg per 1,000 calories, marked decreases in riboflavin excretion occur.[12]

In three areas of Nigeria our modest allowance can be satisfied without adding to the cost of the diet, but in the moist forest areas the cost of meeting it represents from 29 to 63 percent of the total cost of the least-cost diet. Because of its importance in these three ar-
trients in the country. The necessity of satisfying the allowances in
eas, riboflavin becomes one of the two most important controlling nu-
these areas has considerable effect on the patterns of production and consumption provided by these solutions.

As was noted, nutritionists differ as to the prevalence of riboflavin deficiencies in Nigeria. The evidence of these studies, although they deal with the production capacity rather than with nutrient intake, supports the findings of low intake levels. Even with the most efficient use of the food produced, Nigeria's productive capacity will not permit intake levels much in excess of our recommended allowance, 1.02 mg per day per person. As actual production is likely to be below capacity, and since the nutrient is not, in fact, distributed geographically or among persons in accordance with nutritional needs, numerous cases of low intake levels are to be expected.

Nutritionists also may disagree as to whether the allowance proposed in these studies is worth attaining at the economic cost involved. Gurney, for example, believes that deficiencies in riboflavin intake do little physiological damage.[13] The ultimate judgment as to the effect of a given nutritional deficiency upon human well-being must be made by the nutritionist, but to decide whether that effect must be borne or should be eliminated by a higher level of nutrient intake requires knowledge of the cost of providing the nutrient required. This study, for the first time, measures the necessary cost to a country of attaining any specified level of nutrient availability.

Some nutritionists may feel, as does Gurney, that the riboflavin allowances for the moist forest areas have too much influence upon the patterns recommended in these solutions. Gurney does not seem to be disturbed by the sacrifice of income required to provide a diet that

meets the riboflavin allowance specified here;[14] what he does fear is that the riboflavin allowance assumes too much importance in these calculations, when it is the problem of protein-calorie malnutrition that matters.[15]

Under the circumstances, it is natural to feel that a solution heavily influenced by the riboflavin allowance must be misleading. However, as already has been seen, the problem of producing sufficient calories is dealt with squarely in these solutions. As for producing enough protein, that problem has not been overlooked; it has been solved. With the method used here, no nutrient for which an allowance has been specified can be overlooked. Any solution must satisfy all nutrient requirements. For some allowances, this is easily accomplished, but for others it is more difficult.

The nutrients that are most vital to human well-being are not necessarily those that are the most difficult or costly to produce in the quantities commonly recommended. The productive powers of a country may be such that the most vital nutrients can be produced at recommended levels more readily than can some of the less important ones. In such a case, the economizing process, in order to produce the desired quantities of *all* nutrients, may turn heavily upon some nutrients of lesser physiological importance. The costs that must be taken into account in order to attain the complete set of goals in an efficient way are costs of *production*, not measures of the *nutritional* importance of particular goals.

That is what has happened here. Nigeria's productive powers satisfy a reference protein allowance of 34.4 g per day per person more easily than our riboflavin allowance of 1.02 mg, even though our protein allowance is 20 percent above the FAO figure of average requirements,[16] while the riboflavin allowance is only at the average level. As Gurney has pointed out, protein and riboflavin tend to occur in the same foods,[17] so it is not surprising that the productive organization that provides adequate quantities of riboflavin also provides the protein desired.

In the solution for Model Three, the daily protein intake per capita ranges from 47 g in the western moist forest to 74 g in the dry savanna. If the quality is high enough, these quantities are adequate.

The quality, measured by the chemical score, *is* high enough. In every area it is more than is necessary to yield the average reference protein allowance of 34.4 g. In the western moist forest the allowance could be met at a chemical score of 80; the score of the protein pro-

vided by the solution is 83, three percentage points more. In other areas the margin is larger, ranging up to 33 percentage points over the minimum score for adequacy.

The riboflavin level used here imposes no sacrifice of nutritional goals, but in the three moist forest areas there is a sacrifice of income. Lowering the allowance by one-fifth (to .8 mg) would reduce the cost of the diet. Reducing it further may be hazardous; clinical evidence of deficiency has been observed at intakes below .7 mg per day.[18]

The maximum saving possible by reducing the riboflavin level to .8 mg is about one penny per day in the western and eastern moist forests (.08s and .09s, respectively) and two pence (.19s) in the central moist forest. These amount to 6, 9, and 13 percent of the respective costs of the diets in these areas. As the total value produced by the agricultural sector in this solution is only 4 percent greater than the aggregate value of the least-cost diets for all Nigerians, these are appreciable savings. At lower costs the diets would be available to more people.

They would not be the same diets, however. If riboflavin levels were lowered, production and consumption patterns would change somewhat. The excesses of protein and other nutrients over the specified allowances would diminish until the minimum set by some other allowance was reached. Beyond this point that other nutrient (very likely protein) would become a costly element, and the savings to be made by reducing the riboflavin allowance would diminish or disappear. Reduced protein levels could be prevented by raising the protein allowance, but again the savings possible by reducing riboflavin requirements would be reduced.

The present solution provides efficient diets that contain at least 1.02 mg of riboflavin daily. Less costly diets are available by sacrificing some riboflavin. If that were done, the protein production problem, now concealed from view because riboflavin production is more difficult, probably would appear. How much this might alter optimal patterns of production, trade, and consumption is uncertain. The greater the correspondence between good sources of riboflavin and good sources of protein, the less effect there would be on optimal organizational patterns. The present solutions, with riboflavin at 1.02 mg per person, do not provide quite the most economical patterns available using the present method, but they do provide patterns for adequate nutrition that are more economical than any likely to be at-

tained by any other method. Moreover, they avoid the possible undesirable consequences of setting national goals for riboflavin intake at levels that may involve unnecessary nutritional risks.

The basic policy question to be settled by planners concerns the level of riboflavin intake to be sought for the moist forest areas. The data given in chapter 4 define the least cost of providing for an average intake of 1.02 mg per capita with the agricultural techniques of 1963; the data given here indicate reductions in cost that are possible if the desired intake level is reduced.

Given that increases in the availability of riboflavin (or reductions in its cost) are desirable, policies such as the following are in order.[10]

(1) *Encourage the expansion of food production activities that are economical as sources of riboflavin for the rain forest zone.* (See chapter 6.) Note, however, that to be economical as a source of riboflavin a food also must be economical as a source of the other costly nutrients it contains. The search for economical food production activities must consider all the nutrients that are economically scarce, not just one.

(2) *Encourage the consumption of foods that are economical sources of riboflavin.* In the moist forest areas these include goat meat, soybeans, cowpeas, groundnuts, millet, maize, and Guinea corn. Seek ways of introducing millet and soybeans into the moist forest diets, where they are now uncommon. Methods of preparation that are compatible with Nigerian cooking habits are needed. The soybean is now grown primarily for export, but it would be far more valuable as a food. Milk from goats or sheep could be a valuable source of riboflavin if people could be induced to consume it.

(3) *Seek improvements in transportation, marketing, storage, and processing that will facilitate moving foods that are economical sources of riboflavin into the rain forest zone.* The trade in meat animals, millet, and maize is particularly important in this respect.

(4) *Search for additional sources of riboflavin.*

(a) Look for indigenous sources in natural foods, especially those that the Western trained nutritionist might overlook. Consider insects, fungi, yeasts, leaves, condiments (such as chillies or the fermented locust bean), legumes (such as the locust bean and the soybean), other nuts and seeds, and milk products. Leaves play an important part in the Nigerian diet. In different parts of Nigeria they come from a variety of plants: the cowpea, the amaranth, Malabar spinach, and many others. In the Congo the

cassava leaf is eaten. Most leaves are not grown for their own sake, but are gathered from field, forest, or roadside. Little is known about the quantities consumed or the nutritional value of the various leaves. As urbanization proceeds the use of leaves gathered from the bush or the fields will dimish. Now is the time to obtain information about the nutritional composition of the different leaves and to develop production information about those that can be grown efficiently for sale in the cities. Some work already has begun. Dr. O. L. Oke of the University of Ife has published analyses of a number of Nigerian-grown leafy vegetables, while Mr. Donald Schmidt has made studies of production responses in terms of yields and nutrient content.[20]

(b) Look for economical supplements of natural or chemical origin, although no program of food additives is likely to be adequate by itself in a country where most of the population eat little that passes through commercial processing channels. Dried milk products certainly should be examined. They provide calories, calcium, and protein as well as riboflavin. Their cost should be compared with the cost of using chemical supplementation.

(c) Look for possibilities of using the by-products of existing activities. Cottonseed flour has a high riboflavin content.[21] Find out whether there are ways of using it for human nutrition (for its riboflavin, calories, and calcium) that are more economical than exporting the cottonseed.

(d) Support research into the nutritional significance of germination and fermentation processes in the preparation of Nigerian foods. Fermentation can increase the riboflavin content significantly. Per unit of grain employed, the riboflavin content of millet beer is four times that of the grain itself. Guinea corn beer provides about three times as much riboflavin per unit of grain as is found in the whole grain. The fermented locust bean, another traditional food, is also a good source of riboflavin. Soy-ogi, recently developed by the Federal Institute of Industrial Research at Oshodi, is a fermented mixture of maize and soybeans.

Protein

Given the volume of meat products available from the traditional animal industries, Nigeria can provide reference protein for its population at recommended FAO levels more easily than it can meet our allowances for calories or for riboflavin, yet Nigeria suffers from wide-

spread protein deficiency, especially among children under six. A possible explanation is that Nigeria has a limited productive capacity for protein foods of the particular types required by young children, even though productive capacity is adequate on the whole. This study did not examine that issue.[22]

Other possible causes lie outside the sphere of production. Limited incomes among the masses may prevent productive capacity from being used fully or prevent the poor from obtaining an adequate share of the protein produced. When only enough protein is available to provide the average amount for each person, if the well-to-do take more than the average for their own consumption, the poor receive less. Moreover, the protein produced may not be distributed among areas in accordance with nutritional needs, even though this could be done, as the solutions of these models show. Within the family, too, there may be a distributional problem. The family may have adequate amounts of protein, but younger members may not be given what they need. In addition, consumption preferences may prevent the foods produced from being used as efficiently as is assumed in these solutions. Adequate protein can be made available if Nigerians are willing to consume the appropriate mixtures of animal and vegetable proteins, but these may not be the food combinations that are common in Nigerian diets. Finally, some cases of inadequate protein intake may occur because disease, parasitic infestations, and other forms of stress raise the bodily requirements for protein above the levels that were set as goals for these studies.

To facilitate a nutritionally efficient distribution among areas, certain policy measures are indicated. The solution provides adequate protein in the rain forest areas in part because of all of the beef, goat meat, and mutton produced in the two savanna areas is transported to the moist forest (plus, in Model Four, the forest-savanna mosaic). (Milk products from the Fulani herds, along with dried fish and gathered and collected foods, provide animal protein in the savanna areas.)

One would not seek to obtain this degree of specialization in practice, but it is important to recognize and take advantage of the economies inherent in such trade. While the trade is nutritionally efficient at the levels of weight loss and transportation cost used in this model, it would be even more efficient with improvements in transportation, marketing, processing, and storage. Sound public policy

will encourage such improvements if the cost of bringing them about is less than the value of the benefits accruing from them.

Two other policy recommendations stem from the structure of the model. The model assumes that there are no political or cultural barriers to trade among areas and that consumers in each area will pay what is necessary to buy the nutrients brought in from other areas. (These will be no more expensive—and usually less expensive—than the same nutrients obtained in any other way.) The policies indicated are the elimination of political and cultural barriers to internal trade, where any exist, and income improvement policies for those who cannot afford to buy adequate quantities of the animal proteins.

If the moist forest areas are to have sufficient protein without reducing the quantities now consumed in the savanna, or if the poor are to have enough without reducing the quantities now consumed by the well-to-do, total protein production in Nigeria will have to increase above the levels provided in these solutions. Similarly, if diseases, parasites, and stress continue to keep average protein needs above the levels that would be satisfactory for a healthy person, additional protein must be provided. Of course, the same is true for other nutrients,[23] but protein malnutrition is sufficiently important in Nigeria to justify special concern for additional protein production. If production levels are high enough, there may be protein for the poor even after the weevils and the worms and the well-to-do have made their claims.

Programs to increase the output of the animal industries already exist in Nigeria. Unfortunately, given the present state of affairs they benefit the well-to-do at the expense of the nutrition of the poor. Traditional methods of animal production prove to be efficient sources of nutrition in this study, but largely because the resources they consume have few alternative uses. The "modern" methods are inefficient in almost every case, whether used in producing beef, pork, or poultry. In most cases, the nutrients producible by animal industries using modern methods could be more than replaced by using the same resources in other ways. Given the volume of animal protein available from the traditional animal industries in Nigeria, supplementation by vegetable sources is more economical than the production of additional animal protein by modern techniques. When cereals that can meet the nutritional needs of the poor directly are converted into animal feed, the resulting animal products will sustain smaller numbers of people than the original cereals. A certain minimum level of trans-

formation of cereal foods into animal foods may be necessary in order to obtain protein that is adequate in quality, but for the protein levels specified in this study, the traditional animal industries can provide sufficient animal protein to maintain quality when the supplementary foods are chosen properly.

The protein needs of the country will increase, of course, as population levels grow. Outputs from the traditional animal industries cannot be expected to grow proportionately, so the time will come when alternative methods of animal production will be nutritionally efficient. Research in protein production should be underway now in preparation for that time.

If our concern is for low-cost protein, these studies lead to certain suggestions. (1) Devote particular attention to sources of animal protein that already exist in the rain forest zone or that can be developed there. For example, Dr. A. J. Coutu, from his experience in Peru, has suggested that the guinea pig might prove to be a useful source of meat. The milk of sheep or goats is not commonly used in the south, but could be valuable for both protein and riboflavin. More emphasis should be placed on goats and sheep as meat sources for the moist forests and, for that matter, all parts of Nigeria. In these studies these animals often are more efficient sources of nutrition than cattle, partly, however, because of the value of their skins and the relatively high proportion of riboflavin in their meat. Should riboflavin be de-emphasized, this advantage would diminish.

(2) Look for ways of maintaining the advantage that now inheres in the traditional animal industries—the use of resources that have little alternative value. In this respect the feeding habits of goats and, perhaps, sheep give them an additional claim to more attention than they have received. Rabbit culture, now beginning to catch on in the east, fits nicely into this category. Leaves for food can be obtained almost anywhere, at least in the moist forest zone.[24]

(3) Look at the protein problem as a whole, not just for sources of animal protein. Supplementation by vegetable sources undoubtedly will continue to be central to any effective program to increase the quantities of low-cost protein available.[25] Unfortunately, the food legumes, from which so much has been hoped, generally appear to suffer from low yields and lack of responsiveness to production inputs such as water and fertilizer.[26]

(4) Most important of all, look beneath the surface of the problem. It is not enough to talk about the total quantity of protein in the diet, or

even about the proportion of total protein which comes from animal sources. If efficient sources of protein are to be found for Nigeria one must examine the amino acid composition of the protein available in the diet as a whole and design protein improvement programs to increase the proportion of the essential amino acid or acids that is limiting in Nigerian diets. There is little evidence that attention has been paid to this aspect of the problem in Nigeria.

Where protein has been considered at all, plant breeding programs often have proceeded as though one protein is as good as another. The breeders are willing, but they have not been adequately informed as to what nutritional needs are to be met.

From these studies it is clear that under Nigerian productive conditions the limiting essential amino acids are the two sulfur-containing acids, methionine and cystine. Protein improvement policy should be directed toward seeking more economical sources of these two.

Nigerian plant-breeding programs have given some attention to the levels of the amino acids, but that attention has been misdirected. A high-lysine variety of maize (Western White 1) has been developed, but lysine is not the limiting factor in protein quality. As a matter of fact, the new high-lysine maize has less of the sulfur-containing amino acids than does ordinary maize, so introducing Western White 1 into the Nigerian diet might be expected to make the protein problem worse rather than better. To be sure, Western White 1 does have higher yields than the native varieties, so its contribution as an improved source of calories and riboflavin may be sufficient to offset its deficiencies as a protein source in the Nigerian setting. Still higher yields could have been achieved, however, if the high-lysine gene, Opaque II, had not been used. Furthermore, a gene also exists (Floury II) that yields a high methionine content.[27] Unfortunately for Nigeria, the high-lysine gene has attracted the most attention.

Once it is recognized that the sulfur-containing amino acids are the limiting factors in protein quality in Nigeria, the research problem takes different shape. There are indications that the sulfur-containing amino acids tend to be limiting in protein from legumes (such as cowpeas and groundnuts), while lysine (or, in the case of maize, tryptophan) tends to be the limiting amino acid in cereal protein.[28] To the extent that this is true, expanding cereal production would contribute to the solution of the protein problem by improving the balance of the essential amino acids in a diet that at present is generally low in the sulfur-containing acids. Emphasis on increasing the output

of legumes may not be as promising as has been thought. One must look at the balance of the diet, not at single foods.

Nigeria already produces on a small scale two sources of protein high in the sulfur-containing amino acids that may have been overlooked: sesame seed (benniseed) and sunflower seed.[29] More attention should be devoted to the use of these crops as foods. It may be that, as with the soybean, Nigeria is exporting products actually worth more as nutrients than as income in the export market.

Calcium

When the average calcium allowance is set at 389 mg per person per day, but the dry savanna is required to have only 330 mg, meeting the allowances becomes an insignificant problem. (See Model Four, discussed in Part Two.) In the Model Four solution, calcium is costly only in the dry savanna, and there the cost of the daily ration is less than one-twentieth of a shilling.

From the long-run point of view, however, research might be worthwhile along two fronts: Determine the human need for calcium more precisely and obtain better measurements of the actual dietary intake of calcium. Gathered and collected foods, including the edible earths, may be important as sources of calcium. These foods have been neglected too long by nutritionists. If gathered and collected foods are important calcium sources, densely populated areas like Kano State may need to pay special attention to meeting their calcium needs in other ways.

Among the foods that are economical sources of calcium are milk (in the two savanna areas) and dried freshwater fish with edible bones (in almost all areas of Nigeria).

Vitamin A

In the moist forest areas, attaining the vitamin A levels specified in this model involves no additional cost. Outside those areas the cost is very small (between .02s and .10s per capita per day). No action is called for other than encouraging adequate use of red palm oil outside the producing areas.

More on Nutrition

Efficient Foods

A food that is nutritionally efficient provides nutrients that are worth at least the full cost of the food.[30] If it contains nutrients that

are just equal to the cost of the food it may be called minimally efficient; if for some reason, perhaps a limitation on the quantity of the food that can be used, the nutrients in the food are worth more than the cost of the food, the food is more than minimally efficient. Such a food provides a surplus of nutrient value.

Every food that is in the solution for no other reason than for the nutrients it provides is an efficient food. A food that is in the solution for some other reason as well, perhaps because it is needed to satisfy a requirement for the consumption of alcoholic beverages or of a stimulant such as the kola nut, will not be nutritionally efficient. Such a food may be the most economical food available for the satisfaction of this behavioral requirement, given the nutritional requirements that also must be satisfied, but its nutritional composition alone would not warrant its inclusion in the diet.

Normally, the quantity of an efficient food in the optimal solution is such that the nutrients in that food are worth exactly what it costs to include the food in the diet. However, if the quantity consumed is restricted by some factor other than the cost of the food, the nutrients it provides may be worth more than it costs to include the food in the diet. Such foods are unusually efficient sources of nutrition. For the two models discussed in this volume these foods are listed in Tables 9 and 32.

If a food yields a surplus of nutrient value, as do these unusually efficient foods, the cost of an adequate diet can be reduced by increasing the consumption of such a food beyond the levels allowed in these models. Consumer education may well seek to increase consumer acceptance for these foods.

Such foods, however, being limited in consumption, may not be nearly as important to meeting present dietary needs as other foods that are only minimally efficient, but are consumed in large quantities. Included in the latter group are many such traditional foods as yams, maize, red palm oil, millet, and sorghum.

Millet, although not now widely consumed in the moist forest areas, could become a very significant source of economical nutrition for the eastern moist forest and the forest-savanna mosaic if wider consumer acceptance for it could be developed.

The soybean, similarly, is a highly nutritious food that is not now widely used. Ways of preparing it should be sought that are compatible with Nigerian cooking practices. This legume is far more valuable for its nutrients than as an export crop.

Dried freshwater fish with edible bones form an economical source of nutrients in five of the six areas of Nigeria, although stockfish—salt cod—never appear in the optimal solution. At a low enough price (perhaps one-half to one-third of the price of dried freshwater fish), stockfish might appear, except where the dried fish are important for their calcium content as well as for the calories and riboflavin they provide. At least for the dry savanna, methods of fish preservation should be encouraged for both fresh and saltwater fish that retain the bones in edible form. Expanded consumption of fish with edible bones is especially indicated in that area.

Milk is an efficient food in the savanna areas. (It was not included in the model for other areas except as one of the foods consumed in fixed amounts.) In the solution for Model Three, milk provides 27 percent of the calcium allowance in the intermediate savanna and 13 percent of the riboflavin required. This helps explain why neither of these nutrients is costly in that area. Milk provides all four of the nutrients that are costly in Nigeria: riboflavin, calcium, calories, and vitamin A, not to mention animal protein.

This study did not ask whether milk would be an efficient food outside the two savanna areas, but it would be desirable to rerun the model with whole milk and milk products included as variable consumption possibilities in each area. Given the importance of riboflavin, either locally produced milk or imported dried milk products might prove to be efficient in many parts of the country.

The possibility of using the milk of sheep and goats should be studied. In much of the country these animals are better adapted to Nigerian conditions than are cattle. Their milk does not appear to be widely consumed, but it could provide significant additions to the Nigerian diet and might be less expensive to produce than cow's milk in some parts of the country. Sheep's milk provides more than three times as much riboflavin per gram as does cow's milk, and it is also richer in calories, protein, calcium, and vitamin A.

It would be well to re-examine the emphasis on meat production which seems to dominate research and development activities in the animal industries. Shifting the emphasis to milk production might contribute much more to the solution of Nigeria's nutritional problems. Processing and transportation problems would have to be solved, however.

Emphasis on expanding meat, poultry, and egg production as sources of protein is not warranted if adequate diets are sought for the poor.

In most of Nigeria the commercial methods of producing swine, poultry, and beef are wasteful means of providing the essential nutrients. Goat meat, mutton, and beef, when produced by traditional methods, are efficient in the central and eastern moist forests, but because of their riboflavin and calories, not their protein. They still might be efficient even if the riboflavin goal were lowered, for in that case the protein allowance might become difficult to meet, making protein a valuable (costly) nutrient.

Pigs

Information should be collected on the nutritional and economic significance of swine owned as household animals. They are undoubtedly of considerable nutritional importance, but the absence of data prevented pig production from being considered as an activity in this study.

Hides and Skins

There should be an inquiry into the nutritional merit of using hides and skins for food. This model assumes that no hides and skins are eaten, but in fact large numbers of hides are used for food. It seems likely, however, that they are worth less as food than as industrial raw materials.

Nutritional Information for Planners

Of great importance to Nigeria would be the development of a systematic procedure whereby plant breeders and agricultural planners could be kept informed of the nutritional needs of the people and the nutritional composition of the various foods available. The nutrient composition data available for use with this model were not sufficiently precise to permit more than an outline of the major features of a nutritionally efficient organization of agricultural production, but even these data enabled information to be obtained which could have prevented some nutritionally inefficient expenditures had it been available when those expenditures were being planned.

Better nutritional composition data are now available. The Food and Agriculture Organization of the United Nations, in cooperation with the Public Health Service of the United States Department of Health, Education and Welfare, recently has published a *Food Composition Table for Use in Africa,* which provides a convenient source

of information. It describes the limitations of the data available and the "immediate need for more analytical and biochemical investigation of foods used in Africa."[31] Unfortunately, the volume contains data on none of the amino acids except tryptophan. Although information is extremely scarce, data concerning the principal essential amino acids are of vital importance to anyone concerned with the protein problem. A program for amino acid analysis definitely is required.

This basic FAO/HEW compilation needs to be kept up to date as gaps are filled and new information is provided by current studies. The bits and pieces of nutrient composition data scattered through the literature should be organized and compiled as they appear, so that they may be used in current work.

A standard part of all plant breeding work should be the nutritional analysis of new varieties under development. The nutrient composition of food varies greatly in accordance with the variety of the crop and the conditions of the soil, climate, and culture under which it is grown. Data should be obtained as a routine part of all cultural and breeding experiments so that the changes in nutrient composition that developmental work brings about will be the changes desired, not accidents both unforeseen and unfortunate. (It is reported, for example, that many of the new high-yielding cereal varieties of the green revolution contain less protein than the varieties they are replacing.)

A similar systematic presentation of basic nutritional needs is also needed for plant breeders and agricultural policy makers. At present these scientists are operating, necessarily, with information little better than that available to the well-informed educated man generally, but this does not give them the accurate knowledge of nutritional needs that is required if their work is to provide the nutritional benefit for Nigeria of which it is capable. Scientists in these fields cannot be expected to assume the responsibility for determining which are the most pressing nutritional needs of the people, but unless there is an established method of providing them with the best information being developed by the nutritionists, much of their effort will be misdirected. One illustration is the effort devoted to the development of a high-lysine maize for Nigeria, when it is the sulfur-containing group of the essential amino acids that is scarce.

One type of information essential for planning for low-cost production of the nutrient needs of the country did not exist until this study was made. Now it is known that calories, riboflavin, vitamin A, and calcium are the nutrients most costly to produce in Nigeria and that

the sulfur-containing amino acids are likely to be the limiting factors in determining protein quality in a low-cost Nigerian diet. Planning to increase the production of other nutrients is liable to be a wasteful use of resources as long as the structure of Nigerian productive capacity remains as it is today.

Selecting Production Activities

Food Production

Funds for educational and developmental work in the promotion of agricultural expansion are limited, so it is important that they be used efficiently. Optimal efficiency in the expenditure of a given amount of money on crop promotion requires an allocation such that an additional £1,000 spent on promoting crop A will yield the same anticipated increase in net agricultural income (or value of nutrients produced) as would an additional £1,000 spent on crops B, C, or any other.

The anticipated increase in agricultural revenue from an expenditure of £1,000 is equal to the anticipated increase in acreage times the net income or value of nutrients per acre to be expected from that acreage. How much acreage expansion can be expected from a given promotional expenditure must be estimated by those who are skilled in directing the use of such funds. This study provides estimates of the net income or value of nutrients per acre that can be earned from the expanded acreage.[32]

For the purpose of maximizing Nigerian income from agriculture while maintaining adequate levels of nutrient availability, there is more to be gained from the expansion of selected food crops than from the expansion of the animal industries. In the eastern moist forest, however, food crop expansion has little to offer.

Crops that deserve promotion because of their efficiency as sources of needed nutrients include yams in four of the six areas, soybeans in the forest-savanna mosaic, maize (except in the dry savanna and the eastern moist forest), and cocoyams in the western and central moist forests. In most areas some mixed crop combinations will yield more than any of the sole crops.

Of the traditional animal activities, the least efficient as a source of nutrients are the migratory cattle of the Fulani. Both sheep and goats make more efficient use of the limited pasture available.

In terms of nutritional efficiency per acre, sheep production is the

most efficient of these three animal activities in the dry savanna, bush cattle production in the intermediate savanna and the central moist forest, and goat production in the remaining three areas.[33] One policy implication of these results is clear: More of the research and development effort now being spent on the animal industries should be devoted to goat production.

Except for commercial cattle production in the forest-savanna mosaic, the modern animal activities do not produce nutrients that are worth the resources required for their production. If their development is to be encouraged, it must be on the ground that their products find a profitable market among the well-to-do, who can afford to pay more than is necessary for the nutrients they require.

Income Production

Income production also contributes to the solution of the nutritional problem, for only those with adequate incomes can afford the food they need, even when that food is produced in the most economical way possible. From the national standpoint, the most efficient way to provide the nutrients needed involves a degree of dependence upon internal trade. Only those whose incomes allow them to purchase food brought in from other parts of the country will be able to utilize such a diet, which is beyond the reach of the family that must be wholly dependent upon subsistence farming.

In the Model Three solution, 16 percent of the aggregate value of the output of the animal industries consists of the value of the hides and skins sold. (None of the skins, in contrast to actual practice, was used as food.) In view of the magnitude of this figure, an income improving policy would include an investigation into the possibility of improving the processing and marketing of hides and skins. There also should be elimination of any monopolistic barriers to efficiency that may exist in the industry.

With a few exceptions, Nigeria can increase its income from agriculture more, at the recommended levels of nutrition, by expanding its production of certain food crops than by expanding its output of cash crops. If the level of nutrient availability specified in this model is important to Nigeria, and if export production uses only the resources left over after the specified levels of nutrients have been provided, promotional activity pointed toward the expansion of properly selected food crops can be more effective than similar activity spent in promoting additional planting of export crops. The nutrients that

could be provided by expanded food crop production can replace those now obtained from groundnuts and palm oil, freeing more of those products for export sale. An acre devoted to the production of the right kinds of foods can release for export the product of more than an acre of existing groundnut or oil palm production, with the possible exception of oil palm production in the forest-savanna mosaic. Put more generally, an additional acre of any one of a number of food crops would provide enough nutrients so that resources set free from nutrient production would permit expanding the production of most income crops by more than an acre.

To be sure, there is no certainty in practice that the nutrients provided by an extra acre of bush maize in the intermediate savanna automatically will be made available to the farmers in the moist forest zones and that the latter therefore will reduce their consumption of homegrown foods in favor of production for export. This study shows that the possibility of such substitution exists and identifies foods that would be especially effective for this purpose. It is certainly true in a general way that the more productive the land used for food production, and the more efficient the marketing processes that make possible internal trade in food products, the more resources will be available for those who wish to specialize in export production in the areas where export production has a comparative advantage.

It must be remembered that the purpose of greater nutrient production is to allow an expansion of sales for nonfood purposes, without sacrifice of nutritional standards. Direct attention to the expansion of revenue crops also can contribute to the growth of Nigerian agricultural income. The major income crops (cocoa, oil palm, and groundnuts) are worth producing at levels at least 20 percent higher than in 1963. (Oil palm and groundnuts are being grown for nutrition as well as for cash income.) Obviously these crops deserve continued attention from planners and production specialists. However, cash crops in general are not likely to require as much promotion as food crops of equivalent merit, for profitability in money is easy to recognize, while the average citizen may know little about the nutritional advantages of the various foods.

One income producing activity is comparable with several of the most promising food producing activities. Tobacco yields a product worth 700s to 900s per acre more than the opportunity cost of the resources required for its production. However, it is not quantitatively very important (the model allows only 15,000 acres), and these calcu-

lations take no account of the damage tobacco does to Nigerian health. Any large expansion of tobacco production should be expected to reduce its profitability at a rapid rate.

All the tree crops except rubber are worth producing at levels at least 20 percent above the 1963 figures. Rubber manages to pay its way in the central moist forest and yields a small surplus in the western moist forest, but it is not a promising candidate for promotion.

Cocoa in the western moist forest shows the most promise. It earns 400s per acre more than the opportunity-cost value of the resources required for its production. This figure is comparable with what some of the food crop activities will earn.

In the Model Three solution, oil palm also looks like a promising candidate for expansion in the western moist forest and the forest-savanna mosaic. However, world prices for oil palm products have been below 1963 levels in several years since then. To have an adequate evaluation of the roles of the tree crops in the Nigerian economy, the model should be solved again, using the best estimates of future prices that are available for the major export crops.

Among the field crops, the groundnut is profitable in both savanna areas and in the forest-savanna mosaic. It yields modest surpluses (of from 100s to 300s per acre) in excess of the opportunity-cost value of the resources it requires. Cotton, on the other hand, yields only small surpluses when it yields any. When grown in the dry savanna, it does not even pay for the resources it uses.

Trade

Within the Agricultural Sector

In the solution based on 1963 agricultural methods, two of the three major income producing areas, the eastern and western moist forests, are able to maintain their levels of income production without sacrificing the nutritional well-being of their people only because of the food they receive from other parts of Nigeria. The third important income area, the dry savanna, is both a major exporting area and the most important source of food for other parts of the country. The dry savanna provides millet, rice, groundnut oil, and meat to other areas, but receives cowpeas, red palm oil, and kola nuts.

The intermediate savanna takes groundnut oil, palm oil, and kola nuts from the areas north and south of it, while it provides maize,

cowpeas, meat, and assorted field crops for other parts of the country. The central moist forest takes meat and field crop products from other areas, but provides gari and yams for the western moist forest. The forest-savanna mosaic provides field crops for the central and eastern moist forests and red palm oil for the savanna areas.

Without these internal movements of foodstuffs, Nigeria's capacity for earning income by production for sale or export would be seriously reduced. Facilitating internal trade in food products is essential to the full development of Nigeria's potential as an exporting country. This requires, of course, improvements in the food processing and storage industries.

Outside the Agricultural Sector

Willingness to make use of foods obtained from outside the agricultural sector is also vital to the full development of Nigeria's potential as a producing country. In the model that assumed the use of 1963 agricultural methods, it was more economical to purchase dried freshwater fish and white sugar than to provide the same nutrients by direct production, using the resources of the agricultural sector.[34] Fish were important in that solution partly for the calcium they provided. However, in the model where some traditional methods were employed, calcium was of little importance, yet still it was more economical to purchase fish than to produce the equivalent nutrients within the agricultural sector.

The Role of Technical Change

Research in agricultural methods has been carried on for years in Nigeria. The nation's success as an exporter of agricultural produce and its ability to feed its people as well as it does reflect the willingness of Nigerian farmers to adopt promising new crops and improved methods of cultivation. Continued dedication to research and to the task of disseminating that research among farmers is essential if Nigeria is to be able to raise the nutritional condition of its people to a satisfactory level and to maintain it there in the face of a rapidly growing population.

It is probable that Nigeria now has the capacity to provide adequate nutrition for all its people, given sufficient dedication to the task, but the margin available for meeting the needs of a growing population is very small. With the agricultural methods employed in

1963, the estimated 1967 population of 61 million people could produce nutrients sufficient to provide themselves with the allowances specified in this study *if* patterns of consumption, production, and trade were organized with maximum efficiency and *if* the nutrients produced were divided among people in accordance with nutritional needs rather than with incomes.

Even this level of productive capacity is heavily dependent upon the use of agricultural techniques rather recently adopted. If 1963 methods are replaced by traditional methods outside the moist forest areas for only ten crops, Nigeria is no longer physically capable, under the conditions of the problem, of providing the whole set of nutrients specified for 61 million people. Calories and riboflavin appear to be the limiting nutrients. Only by assuming nearly a 3 percent increase in the quantities of gathered and collected foods consumed does a solution become possible.

The income Nigerian agriculture can earn without reducing the nutritional status of the people below satisfactory levels also depends heavily upon the technical level of food producing acivities. Adoption of 1963 methods outside the moist forest areas for those ten crops permits Nigeria to raise the annual value of the output of its income producing activities from 1.3 to 2.6 billion shillings.

It is evident that meeting the nutritional and income needs of a growing population requires continuing improvement in the agricultural methods in use. From the standpoint of Nigeria's nutritional well-being it is essential that agricultural development programs place emphasis on improving effectiveness in the production of food, in particular, effectiveness in the production of food energy (calories). If protein production is to be increased, the needs of the poor will be met better by encouraging the development of vegetable rather than animal sources. For efficient protein production the emphasis should be on the development of additional sources of the sulfur-containing amino acids, methionine and cystine.

Even if someone should regard the production of income as more important than a well-fed people, he would do well to devote a considerable portion of his developmental activities to expanding and improving food supplies. These studies have shown repeatedly that increased efficiency in food production can make possible large increases in income production either by increasing the proportion of groundnuts and palm products available for sale or by increasing the quantity of resources that can be devoted to income crops.

Adapting to Change

Nigerian agriculture continually adjusts as it is confronted with new transportation facilities, changing market opportunities, new agricultural methods, and new varieties of crops. These models were designed to be useful in directing that change along desirable lines. They were not designed to define an ideal organizational pattern for Nigerian agriculture, but to indicate directions of change from the 1963 pattern that would improve nutritional well-being or increase income levels without sacrificing nutritional status.

To use the model effectively it must be kept current. The moderately optimistic results that have been obtained for a population of 61 million underestimate the difficulty of feeding a population of 70 million. It is not too soon to ask what organization of agriculture would be efficient for feeding the 95 million people that Nigeria may well have by 1985.[35]

Moreover, the urban population is growing more rapidly than the total. City dwellers cannot be expected to have access to the gathered and collected foods that are so important to the rural diet. What production and dietary patterns would be efficient for an urban population that does not have access to these foods and a rural population that does?

External events may require revision of the model. As world prices of export commodities change, new solutions are needed, for an efficient organization under one set of prices need not be efficient under another. Considering the importance of tree crops in Nigeria, two kinds of new solutions are needed: those that reflect new levels and patterns of world prices when there is a sharp change (as occurred for palm products in 1968) and those based upon long-range forecasts of world prices of export crops. Because adjusting tree crop acreage takes time, organization patterns based upon long-range forecasts are essential, even though all such forecasts must be used with discretion. (An incidental advantage of programming models like these is that solutions may be obtained for a range of price forecasts. Quite often very little change in the organizational pattern is called for over a certain range. Only where a given price change requires a marked change in productive organization does it become important to have a high degree of confidence in a price prediction before taking action based upon it.)

The model also should be solved with less restrictive maximum

limits on the acreage to be devoted to export crops. Given the conditions embodied in the models reported here, the maximum limits were not unduly restrictive, but there could be conditions in which expansion well beyond 120 percent of 1963 levels would be desirable. To identify such possibilities the model should be solved with considerably relaxed limits on export production.

Considerations of nutritional strategy also may suggest revisions of the model. Should Nigeria's nutritionists conclude that a lower level of aspiration would be preferable for riboflavin, or a higher goal for protein, the model could be solved again for these new goals.

In addition, the nutritionists may wish solutions from models revised to provide specific information concerning a number of problems that have been mentioned in this volume, but not studied directly. Several of these are noted below. (1) *Diets for the very young.* Some foods that are quite satisfactory for adults do not provide adequate nutrition for young children because the digestive apparatus of the young child cannot process a large enough volume to meet his nutritional needs. If the population is divided into those under and over six, what would be the efficient production and dietary patterns that would meet the nutritional needs of each group? (2) *Diets for the hungry season.* Seasonal hunger is a serious problem in many parts of Nigeria. Are there patterns of agricultural production that could be adopted which would provide minimum nutritional needs during the hungry season as well as adequate nutrition during the rest of the year? (3) *Production patterns that allow for wastes.* The present models provide nutrients that would be adequate for Nigeria if no one received more than called for by his nutritional needs. What kind of production pattern would be needed if those who already are receiving more than they need of specific nutrients were to continue to do so, while those who receive less than the per capita allowances were to be raised to that level? What production pattern would be needed if no area or income class were to receive less meat than it now consumes? What pattern would be needed to offset losses of nutrients during cooking and to provide the extra nutrients needed because of disease, parasitic infestation, and stress? (4) *Other questions.* Is milk an efficient food outside the savanna areas? Is sugar cane production an efficient activity? What is the nutritional role of traditional pig production?

Even the changes in production patterns that would result from encouraging farmers to effectuate suggestions drawn from these studies

would create the need for revising the model. As the production pattern changes, a new set of acreage maxima needs to be developed that reflects the new structure of production. Changes in the cropping pattern also would change the technical coefficients—the quantities of land and labor required and the yields to be expected. These new technical data should be introduced into the model and a solution obtained using the new acreage maxima. That solution would indicate additional desirable changes.

In addition to the effects of altered production patterns there will be changes caused by the adoption of new methods or the introduction of new crops or varieties. The experiment stations and extension services have recommended many improvements in agricultural techniques that have not yet been adopted by Nigerian farmers. If such improvements were adopted generally, how would this affect the patterns of production and the income that Nigerian agriculture could earn while feeding its people at the levels called for in this model? Which of these improvements would it be most beneficial to adopt?

Many new varieties of plants are being developed for use by Nigerian farmers. How would adopting these new varieties affect the pattern of agricultural production and the incomes that could be earned? Which new varieties would it be most beneficial to develop? Appendices A and B provide answers to some of these questions.

In addition, there are numerous other problems that profitably could be examined with the aid of revisions of these models. A few are listed below. (1) How would changes in the costs of transportation or the opening of new transportation routes alter an efficient organization of production and the income potential of Nigerian agriculture? (2) What would be the consequences of specific improvments in food processing or storage? A large part of the food produced in Nigeria is lost through waste or spoilage. Perhaps improvements in marketing, transportation, or processing would be more effective ways to improve nutrition or income than changes in the production pattern or improvements in production techniques. (3) What would be an optimal production organization if the model provided a higher ratio of land per laborer? This solution would indicate whether there are efficient ways of using larger quantities of land per man and would identify labor-saving cropping patterns that could be used by the man who cultivates more land than the average in his area. It also would indicate what gains might be accomplished if land use per man were increased, perhaps by con-

solidating scattered fields to save time now spent in travelling between fields, or by expanding the total land under cultivation in certain areas. (4) Finally, how should production be organized when the total demand for food expands as income rises (as it does, in fact)? The present models assume that people are to be equally well fed at all income levels, but in actuality the quantity of food that must be produced to satisfy market demands rises as the per capita income rises. Even though population increases diminish in magnitude, these income related increases in the demand for food must be expected to continue as Nigeria grows increasingly prosperous.

Not all of these questions can be studied at once, let alone the many other questions for which a model of this type is useful, but progress can be made by proceeding with the analysis of one or two of the most significant questions. The greatest part of the cost of such an investigation already has been borne: The basic model has been constructed. Adaptations to specific problems are comparatively inexpensive.

This type of analysis is particularly important where changes in one part of the economy are likely to affect other parts in a significant way. Major changes in export prices, changes in the methods of production of important crops, and alterations in the distribution of population within the country are examples of changes that are occurring within Nigeria and that will have repercussions throughout the economy. To determine the nature of those repercussions requires a general equilibrium model such as this. Partial analysis is likely to be misleading. Many of the major changes that Nigeria must face in the future can be foreseen; with general equilibrium models of this sort one can predict some of the consequences of those changes in order to be ready to deal with them before they burst full-blown upon our consciousness.

Conclusion

Basically, sound policy for the simultaneous improvement of income and nutrition calls for two approaches: an action program that encourages the production and consumption of the foods that are most efficient nutritionally and a research program that fills in the most important gaps in our knowledge of the nutritional situation. An action program not guided by sound nutritional information may do more harm than good; a research program that does not lead to action

may accomplish little more than the education of the scientist involved. Properly integrated, much can be accomplished. From the discussion in this chapter it is clear that there is abundant work to be done in both areas.

Notes

Introduction

1. "Food vs. People," *War on Hunger* 5, no. 9 (September 1971): 10–11.
2. For an impressive review of the evidence see Pedro Belli, "The Economic Implications of Malnutrition: The Dismal Science Revisited," *Economic Development and Cultural Change* 20 (1971): 1–23.
3. Ibid., p. 15.
4. Ibid., p. 19.
5. Rainer Schickele, "Critical Issues in the Economics of Development," privately circulated, 1971.
6. Jacques M. May, *The Ecology of Malnutrition in Middle Africa (Ghana, Nigeria, Republic of the Congo, Rwanda Burundi, and the former French Equatorial Africa)*, Studies in Medical Geography, vol. 5 (New York: Hafner, 1965), pp. 62–67.
7. In the north, he says, providing adequate food for his family is the farmer's first priority. There is no evidence that the nutritional situation was worsened there because cash crops have expanded. See Ephraim Osabor Idusogie, "A Critical Review of the Role of Cash Cropping on the Nutrition of Nigerian Peoples," Ph.D. diss., University of London, 1969, pp. 224–30.
8. See ibid., pp. 39, 145, 156, 164–65, 208, 233.
9. Ibid., p. 171.
10. This is the first such model to have been developed for a whole country. See the following by this author: "A Model of Nigerian Agriculture: Programming for Nutrition as Well as Income," Michigan State University Econometrics Workshop Paper no. 6811 (East Lansing: De-

partment of Economics, Michigan State University, April 1969); *Optimal Resource Allocation for Income and Nutrition*, Working Paper no. 11 (East Lansing: Consortium for the Study of Nigerian Rural Development, Michigan State University, June 1969); and "Agricultural Planning and Nutrient Availability," *Nutrition Reviews* 28 (1970): 143–50.

11. Some results from the first model appeared in Smith, "A Model of Nigerian Agriculture"; second model results are described in Smith, *Optimal Resource Allocation*.

Chapter 1

1. May, *Ecology of Malnutrition*, pp. 58–59, 62.
2. National Institutes of Health, Office of International Research, Nutrition Section (hereafter NIH), *Republic of Nigeria: Nutrition Survey, February–April 1965* (Washington, D.C.: Public Health Service, U.S. Department of Health, Education and Welfare, 1967), pp. 57, 85, 137, 165.
3. May, *Ecology of Malnutrition*, p. 58.
4. Idusogie, "A Critical Review," pp. 158, 174, 192–93, 229.
5. May, *Ecology of Malnutrition*, pp. 66, 58.
6. Ibid., p. 63.
7. J. M. Gurney, "Considerations in Agricultural Planning," *Nutrition Reviews* 29 (1971): 50–52.
8. Ibid., p. 51; May, *Ecology of Malnutrition*, p. 66; and NIH, *Nutrition Survey*, pp. 99, 137.
9. May, *Ecology of Malnutrition*, p. 66.
10. NIH, *Nutrition Survey*, pp. 57, 85, 96.
11. Michael Latham, *Human Nutrition in Tropical Africa* (Rome: Food and Agriculture Organization of the United Nations, 1965), p. 85; and Food and Agriculture Organization (hereafter FAO), *Report of the FAO/WHO Seminar on Problems of Food and Nutrition in Africa South of the Sahara*, Lwiro, Bukavu (Congo), 18–29 May 1959, FAO Nutrition Meetings Report Series no. 25 (Rome: FAO, 1961), p. 12.
12. NIH, *Nutrition Survey*, pp. xx, 57, 96.
13. Gurney, "Considerations," p. 51, citing Stanley Davidson and Reginald Passmore, *Human Nutrition and Dietetics*, 4th ed. (Edinburgh: Livingstone, 1969), p. 225.
14. May, *Ecology of Malnutrition*, pp. 62, 59.
15. NIH, *Nutrition Survey*, p. 57; and Gurney, "Considerations," p. 51.
16. FAO, *Seminar on Food and Nutrition*, p. 13.
17. This is a prewar estimate of the 1967 population. Although the civil war began in 1967, this study abstracts completely from war and postwar problems. Our concern is with the fundamental problems arising from the pressure of population upon productivity in a united Nigeria.

18. The model thus embodies the principle suggested by Belli after this study was under way: "Investments should be undertaken subject to a constraint—the nutritional level of the population." Belli, "Economic Implications," p. 20.
19. Net of any sums expended on materials or services obtained from the nonagricultural sectors or on the purchase of food from the nonagricultural sectors or from abroad.

Chapter 2

1. One also might ask how much land should be used as pasture instead of for arable crops. However, there is little evidence that land otherwise available for arable use actually is being withheld for use as pasture.
2. A detailed statement of the nutrition restraints ($i \epsilon N$) will be given in chapter 3. One restraint in this set is nonlinear.
3. Rather than include a separate selling activity in the model, the selling and production activities are consolidated into one.
4. R. W. J. Keay, *An Outline of Nigerian Vegetation*, 3d ed. (Lagos: The Federal Government Printer, 1959); and L'Association pour l'Étude Taxonomique de la Flore d'Afrique Tropicale, *Vegetation Map of Africa South of the Tropic of Cancer* (Oxford: the University Press, published with the assistance of UNESCO, 1959).
5. I am indebted for counsel concerning the selection of these areas to Dr. John M. Hunter, Department of Geography, Michigan State University (then at the University of Durham, Durham, England) and to Mr. Omolade Adejuyigbe of the University of Durham.
6. Keay, *An Outline*.
7. These same bands continue across all of West Africa.
8. The fourth of the regions, the midwest, was created on 9 August 1963. See *Nigeria Year Book 1966* (Lagos: Times Press Limited, n.d.), p. 189.
9. These were created by decree of the federal military government on 27 May 1967, to become operational on 1 April 1968. See Orlin J. Scoville, "The Twelve States of Nigeria: Background and Current Issues," mimeographed, November 1968, p. 11.
10. Using resources appears as a positive entry in the model.
11. In the algebraic statement of the model, both growing and processing activities are included in the set $j \epsilon P$.
12. FAO, *Agricultural Development in Nigeria, 1965–1980* (Rome: FAO, 1966), p. 223.
13. This study does not deal with the special problem of the seasonality of food supplies.
14. In most areas there is land available that can be taken into cultivation as the population grows.

15. This allows 9.5 percent for population growth and 10 percent for any desirable expansion that would be disproportionate to the assumed growth in the manpower and arable land available.
16. The land already in use by an expanding activity need not be technically superior, for this crop, to the land released by the contracting activities. Many factors other than the technical properties of the land determine what crops will be grown on a particular plot of ground. They include ownership rights, village custom, ignorance concerning the capabilities of the land, location, and the competition of other crops that can be grown on the plot.
17. This is also largely the case in fact, except in the north, where land has been transferred from pasture to arable land as the population has grown and where signs of overgrazing now have appeared. Some complementarity also exists between the traditional animal industries and arable cropping. The droppings left by grazing animals add fertility to the land, and some farmers pay the Fulani herdsmen to let the animals graze over their idle fields. The model does not take account of this relationship.

    Outside the north the pasture used for animals generally has been land that is not in current use for field or tree crops in any case, and more has been available than actually was utilized. As for labor, the nomadic herdsman of the north generally has not been available for settled agricultural pursuits (although there are exceptions), while the animals owned by settled farmers normally are tended by children or elderly people not well suited for work on the cultivated plots.
18. B. S. Platt, *Tables of Representative Values of Foods Commonly Used in Tropical Countries*, Privy Council, Medical Research Council Special Report Series no. 302 (London: Her Majesty's Stationery Office, 1962); M. L. Orr and B. K. Watt, *Amino Acid Content of Foods*, Home Economics Research Report no. 4, Institute of Home Economics, U.S. Department of Agriculture (Washington, D.C.: U.S. Government Printing Office, December 1957); and FAO, *Amino Acid Content of Foods (Provisional)* (Rome: FAO, July 1963).
19. (Rome: FAO, 1966).
20. Federal Office of Statistics, *Rural Economic Survey of Nigeria*, including *Farm Survey*, 1963/64, RES/1966/1, *Livestock Enquiry*, 1963/64 and 1964/65, RES/1966/2, and *Farm Survey*, 1964/65, RES/1966/5 (Lagos: Federal Office of Statistics, 28 February 1966; n.d.; n.d.), hereafter *Rural Economic Survey*.
21. Tom Alan Phillips, *An Agricultural Notebook, with special reference to Nigeria*, 2d ed. (Ikeja: Longmans of Nigeria, 1964).
22. FAO, *Agricultural Development*, p. 20.
23. *Rural Economic Survey*.
24. Phillips, *Agricultural Notebook*.
25. One important advantage of using an explicit model is that one easily can measure the effects that alterations in the data might have upon the solution or upon policy recommendations based thereon.

26. On the basis of certain materials made available to me by Dr. J. C. Caldwell of the Population Council (245 Park Avenue, New York, N. Y.), it appears that there is no longer any reason to doubt the general level of population indicated by the 1963 census. There is also evidence that an annual growth rate of at least 2.3 percent per annum existed as of mid-1966.
27. Mr. Ephraim O. Idusogie (now Dr. Idusogie) was largely responsible for the development of these allowances. He is now FAO Secretary for the Joint FAO/WHO/OAU Food and Nutrition Commission for Africa. Valuable assistance was received from Dr. Philip R. Payne of the London School of Hygiene and Tropical Medicine and from Dr. Dena Cederquist of the Department of Food Science and Human Nutrition, Michigan State University.
28. Their digestive tracts cannot process enough of the bulkier foods to meet their protein needs.
29. Calcium and riboflavin are below the goals originally sought since those turned out to be unattainable.
30. For earlier reports see Smith, "A Model of Nigerian Agriculture," *Optimal Resource Allocation*, and "Agricultural Planning."
31. Smith, "A Model of Nigerian Agriculture" and *Optimal Resource Allocation.*
32. If all slaughter occurred at the point of production so there were no weight losses in transportation.
33. FAO, *Agricultural Development in Nigeria*, Tables 2, 4, and 6, pp. 223–24. The figures include the output of the small commercial beef industry. For more detail see Smith, *Optimal Resource Allocation*, pp. 1–3.
34. We do not adjust for weight losses during transportation.
35. FAO, *Agricultural Development in Nigeria*, Table II-1, p. 392.

Chapter 3

1. There are also differences in availability as well as other problems related to the metabolic processes, as there are for other nutrients. As yet, the information needed for dealing with such problems in the formal model is not available.
2. FAO, *Protein Requirements: Report of a Joint FAO/WHO Expert Group*, FAO Nutrition Meetings Report Series no. 37 (WHO Technical Report Series no. 301) (Rome: FAO, 1965), p. 68.
3. FAO, *Report of a Joint FAO/WHO Ad Hoc Expert Committee*, FAO Nutrition Meetings Report Series no. 52 (WHO Technical Report Series no. 522) (Geneva: WHO, 1973).
4. FAO, *Protein Requirements*, pp. 68, 13.
5. Ibid., p. 13.
6. Ibid., p. 67.

7. Cystine, however, cannot be used to synthesize methionine.
8. In contrast with human milk, egg protein is easily fed to persons of all ages in experiments that require a control group to receive a reference essential amino acid pattern from a natural source.
9. E. W. Hartsook and H. H. Mitchell, "The Effect of Age on the Protein and Methionine Requirements of the Rat," *Journal of Nutrition* 60 (1956): 173–95.
10. FAO, *Protein Requirements*, pp. 33–39.
11. Ibid., Table 6, p. 36.
12. Ibid., p. 33.
13. Ibid., Table 6B, p. 36.
14. Ibid., Table 6A, p. 36.
15. Ibid., pp. 35, 39.
16. Ibid.
17. Ibid., Table 6A, p. 36.
18. Ibid., p. 33.
19. Ibid., pp. 35, 37.
20. By a "fully utilizable protein" is meant that all the protein that is absorbed is fully utilizable.
21. If the nicotinamide supplied by the diet is inadequate, part of the tryptophan will be diverted from tissue formation for use in the synthesis of nicotinamide. The completed model requires the diet to provide amounts of nicotinamide such that this diversion will not occur.
22. As previously noted, the requirement for methionine (column 2) has been set at 50 percent of the total sulfur-containing amino acid group instead of using the proportion of methionine in egg protein. Compare Hartsook and Mitchell, "Effect of Age," p. 179.
23. There is some evidence, however, that the acceptable tryptophan level may be as much as .22 g below that suggested in the 1957 FAO pattern. See Food and Nutrition Board, Committee on Protein Malnutrition, *Evaluation of Protein Quality; Report of an International Conference*, publication no. 1100 (Washington, D.C.: National Academy of Sciences/National Research Council, 1963), p. 17. The allowance in the present study is essentially at this lower level.
24. "When NPU is determined on food mixtures as ordinarily eaten by man . . . [values] are influenced not only by the amino acid composition of the diet but also by the concentration of protein and, where food is restricted, by the caloric intake. It would appear that in human diets these last two factors are the more important in determining the efficiency of protein utilization." Ibid., p. 26.
25. The "operative" net protein utilization is the value determined when the protein intake is above maintenance levels. FAO, *Protein Requirements*, p. 67.
26. Ibid., p. 68.
27. See D. S. Miller, "A Procedure for Determination of NPU Using Rats: Body N Technique," Appendix C, pp. 34–36 of "Biological Assay

Methods for Protein Evaluation," in National Research Council, *Evaluation of Protein Quality* (Washington, D.C.: the Council, 1963); and D. S. Miller and P. R. Payne, "Problems in the Prediction of Protein Values of Diets: The Use of Food Composition Tables," *Journal of Nutrition* 74 (1961): 413–19, and "A Theory of Protein Metabolism," *Journal of Theoretical Biology* 5 (1963): 398–411.

Our equation (4) may be converted to the notation of Miller and Payne by using the following definitions: $z = NPU_{(op)}$, $\frac{100\,u}{t}$ = the chemical score = $NPU_{(st)}$, $0.019 = k$, and $\frac{4(100)t}{C}$ = the percentage of protein calories = P. Equation (4) thus becomes

$$NPU_{(op)} = (NPU_{(st)} + 8)\ (1 - kP). \qquad \text{(A)}$$

This may be derived as follows: Miller ("A Procedure") gives

$$NPU_{(st)} = \frac{54[NPU_{(op)}]}{54 - P} - 8, \qquad \text{(B)}$$

where $NPU_{(st)}$ = net protein utilization (standardized), $NPU_{(op)}$ = net protein utilization (operative), and P = the percentage of protein calories. Hence

$$NPU_{(op)} = (NPU_{(st)} + 8)\ \frac{(54 - P)}{54}. \qquad \text{(C)}$$

Equating $1/k$ to 54 ("Problems," p. 414) yields

$$NPU_{(op)} = (NPU_{(st)} + 8)\ (1 - kP). \qquad \text{(A)}$$

Setting $NPU_{(st)} + 8$ equal to b, this is equation (8) in "Problems," p. 414. $NPU_{(st)}$ = the chemical score (ibid.).

In "A Theory" Miller and Payne give the same equation in different notation: $\theta = S(1 - kP)$. Although S is defined simply as protein score (p. 399), it is evident that the constant, 8, has been combined with it, for the value of S used for egg protein is 1.08 (pp. 402, 403). The empirically determined value of $k = 0.0189 \pm 0.0003$ (p. 402).

Miller and Payne foresaw exactly such use for their theory of the interrelationships between protein and energy metabolism as is made in this study. Knowledge of these relationships, they said, "would have an obvious application to agricultural practice . . . in planning the diets of human populations by regulating agricultural policy" ("A Theory," p. 398).

"A theory of nitrogen metabolism which can be applied to these problems must lead to a series of equations which can be used for quantitative predictions . . . . The resulting set of equations could be used . . . to programme a computer dealing with the problems involved in utilizing limited supplies of foodstuffs to meet the needs of the

vulnerable groups of a population which has a low purchasing power" (ibid., pp. 398–99).

The theory "should prove useful to economists and nutritionists concerned with the planning and utilization of food resources" (ibid., p. 411).

28. A brief summary of the results is contained in Smith, "A Model of Nigerian Agriculture."
29. This is in the range expected for developing countries. See FAO, *Protein Requirements*, p. 54.
30. The right-hand side values are also averages for Nigeria as a whole. They result from applying the scale of allowances by age and sex to each of the several areas within the country. Because of differences among areas in the age and sex distribution of the population, the actual per capita allowances vary somewhat from area to area.

Chapter 4

1. This was impossible prior to the development of linear programming, but now it can be done, as this chapter shows.
2. Arable land in the eastern moist forest can be expanded only at the expense of a reduction in yields. Bush pasture in the dry savanna is *reduced* by the amount of the increase in arable land in that area.
3. Such a result occurs often in least-cost diet studies. Meeting the protein requirement added nothing to the cost of the diet in two out of three of my models for Lansing, Michigan, at 1955 prices. See Victor E. Smith, *Electronic Computation of Human Diets*, MSU Business Studies. East Lansing: Bureau of Business and Economic Research, Michigan State University, 1964, Table V-3, *Supplement*, p. 33. In Father Fonseca's study of diets for 42 industrial centers in India, protein was usually not one of the controlling nutrients. A. Fonseca, "The Need-Based Wage in India: A Computerised Estimate," in Centre of Advanced Study in Economics, *Wage Policy and Wage Determination in India*, Papers and Proceedings of the Seminar held by the Centre of Advanced Study in Economics, University of Bombay, March 1969 (Bombay: the University, 1970), pp. 181–97.
4. The model provides for the consumption of milk from the herds of the Fulani, but it does not take account of the possibility of consuming the milk of camels, goats, or sheep, or, outside the savanna areas, of the possibility of altering the level of consumption of cow's milk.
5. Although higher levels might be attained in one or more individual parts of Nigeria.
6. The calcium allowance is 91 percent of the maximum attainable at the present riboflavin level; the riboflavin allowance is 88 percent of its maximum at the present calcium level.
7. NIH, *Nutrition Survey*, p. xx.

8. *Nigeria Year Book, 1973* (Lagos: Daily Times Magazine Division, n.d.), p. 191.
9. The CSNRD figure of £1.591 billion for 1967 works out to £26 per capita or 1.42s per day. This is *less* than the least cost of an adequate diet in one area (the central moist forest). Glenn L. Johnson, Orlin J. Scoville, George K. Dike, and Carl K. Eicher, *Strategies and Recommendations for Nigerian Rural Development, 1969/1985*, CSNRD 33 (East Lansing: Consortium for the Study of Nigerian Rural Development, Michigan State University, July 1969), Table I.1, p. 19.
10. In Part Two we will examine the effects of reducing the Area I calcium allowance to 330 mg.
11. See W. Godden, "Notes on Certain Edible Earths and Native Salts in Nigeria," *West African Medical Journal* 2 (1929): 187–89.
12. République du Mali, Mission Socio-Économique du Soudan, 1956–1958, *L'Alimentation des Populations Rurales du Delta vif du Niger et de L'Office du Niger* (Paris: Service des Statistiques, Chargé des Relations et de la Coopération avec les États d'Outre-mer, 1961), p. 14.
13. In my report on the previous model I suggested that attaining the specified protein levels involved no extra cost because of the high output levels allowed the animal industries in that model. It is now clear that it was not an overestimate of animal outputs but the basic relationship between production capability and the needs for riboflavin and calcium that caused this result. See Smith, *Optimal Resource Allocation*, pp. 1–2, 45–46.
14. The total food protein provided by this solution (in grams per capita per day) is:

Area	*Food Protein*	*Area*	*Food Protein*
I	74.0	IV	55.1
II	55.3	V	52.0
III	46.6	VI	69.1

15. The chemical scores are given below.

Area	*Actual score*	*Minimum score to provide specified allowance of reference protein*	*Excess of actual over minimum score*
I	88	55	33
II	82	70	12
III	83	80	3
IV	80	68	12
V	100*	68	32
VI	86	57	29

* Area V, the eastern moist forest, makes large purchases of millet from the dry savanna to help in meeting its allowances for riboflavin and calories and, possibly, calcium. The solution provides such quantities of the various essential amino acids that the whole of the food protein consumed can be employed in tissue formation (is fully utilizable). Indeed, there are excesses, for each of the essential amino acids, that cannot be used in the special roles of the essential acids because total nitrogen is the limiting element in this case (as it is for the protein of the hen's egg).

16. Gurney, "Considerations," pp. 50–51.
17. World Health Organization (hereafter WHO), *Requirements of Vitamin*

A, Thiamine, Riboflavin and Niacin, Report of a Joint FAO/WHO Expert Group, September 1965, WHO Technical Report Series no. 362, FAO Nutrition Meetings Report Series no. 41 (Geneva: World Health Organization, 1967), p. 40.

18. Ibid., p. 14.
19. Ibid., p. 40.
20. These are the maximum savings because the greater the reduction, the less one saves, in general, per unit of reduction.
21. WHO, *Requirements*, p. 40.
22. The minima for protein might be reached quickly in two of the three moist forest areas. In the present solution the actual chemical score exceeds the minimum required score by only 3 percentage points in Area III and 12 percentage points in Area IV.
23. For example, in the process that converts maize into ogi, a traditional infant food, some 40 percent of the protein and more than 50 percent of the calcium and phosphorus are lost. O. L. Oke, "Chemical Studies on the Nigerian Food-stuff 'Ogi,'" *Food Technology* 21 (1967): 202–204.
24. Other problems, such as faulty food choices for young children and the custom of feeding wives and children with leftover food, will not be helped much by a simple increase in the level of protein production. May, *Ecology of Malnutrition*, p. 61. Children do not receive an adequate share of the total food supply of the family. FAO, *Seminar on Food and Nutrition*, pp. 3, 13.
25. Nor do they allow for the limitations imposed by the fact that children under five are not physiologically able to make effective use of all the foods that can be consumed by adults.
26. Although it might be limiting with respect to a particular food, such as ogi, which is derived from maize.
27. Except for wine and beer. The maximum per capita limit for these commodities was equal to estimated 1963 consumption, as was the minimum limit for kola nuts.
28. In the western and central moist forests the limit is 12.2 kg per capita annually, while in the eastern moist forest it is 6.7 kg and in the forest-savanna mosaic 4.5 kg.

Chapter 5

1. Valued at the marginal costs of the nutrients provided in each area (the costs of adding one unit to the level of the allowance in that area).
2. Remember that the unnecessarily high calcium allowance had a large effect in the dry savanna, where it was extremely difficult to meet.
3. Reducing the level of the calcium requirement in the dry savanna would increase it, however, as would reducing our aspirations with respect to riboflavin levels in the moist forest areas.
4. John Cownie, *Nigerian National Income Accounts: Historical Summary*

and Projections to 1985, CSNRD 14 (East Lansing: Consortium for the Study of Nigerian Rural Development, Michigan State University, August 1968), p. 4.

5. There are indications that the authorities are beginning to re-evaluate the effects of such policies. For a recent study of consequences for land and labor utilization see Francis Sulemanu Idachaba, "The Effects of Taxes and Subsidies on Land and Labor Utilization in Nigerian Agriculture," African Rural Employment Paper no. 7 (East Lansing: Department of Agricultural Economics, Michigan State University, April 1973).
6. Federal Office of Statistics, *Review of External Trade, Nigeria, 1968* (Lagos: the Office, 1969), Table 4, p. 11.
7. The figures in Table 11 include the cost of transportation from the port. The model also assumes that the purchase of dried freshwater fish requires no foreign exchange, but this is unlikely to be true.
8. Their value is credited to the areas where the animals are slaughtered.
9. Johnson et al., *Strategies and Recommendations*, p. 23.
10. Although these fish come, in part, from Nigerian waters, they are not included as products of the agricultural sector.
11. Both stockfish (dried codfish) and dried freshwater fish (bones included) fulfill a special role in the actual Nigerial diet, for few foods are as easily transported and stored. Their low transportation cost is taken into account in this model, but not the ease with which they can be stored until the period of seasonal food scarcity.

    Stockfish, according to our data, cost less per kilogram than do dried freshwater fish, but the value of the nutrients they provide per shilling is much less than for the dried freshwater fish. In most areas the nutrients in the stockfish are worth only 11 to 35 percent of the price of the fish, whereas the dried freshwater fish, in most areas, provide nutrients worth 100 percent of the price. Unfortunately, our data on the prices of dried freshwater fish are less reliable than those for stockfish. However, a massive change in the price of freshwater fish would be required to make stockfish the more economical of the two.
12. Nigeria grows a small amount of sugar cane and is conducting research in sugar production at Mokwa. Insufficient data prevented inclusion of this activity in our model. Given the technical data, it would be simple to determine, from results already obtained in this solution, whether domestic sugar production would be a nutritionally efficient activity.
13. No data on fertilizer use for other production activities were available, although undoubtedly some was being used.
14. We have not calculated the amount, but it could be done.
15. These calculations do not include transportation charges for meat animals brought in on foot. Bringing those animals to market is regarded as part of the agricultural activity of the producing area. Table 12 has entries of 0.0 for the cases in which the animals normally are delivered on foot.

16. Table 14 shows 310 million pounds of red palm oil being shipped from Area II to Area I. This is simply passing through Area II after being purchased from Areas III and VI.

Chapter 6

1. Normally there would be fractional withdrawals from a number of activities because that would mean less loss of income than if the whole acre were taken from one activity. Furthermore, because some activities might expand their land use, the total amount of land withdrawn from the activities losing land well might exceed one acre in order that the net reduction in use would be exactly one acre. (If land were withdrawn from one food crop, some other food crop would have to expand in order to maintain the required level of nutrient production.)
2. More precisely, 1.095/1.200 or 91.25 percent of maximum levels.
3. Of course, the model is not intended to represent the actual nutritional and income goals of Nigeria, in 1963 or at any other time.
4. In a few special cases the gain from expansion may be less than the loss from contraction. Computationally, the entries in Table 17 relate to small *reductions* in acreage levels, but they will be discussed in terms of expanded acreage in conformity with the conventional practice among economists of letting the marginal increment be positive.
5. Eric Tollens, Agricultural Economist, personal communication, 31 March 1971; and John Whitney, personal communication, May 1969.
6. Export commodities can be subject to large fluctuations in price. Between May and September of 1968 the prices of palm oil in Singapore and of palm kernel oil in European ports dropped by nearly one-third. The palm oil price fell from $35.4 to $24.8 per 133.3 pounds, and the price of palm kernel oil fell from £170.1 to £121.2 per long ton. See FAO, *Monthly Bulletin of Agricultural Economics and Statistics* 18, no. 4 (1969), Table 22, p. 47. The low prices did not last long, to be sure. In 1970 and 1971 palm oil prices were above their levels in 1963 and 1964, but prices were down again in 1972, 16 percent below the 1963–1964 level. Palm kernel oil prices were above 1963–1964 levels through most of 1970 and 1971, but they were 25 percent below 1963–1964 levels in 1972. See FAO, *Monthly Bulletin of Agricultural Economics and Statistics* 20, no. 10 (1971), Table 25, p. 50, and 22, no. 4 (1973), Table 20, p. 47.
7. Although the same yield and input coefficients have been used in each area, it is, in fact, unlikely that soil and climate are as well suited to oil palm production in Area VI as in the moist forest areas. These results should be taken to mean that expansion of oil palm production could be advantageous (at the prices used in this model) in those parts of Area VI best suited technically to palm production (presumably, near the area's southern boundary). Of course, if the opportunity cost

of land varies gradually from Area III to Area VI, the true surplus in the relevant part of VI may be considerably less than the calculated figure of 754s.

8. While there are conventional limits on the aggregate level of consumption of a particular food in any given area, these are not likely to prevent an efficient crop from expanding to its maximum limit. The model permits consumption to expand by 300 percent in any one area, while an individual production activity can expand by only 20 percent. Only if consumption in an area is much less than production (as when an activity produces largely for shipment to other areas) can the consumption limit prevent an efficient production activity from expanding to its own production limit.
9. This is not surprising. Deviations from a pattern that is optimal in the sense of this study can be caused by ignorance of nutritional needs or of the nutritional merits of the various foods, an income or productive capacity that is too low to provide the full set of nutrients needed, or a preference for using one's income or productive capacity for other purposes than obtaining fully adequate nutrition.
10. In Part Two it will be seen that when the calcium allowance is revised downward maize becomes a nutritionally efficient crop.
11. For mixed rice, they are 400 pounds per acre in Areas I and II; for sole rice, 600 pounds per acre in Area I and 640 in Area II. These are perhaps not too far off for upland rice, but under traditional practices swamp rice yields easily reach 1,100 pounds per acre. R. B. Woodroofe, Chief Agricultural Officer, Kano State Ministry of Natural Resources, Kano, Nigeria, personal communication, 1969.
12. There also might be profitable export opportunities for certain food crops if the problems of transportation, storage, and national barriers against imports could be solved. This study, however, did not examine these possibilities, except for foods that already are being exported in significant amounts—groundnuts, red palm oil, soy beans, and cocoa. (Cocoa is not regarded in this model as a food that can be used within Nigeria.) Where a food that can be used within Nigeria has an export market alternative, the part of the food that is exported is valued at prices determined in the foreign market, while the part that is consumed within Nigeria is valued at the value of the nutrients it contains. The existence of the export opportunity equalizes these two valuations, after adjustment for marketing and transportation charges and so forth.
13. What is called here sole bush maize in the central moist forest actually may represent an improved method of cultivation. At least our yield estimate, 1,870 pounds per acre, is in the range appropriate for commercial maize. The acreage grown as sole maize in Area IV in 1963 was very small.
14. The yield estimate on which this figure is based, 800 pounds per acre, probably implies that improved methods of cultivation were employed. The acreage grown as a sole crop in 1963 was very small.
15. This question will be discussed further in Part Two.

16. The average number of crops grown together was as follows, by areas:

Area	*Number of crops*	*Area*	*Number of crops*
I	2.42	IV	2.25
II	2.43	V	2.62
III	2.32	VI	2.23

17. Fortunately, intercropping is beginning to receive more attention. See David Norman, *An Economic Survey of Three Villages in Zaria Province: 2. Input-Output Study, Vol. 1. Text*, Samaru Miscellaneous Paper 37 (Zaria, Nigeria: Institute for Agricultural Research, Ahmadu Bello University, 1972), pp. 71–101, and *Economic Analysis of Agricultural Production and Labour Utilization among the Hausa in the North of Nigeria*, African Rural Employment Paper no. 4 (East Lansing: Department of Agricultural Economics, Michigan State University, January 1973), pp. 21–27, 32–43. See also David Norman, "Initiating Change in Traditional Agriculture," *Proceedings of the Agricultural Society of Nigeria* 7 (1970): 6–14, "Intercropping of Annual Crops under Indigenous Conditions in the Northern Part of Nigeria," paper presented at a conference on Factors of Agricultural Growth in West Africa, organized by the Institute of Statistical, Social and Economic Research of the University of Ghana, Legon, Ghana, March, 1971, and "The Rationalization of a Crop Mixture Strategy Adopted by Farmers under Indigenous Conditions: the Example of Northern Nigeria," mimeographed, n.d., and work cited in these papers.
18. Norman also has found mixed cropping the more profitable. See his *Production and Labour Utilization among the Hausa*, pp. 34–43, and "Rationalization of a Crop Mixture Strategy," pp. 8, 12–13. See also his "Initiating Change in Traditional Agriculture," and the research cited on p. 10 of "Rationalization of a Crop Mixture Strategy."
19.

Area	*I*	*II*	*III*	*IV*	*V*	*VI*
Surplus from yams and maize (shillings per acre)	382	1071	1263	703	316	505
Largest sole crop surplus (shillings per acre)	1498	673	641	658	233	837

20. See also Norman, *Economic Survey*, pp. 87–101.
21. With the proviso that policy should not be built on the results for the dry savanna because of the unnecessary importance that the calcium allowance has in that area. The selection of activities in Area I is heavily influenced by the difficulty of finding economic sources of calcium there. Although our calcium allowance (389 mg per capita) is low, there is little evidence from physiological studies that calcium deficiencies are common in this area. Some nutritionists maintain that as little as 300 mg of calcium per day may be adequate. If we were to accept that level as a satisfactory allowance for Area I, the list of most advantageous crops in that area might be quite different.

22. Tobacco yields *do* represent improved techniques. The plant is grown by contract with the Nigerian Tobacco Company, under careful supervision.
23. They also may be slightly overstated because the farmers using such improved practices incurred expenditures, for spray materials, fertilizer, and so forth, that were not taken into account in our calculations.
24. The evaluation is based on estimates provided by Mr. Richard B. Woodroofe, Chief Agricultural Officer, Kano State Ministry of Natural Resources.
25. Migratory animals grazing during the dry season add fertility to arable land, but this relationship is not included in the model.
26. Should a lower riboflavin allowance be acceptable, however, the advantage of goats and sheep would diminish or disappear.
27. The calculations do not take account of the damage sheep and goats may do to trees and shrubs (and gardens). In some situations this may be significant.
28. The revenue from the sale of hides and skins is a significant component of the total value of the product from the meat animal industries.
29. It is assumed that all hides and skins are sold.
30. Some observers have stated that the principal outputs of the northern cattle industry are milk and butter, with the beef output simply a salvaging operation.
31. In some parts of Nigeria no one would think of drinking goat's or sheep's milk.
32. While earnings per acre are small, if there are indeed no valuable alternative uses for the resources required, except for the pasture, the return over outlay may be quite respectable. Sheep yield a surplus amounting to 54 percent of the value of the land used; goats yield a 17 percent surplus at these levels of output.
33. This activity uses arable land as pasture.
34. Those are cassava, cowpeas, and okra (as mixed crops), plus okra as a sole crop.
35. FAO, *Agricultural Development in Nigeria*, Tables 2, 4, and 6, pp. 223–24.
36. The use value in this solution of the bush pasture available for Area I animals consists of 1,055 million shillings earned by cattle, 96 million from goats, and 33 million from sheep.

    Not all the land used for Area I animal production is located physically within that area. The Fulani cattle range over lands located in both the dry and the intermediate savannas, going south into the latter areas during the dry season when the tsetse fly retreats from the higher lands. They spend perhaps eight months of the year on land located physically within the intermediate savanna. By Area I bush cattle is meant cattle of the type owned by the Fulani herdsmen. For convenience, all the land they use has been included as Area I pasture. The sheep and goats belonging to the Fulani also range over this area.

However, most sheep and goats in the dry savanna belong to settled farmers and do not leave that area.

37. Although the model does not permit converting arable land to use as pasture, the opportunity does exist and should be taken into account. Specifically, this means that every crop surplus figure shown for Area I in Tables 17, 19, 20, and 21 should be reduced by 2.8s, what the land could earn as pasture.
38. In the dry savanna the period of peak labor requirements comes in June and July rather than in May and June. The May–June data are satisfactory proxies for the June–July period.
39. The surplus from yams and maize is 1,263s; the value of the land use is 309s (Table 25); the total value of the nutrients produced is 1,572s per acre. For cocoyams as a sole crop the calculation is: surplus (559s) plus land use (309s) = 868s.

Chapter 7

1. The calcium allowance is undoubtedly too high in the dry savanna. There are also nutritionists who would accept a lower riboflavin allowance.
2. Although some nutritionists feel that a lower riboflavin intake would do little damage to health.
3. If the riboflavin allowance were lowered, eventually some other allowance, perhaps that for protein, would replace riboflavin as a determinant of trade.
4. Planning for tree crop production, of course, should be based upon projections of world prices for exports, not upon the prices existing at some past date. Our results are quite favorable to palm oil production, but recent prices have been both above and below the levels used in this model.

   Changes in the levels of tree crop activities take years to bring about (or to undo), so it would be well to run the model using forecasts of the world prices of export crops as a basis for policy decisions with respect to tree crop expansion or contraction.
5. In future years, as the proportion of children in school increases, the available quantity of this type of labor will be even smaller.

Chapter 8

1. Results from the first two models appear in Smith, "A Model of Nigerian Agriculture," and *Optimal Resource Allocation.*
2. The labor required for the care of these animals outside Area I was assumed to be provided by children and the aged, people who would

not have been suited for alternative employment in the fields. At the same time it was assumed that the scale of these activities could expand by 20 percent even though the population grew by only 9.5 percent. If the 1963 levels of activity made full use of the available quantities of such labor, the expansion that could occur, without causing competition for labor with alternative agricultural activities, should have been limited to the percentage growth of population.

3. FAO, *Protein Requirements*, Table 6A, p. 36.
4. Data concerning traditional methods were not available for the rest of the country.
5. As the result of information obtained from Olatunde A. Ojomo, *Cowpea: Production and Research in Western State of Nigeria* (Ibadan: Research Division, Ministry of Agriculture and Natural Resources, September 1967), p. 15.
6. Assistant Research Fellow, Department of Plant Science, Institute of Agricultural Research and Faculty of Agriculture, Ahmadu Bello University, Zaria.
7. Of the Institute for Agricultural Research.
8. The increases were for groundnuts in the dry savanna and for cotton and rice in both savanna areas.

Chapter 9

1. In the previous model using gathered and collected foods at 106.33 percent of 1963 levels placed the solution inside the boundary of the feasible area, even though more calcium was required in the dry savanna.
2. Our average daily riboflavin allowance of 1.02 mg per person essentially equals the recommendation made by the 1965 Joint FAO/WHO Expert Group for an average adult, with no margin for individual variation: .44 mg per 1,000 calories, or .997 mg for the calorie allowance of 2,266 used in this study. See WHO, *Requirements*, p. 40. If riboflavin deficiencies are of little nutritional importance, as Dr. J. M. Gurney maintains, this allowance could be lowered, making the diet easier to obtain and less costly. It seems likely, however, that meeting the calorie allowances still would be difficult under the conditions of the model. See Gurney, "Considerations," p. 51.
3. Where not quite 109 percent of 1963 levels of gathered and collected foods were being used.
4. For equilibrium, the values in the three areas must be related as follows:

$$cp_{c2} + ap_{a2} = cp_{c3} + ap_{a3} + t_{32} = cp_{c0} + ap_{a0} + t_{02},$$

where

c = thousands of k calories in one kilogram of red palm oil;

a = thousands of International Units of vitamin A in one kilogram of red palm oil;
t_{ij} = cost of transporting one kilogram of red palm oil from Area i to Area j, in shillings;
p_{ci} = value in shillings of 1,000 k calories in Area i, and
p_{ai} = value in shillings of 1,000 International Units of vitamin A in Area i.

Inserting the numerical values used in the model yields

$$9p_{c2} + 200p_{a2} = 9p_{c3} + 200p_{a3} + .374 = 9p_{c6} + 200p_{a6} + .374.$$

However, the opportunity-cost value of vitamin A in Areas III and VI is zero, and the transportation cost from either III or VI to Area II is the same in the model, so $p_{c3} = p_{c6} = p_{c2} + \frac{200}{9} p_{a2} - \frac{.374}{9}$. As the opportunity-cost value of vitamin A in Area II is .00175s per 1,000 International Units, $p_{c3} = p_{c6} = p_{c2} + 1/9\ (.350 - .374) = p_{c2} - .0027$. The actual value for either p_{c3} or p_{c6} is 2.8318s per 1,000 k calories; for p_{c2} it is 2.8345s per 1,000 k calories (or 6.42s for 2,266 calories in each area, as in Table 31).

5. Setting a lower allowance for riboflavin would reduce the advantage shown here for goat meat and mutton.
6. Remember, however, that groundnut oil is not used much in Areas III and VI, so the maximum limits on consumption in those areas are very low. In this solution neither groundnut oil nor red palm oil can be spared from use as food for export sale, but a small amount of groundnut seed is exported that could have been pressed for oil.
7. Sugar, groundnut oil, and some other commodities have essentially the same surpluses in Areas II, III, and VI. This is because their principal (or only) contribution is calories, which have the same high value in each of these areas. Moderate differences in transportation costs have little effect.
8. Lower maximum limits on the consumption of millet, sorghum, and certain other foods also contributed to this result, especially in Areas V and VI.
9. The wheat consumed in Area II is produced within Nigeria.
10. Some sugar is actually produced within Nigeria, but because production data were unavailable, in the model all sugar comes from outside the country.
11. Except for the dry savanna, where the unduly high calcium allowance in the earlier model caused an unduly high cost level for 1963 techniques.
12. Riboflavin is not a costly nutrient under traditional techniques in the western moist forest, probably because large quantities of dried freshwater fish are being consumed there.

Chapter 10

1. The model assumes that European-style beer is produced within Nigeria, using imported materials. I regard it as a product of the industrial rather than the agricultural sector of Nigeria.
2. The model treats dried freshwater fish as though all of it comes from the nonagricultural sector within Nigeria. Its purchase does not require foreign exchange.
3. In the limiting case, *as* cheaply as any of the alternatives.
4. There it amounts to .70s per day.
5. Subject to the limitations inherent in the model. There are maximum limits on individual income producing activities that might prevent some transfers from food to income production. Conversely, there are upper limits on food production activities, so it may not be possible to shift all resources from income to food production.
6. The revenues shown in Table 38 represent those attributed to the agricultural sector. The amount of foreign exchange yielded by an agricultural export activity is considerably greater, for the export price includes the value of transportation and marketing services rendered after the produce leaves the farm.

   In turn, the revenue attributed to the agricultural sector exceeds the amount the farmer receives by the amount of the margin retained by the marketing board plus any taxes that may be levied against the produce. These payments are regarded as a part of the social product of the agricultural sector.

   For the same reasons, the cost of food obtained from other countries is more than the foreign exchange required to purchase that food. The cost charged in Table 38 includes payments for transportation and marketing services rendered by the nonagricultural sector within Nigeria. The model regards these as paid for with Nigerian currency. It is true, of course, that the transportation industry itself uses foreign exchange in payment for trucks, road building equipment, and, until recently, gasoline and diesel oil, but this is not taken into account in our calculations.
7. This is almost four times the CSNRD estimate (£1.59 billion) of the total Gross Domestic Product of Nigeria in 1967. See Johnson et al., *Strategies and Recommendations,* Table 1.1, p. 19. Obviously these nutrient values, the opportunity costs of small increases in nutrient output when only traditional production techniques are being used and output levels are already high, represent a very different price level than actually prevailed in 1967 markets.
8. The comparisons here are in physical—adequate levels of nutrition—rather than value terms. The price levels used in the two models are very different, for what is substantially the same set of nutrients is valued at 25.6 billion shillings when 1963 techniques are used and at 119 billion shillings when traditional techniques are employed. Restrict-

ing the techniques available dramatically increased the marginal costs of producing nutrients.

In physical terms, the sets of nutrients provided in the two models may be regarded as substantially equal, although, in fact, nutrient requirements for the model using traditional techniques are somewhat lower since the calcium requirement was lowered for the dry savanna. Consequently, the gain in productivity from replacing traditional techniques by 1963 methods was actually somewhat greater than 9 percent. (While the present model has a higher requirement for the sulfur-containing amino acids, this was not a controlling nutrient in either solution, so the change does not interfere with the comparison.)

The lower calcium requirement for the dry savanna did alter the distribution of value among the costly nutrients to a considerable degree. When 1963 techniques were used, calcium provided some 40 percent of the value, with calories providing another 40 percent and riboflavin nearly 20 percent. Given traditional techniques and the lower calcium allowance for the dry savanna, the percentage of the value formerly allocated to calcium seems to have been divided almost equally between calories (nearly 60 percent) and riboflavin (nearly 40 percent).

The set of resources available to agriculture was even more alike in the two models. From this point of view the principal modifications made in going to the present model were the reduction of maximum limits on the traditional animal industries outside the dry savanna, the imposition of lower limits on the consumption activities for millet and sorghum in Area V and on Irish potatoes and sweet potatoes in Areas III, IV, and V, and the increase in the use of gathered and collected foods by 3 percent (from 106.33 to 109.5 percent of 1963 levels). The effects of these changes more or less offset each other.

9. These are carcass weights at the point of origin.
10. Much lower than the price used in this study. Dried freshwater fish with 20 percent water content provides 3 calories per gram, while salt cod (stockfish) with 52 percent water content provides only 1.25 calories per gram. See Platt, *Representative Values of Foods,* Items 182 and 183, p. 22.

    Buying stockfish would require the use of foreign exchange, of course. However, that would not matter in this solution, for the agricultural sector is providing more foreign exchange than is needed for the purchase of food.

Chapter 11

1. In the present model, soybeans may be grown in both savanna areas as well as in the forest-savanna mosaic. In the earlier model they were permitted only in the latter area.
2. Yet tobacco in Area II yields the fourth largest surplus of all the sole field crops when 1963 techniques are used in all of Nigeria.

3. These surpluses cannot be compared meaningfully with those presented in Part One (in Table 17, for example) because the price level at which nutrients are being valued is very different in the two cases.
4. Palm products not used for food are valued at 1963 world market prices (which measure their worth to Nigeria), not at the lower prices the marketing board pays the farmer.
5. An exception is possible if only a small part of the 1963 production in an area was consumed within an area, so that per capita consumption levels there were much less than per capita production levels. This is rare.
6. This assumes that the hay is used to feed sheep that are raised on hay during the whole year. If the hay were used only during the dry season, it undoubtedly would be worth more. We did not have the data needed to evaluate the latter alternative.
7. See Table 48 below.
8. Onions would be kept below their maximum limit in any case because there is only enough manure available in this area to support a production of 150,000 acres. However, the production level in this solution is actually slightly less than this, 149,691 acres. At this level an acre of land in onions yields a product exactly worth the value of the land employed: 1,380s. No value is attributed to manure in this area, and it has no other use, and therefore no opportunity cost, in this model. In fact, it is not economical to use quite all of the manure available in the area.
9. In the model the average number of crops grown on the same piece of land, by areas, is as follows:

Area	*Number of Crops*	*Area*	*Number of Crops*
I	2.42	IV	2.25
II	2.43	V	2.62
III	2.32	VI	2.23

10. In addition, there is oil palm production in Area III.
11. In both models some of the yield figures for maize in Areas III to VI are rather high:

Bush maize		*Commercial maize*	
Area	*Yield, pounds per acre*	*Area*	*Yield, pounds per acre*
III	850	III	1,700
IV	1,870	V	1,800
VI	1,240	VI	1,400

12. No one recommends feeding sheep on hay alone as an efficient method of production for Nigeria. I have included such an activity simply as a means of evaluating the nutritional importance of the traditional practice of raising cowpeas for hay as well as for seed.
13. The increase in arable land in Area I has been subtracted from the amount of pasture available in 1963.
14. As all the meat produced is consumed in the central and eastern moist forests and the forest-savanna mosaic in this solution, the factors in-

volved in the superiority of goats and sheep include the weight loss in transit and the quantity of riboflavin provided per pound of carcass weight. If the riboflavin allowance were lowered this superiority would diminish or disappear.

15. If labor were the only limiting factor, the relevant criterion for choice among the three activities would be earnings per man-day of labor employed, but I do not have labor-use data for these activities.
16. Again the relevant criterion is earnings per man-day.
17. The reduction in yields would be as large as 5 percent if all of the additional 322,027 acres available were brought into use.
18. The values assigned to resource services must have the property, for each limiting resource, that the total resource requirement of activities that yield products worth more than the services they require shall not exceed the stock of the resource available and that the stock of the resource available shall not exceed the quantity required to support all activities yielding zero surpluses in addition to those yielding positive surpluses. If the second condition is not fulfilled, the resource is not limiting and its opportunity-cost value is zero.
19. Cowpeas, soybeans, and groundnuts as sole crops and cotton and groundnuts as mixed crops.
20. Our solution indicates the directions in which greater output lies, but not how far Nigeria should move in those directions in order to maximize the nutritional productivity of its agriculture. If the model had allowed the especially efficient crops to expand more than 20 percent above their 1963 levels, our calculated aggregate Nigerian nutrient production capacity, using traditional methods, would have been significantly larger. The data do not permit an estimate of how much the aggregate production capacity would be increased by greater specialization in the most nutritious crops. There are obvious limits, set in part by the limited quantities of land that are suitable in situation, soil, and climate for a particular crop, but there are no data that would permit determining just what those limits are.

    Rather than produce overly optimistic estimates of the gains that might result from specialization, arbitrary limits at 20 percent above 1963 levels have been imposed. Thus any recommendations made will be based upon efficiency measures calculated from production patterns sufficiently similar to actual 1963 patterns to ensure that the production coefficients based upon those patterns still will be relevant. Efficiency calculations based upon a solution that doubled the acreage in maize or in yams would be very promising, but to believe that those acreages (or many others) could be doubled without seriously affecting input requirements and yields would be naïve indeed. Consequently, our method is to set arbitrary limits relatively near to the acreage levels upon which the data are based and to compute, at those limits, in which direction additional changes could be made that would yield still further improvements in the total productivity of Nigerian agriculture.

21. If yields of 1,700 to 1,900 pounds per acre can be obtained.
22. In its present form the model does not indicate whether or not oil palm expansion in the eastern moist forest is advisable.

Chapter 12

1. Oil palm production in the eastern moist forest undoubtedly would be at a much higher level (and calories be less costly) if the model allowed Area V to send red palm oil to the savanna areas.

Chapter 13

1. The calcium provided by one kilogram of dried freshwater fish had a value of 4.38s, the calories were worth .76s, and the price of the fish was 5.14s.
2. Other reductions in maximum consumption levels were also effective, but none was of major importance. The increase in the number of foods appearing in the Model Four list of foods possessing superior nutritional efficiency is one consequence of these lower maximum consumption levels, especially in Areas V and VI.
3. If the total quantity of protein to be produced is markedly increased, the relative proportion of protein to riboflavin will be increased in the set of allowances. At some point, as this proportion changes, protein will become a costly food—one of the controlling nutrients—and riboflavin will become less costly, or perhaps even costless. A nutrient is costly when the proportion in which it is to be provided for consumption exceeds the proportion in which it can be produced without extra cost.
4. In Model 4, with one exception, these crops appear on the list only in the areas using 1963 techniques.

Chapter 14

1. For both rice and groundnuts the 1963 data appear to be inferior in quality to the data concerning traditional methods. The rice data for 1963 methods do not discriminate between swamp and upland rice; the groundnut data do not discriminate between yields in the two savanna areas.
2. Nine of these are food crops if two are included that are usable either for food or for export sale. For the tenth crop, cotton, 1963 data actually show smaller yields than the data representing traditional techniques.
3. $R + 6.23 - (R - 1.01) = 7.24$.

4. *Marginal cost* is the cost of adding one unit of a nutrient to the quantity available in a given area.
5. In the dry savanna the calcium allowance was unnecessarily high in the model that used 1963 techniques. This cancelled the benefits from improved techniques.
6. Except in the dry savanna, where the unnecessarily high allowance for calcium dominates the situation.
7. In the model that used traditional methods riboflavin was not costly in the western moist forest because quantities of dried freshwater fish entered the consumption pattern in order to meet the calorie allowance.
8. Except for dried freshwater fish, which occurs in the dry savanna when 1963 methods are used. Probably it occurs there only because the calcium allowance in that model is unnecessarily high.
9. Both groundnut oil and red palm oil provide food energy, but only the palm oil provides vitamin A.
10. That is, it expands to our maximum limit, 20 percent above the actual 1963 level. Using traditional methods in the savanna areas had forced cocoa acreage down to half that actually in use in 1963.
11. Naturally more labor per acre does not necessarily imply more labor per unit of output.

Chapter 15

1. These three paragraphs describe not only the basic results of Models Three and Four, discussed in this volume, but also of Model Two, their immediate predecessor. In all major respects the models corroborate each other. See Smith, *Optimal Resource Allocation*, pp. 1–2.
2. For a summary of commonly recommended levels see Margaret E. Cameron, "Amounts of Nutrients Required by Humans in Their Diet," *Review of Nutrition and Food Science*, no. 1 (October 1965): 17–19.
3. Nor was it usually critical in Father Fonseca's studies of least-cost diets for 42 industrial centers in India. See Fonseca, "Need-Based Wage," p. 194; and Smith, *Electronic Computation*, Table V-3, *Supplement*, p. 33.
4. The International Institute for Tropical Agriculture, Ibadan, Nigeria, plans research on yams and sweet potatoes as well as cowpeas, maize, rice, and cassava. P. A. Oram, "The Technical Advisory Committee (TAC) of the Consultative Group on International Agricultural Research," *PAG Bulletin* 3 (Spring 1973): 22.
5. Gurney, "Considerations," pp. 51–52.
6. When designing the model we did consider determining diets for the very young child as well as for the adult, but decided to leave that refinement for a later time. It could be done quite readily and undoubtedly would be well worthwhile. Because of the need for some relatively concentrated sources of protein, the solutions from such a

model might place more importance on animal protein than does the present study.

7. Of course, unless the model specifically requires it, one cannot be certain that a set of foods nutritionally adequate for the family as a whole will be divisible into two sets, one adequate for the very young and the other for the remainder of the family. To make certain that this will be possible the model must require explicitly that consumption sets appropriate for each of the two age groups be provided.

   The nutrient allowances specified by the model do provide for the special nutrient needs of the growing child, the pregnant and lactating mother, and so on. They were arrived at by adding the allowances for each of the various age groups in the population, not by taking some fraction of the allowances for an adult male.
8. P. V. Sukhatme, "Size and Nature of the Protein Gap," *Nutrition Reviews* 28 (1970): 223.
9. Ibid., pp. 223–25.
10. WHO, *Requirements*, p. 40.
11. Ibid., p. 14.
12. Ibid., p. 40.
13. Gurney, "Considerations," p. 51.
14. And he should not be, for although a significant share of the total cost of the diet is attributed to riboflavin, the diet as a whole provides the desired quantities of the whole set of nutrients in a very economical fashion.
15. Gurney, "Considerations," p. 51.
16. See FAO, *Protein Requirements*, Tables 2 and 11, pp. 22 and 51.
17. Gurney, "Considerations," p. 51.
18. WHO, *Requirements*, p. 40.
19. I now feel that in an early interpretation of my results (Smith, "Agricultural Planning") I assigned too much importance to providing the recommended quantities of riboflavin. I am indebted to Gurney's note, "Considerations," in *Nutrition Reviews* for an evaluation of this matter.
20. Donald R. Schmidt, Agronomy Department, Cornell University, Ithaca, New York, personal correspondence, 22 April 1969.
21. Amounting to .84 mg of riboflavin per 100 g of edible portion. Bernice K. Watt and Annabel L. Merrill, *Composition of Foods . . . raw, processed, prepared*, revised, December 1963 (Agriculture Handbook No. 8), Consumer and Food Economics Research Division, Agricultural Research Service, U.S. Department of Agriculture (Washington, D.C.: U.S. Government Printing Office, 1963), p. 28.
22. That easily could be done by an extension of the study.
23. At least for the four that are costly in these solutions. (The solutions provide only the minimum quantity of any nutrient in an area where it is costly.)
24. Kenyon Payne, Department of Crop and Soil Science, Michigan State University, East Lansing, personal communication, 10 June 1971.

25. Dr. P. Mahadevan has reported that research at the University of the West Indies has shown the pigeon pea to be a valuable source of protein (speaking before the International Conference on Nutrition, National Development and Planning, Massachusetts Institute of Technology, Cambridge, 19–21 October 1971). Dr. Melak Mengesha of Haile Sellassie I University, Addis Ababa, reports that use of the pigeon pea is promising in the semiarid tropics (speaking before the Tropical Studies Group, Michigan State University, East Lansing, 14 February 1973).
26. Oram, "Technical Advisory Committee," p. 22.
27. Personal communication from Dr. Edwin T. Mertz, who discovered the high-lysine gene.
28. Harold L. Rice and Andrew H. Pettifor, "The Probyte: A New Protein Unit System," *Journal of Agricultural and Food Chemistry* 20 (1972): 512.
29. United Nations Protein Advisory Group, "PAG Guideline (No. 14) on the Preparation of Defatted Edible Sesame Flour," *PAG Bulletin* 3 (Spring 1973): 12, 13. Sunflower seeds were not included in the model for lack of data.
30. See Smith, *Electronic Computation*, pp. 121–24, 182–85, 61–67.
31. FAO, Nutrition Division, Food Consumption and Planning Branch, and U.S. Department of Health, Education and Welfare, Public Health Service, Health Services and Mental Health Administration, National Center for Chronic Disease Control, Nutrition Program, *Food Composition Table for Use in Africa* (Bethesda, Md.: U.S. Department of Health, Education and Welfare, 1968), p. 5.
32. The estimates apply to limited expansions in acreage. In general, as acreage expands the gain from an added acre diminishes. Consider two crops, one of which (crop G) will add 1,000s of net revenue per acre and the other 500s. It would be worthwhile to spend more on the promotion of crop G because a considerable expansion of acreage in G might be possible before the yield per added acre was driven down to 500s. Estimates can be computed of the amount of expansion necessary to drive the gain per added acre down to any specific figure, such as 500s, but this has not been done in the present study.
33. The efficiency of goat production is the result, among other things, of the high value attributed to their skins in the model and the high riboflavin content of their meat. Lowering the riboflavin allowance would reduce the relative advantage of goats.
34. No attempt was made to compare the cost of purchasing sugar with that of producing it within Nigeria. Data were unavailable that would permit including growing sugar cane as one of the activities in the model.
35. John C. Caldwell, Demographic Research and Training Unit, Faculty of the Social Sciences, University of Ife, personal correspondence with Carl K. Eicher, 6 April 1969.

Appendix A

Potential Improvements And the Capacity to Produce Nonfood Income

Potential Improvements And the Capacity to Produce Nonfood Income

with Hossein Yaghoobi-Rahmatabadi

In countries where a large part of production is for subsistence, food crop production may receive too small a share of agricultural research and development expenditures simply because the benefits from improving food production are not readily measured, while the benefits from improved production of crops sold for income are quite obvious. In chapters 10 and 14, however, we saw that it is possible to estimate the benefits from improved production methods, whether for food or nonfood crops, and to do so without making use of market prices for food. (In a subsistence economy representative food prices may not exist.) We do this by determining how much nonfood income can be produced from a given set of resources with each set of agricultural methods, subject to the requirement that the same quantities of nutrients be provided in each case.

Method

The method, in summary, is as follows.

We divide the income that agriculture produces into either *food* or *nonfood* items. The former means food consumed within Nigeria; all other income is "nonfood." Let the purpose of food production be meeting nutritional needs (for the urban as well as the rural population). Resources not used to meet nutrient needs can produce nonfood income. To establish a standard basis from which to measure the potential benefit implicit in a set of agricultural improvements, we specify a constant set of nutrient quantities to be provided.[1] An improvement in food production reduces the resources required for meeting these nutrient objectives and permits producing more nonfood goods. Improvements in nonfood production expand nonfood output directly. The effects of every improvement, whether in food or nonfood production, are converted into changes in the output of nonfood income.

Nonfood income can be measured in value terms, at market prices. We take these as constant; based for the most part on world market prices, they are essentially independent of Nigerian output levels. Market prices are not needed for food output, for that is being measured in terms of its nutritional adequacy. Food is simply an intermediate good used in the production of nutrients.

This method is also useful, even when food prices are available, in any country in which nutritional well-being is an important national objective. Evaluating improvements at market prices for food does not measure the nutritional significance of increased food production, for market prices are not good measures of how well foods meet nutritional objectives.

In this appendix we ask how Nigeria's capacity to produce nonfood income would have been affected if certain improved production practices had been available that were not available or in general use in 1967. One set, the "recommended practices," consists essentially of practices being recommended by the Nigerian agricultural extension

[1] A variant procedure would hold constant the bill of food items instead of the bill of nutrients. However, this prevents economizing by making substitutions among foods in response to the differential cost reductions that agricultural improvements bring.

Another variant would specify a set of demand functions to be satisfied, but this requires data on market prices and would mean that the set of nutrients provided would vary.

services in 1969. A second set, the "prospective varieties," is based upon forecasts of what the plant breeders may accomplish by 1975 or 1980. In both sets there are improved methods for nonfood as well as food production. We do not measure the benefits of the two types of improvements separately, although, of course, that could be done. We compare the levels of nonfood income attainable when one or both of these sets of practices is available with the levels attainable with 1963 methods, or by the use of traditional methods in the savanna areas. (See chapters 5, 10, and 14 above.) Yield data for all production activities are given in Table 1A.

The solution of the computer model for any given set of agricultural techniques yields N_a, the gross value at the farm of the nonfood income produced by the agricultural sector, E_a, expenditures by the agricultural sector on production inputs and services from other sectors, and F_b, expenditures by the nonagricultural sectors on the purchase, production, or transportation of food. As E_a and F_b are contributions from the nonagricultural sectors, the net contribution of the agricultural sector to the nonfood income of Nigeria equals $N_a - E_a - F_b$.

Traditional and 1963 Technical Levels

Table 2A gives the numerical results of producing at the traditional and 1963 technical levels. As was seen in chapter 14, using traditional methods in the savanna areas the agricultural sector could produce nonfood income with a gross value of 1.3 billion shillings annually (N_a). (Nearly half of this consists of by-products from food production activities: palm kernel and products, hides and skins, and groundnut cake.) In addition, the nonagricultural sector must provide food worth 6.8 billion shillings and transportation services worth 700 million shillings. The productive capacity of the agricultural sector by itself falls 6.2 billion shillings short of the value of the total food required by the model.

With 1963 techniques the potential value of gross nonfood production becomes 2.6 billion shillings. Increased food production efficiency has made it possible to export groundnuts and red palm oil that otherwise would have been needed as food and has more than doubled the acreage that can be spared for the production of cocoa. The net contribution of agriculture to nonfood income becomes 1.0 billion shillings.

Table 1A. *Yields at Four Technical Levels, in Pounds per Acre*

Crop	Area and level of technique											
	Dry savanna						Intermediate savanna					
	Mixed		Sole				Mixed		Sole			
	Trad	1963	Trad	1963	Rec	Pros	Trad	1963	Trad	1963	Rec	Pros
Maize												
°Bush	740	1,050	840	1,200			520	1,250	540	1,300		
Commercial					1,500	4,500					1,360	4,500
Early												
Late												
°Millet	440	540	470	580	800	3,000	400	540	440	600	790	3,000
Rice												
Unspecified		400		600				400		640		
°Swamp			1,100		1,800	4,000			1,100		1,800	4,000
°Upland			800		1,280	2,400			800		1,280	2,400
Sorghum												
Unspecified	450	590	660	860	1,150	4,000	490	640	560	1,330	980	4,500
Dwarf					2,000						2,000	
Wheat												
Nonirrigated			1,500	1,500								
Irrigated					2,240							
Cassava[a]												
Bitter								2,000		3,150		
°Sweet	1,200	1,450	1,750	2,100	2,375		1,150	1,450	1,750	2,200	2,375	
Potato												
Irish	1,500	1,500	4,000	4,000	10,000		1,500	1,500	4,500	4,500	10,000	
Sweet	3,800	3,800	7,000	7,000			4,200	4,200	6,000	6,000		
°Yam	3,100	7,000	2,670	5,990	3,880		4,100	7,180	4,330	7,520	8,150	
Cowpea												
°Unspecified	120	140	230	800	440		200	160	220	400	410	
New variety					1,000						1,000	
Seed and hay	60[b]											
°Groundnut	350	570	670	600	1,170	1,500	350	600	560	600	1,040	1,500
°Soya bean			500			1,500			390			2,100

Table 1A—*Continued*

Crop	Area and level of technique											
	Dry savanna						Intermediate savanna					
	Mixed		Sole				Mixed		Sole			
	Trad	1963	Trad	1963	Rec	Pros	Trad	1963	Trad	1963	Rec	Pros
Melon seed	400	400	540	540			510	510	480	480		
Okra												
°Onion			6,700		13,000				6,700		13,000	
Tomato												
Irrigated					94,000							
Oil palm												
°Cotton	260	200	375	290	860	1,200	260	256	375	370	630	1,200
Tobacco			514	514					516	516		

Table 1A—*Continued*

Crop	Area and level of technique											
	Forest-savanna mosaic						Western moist forest					
	Mixed		Sole				Mixed		Sole			
	Trad	1963	Trad	1963	Rec	Pros	Trad	1963	Trad	1963	Rec	Pros
Maize												
Bush	560	560	1,240	1,240			800	800	850	850		
Commercial			1,400	1,400					1,700	1,700		
Early					2,400	4,000					2,400	4,000
Late					1,900	3,000					1,900	3,000
Millet			390		650	3,000						
Rice												
Swamp	400	400	1,040	1,040	3,800	6,000						
Sorghum												
Unspecified			330		720	4,000						
Cassava[a]												
Bitter	1,810	1,810	3,530	3,530	10,000		3,870	3,870	4,720	4,720	11,000	
Cocoyam							2,500	2,500	5,750	5,750		
Yam	4,790	4,790	5,630	5,630	12,700		7,000	7,000	5,860	5,860	12,700	
Cowpea												
Unspecified	90	90	190	570								
New variety					600						600	
*Groundnut	300	460	450	610	770	1,200						
Soya bean			370	2,100	2,100							
Melon seed	330	330	420	420			250	250	340	340		
Okra	100	100	200	200								
Tomato												
Early											13,400	
Late											31,000	
Oil palm			2,200	2,200	8,000				2,200	2,200	8,000	
*Cotton	260	220										
Cocoa									400	400	1,100	
Kola nut									440	440		
Rubber									300	300	950	

Table 1A—*Continued*

Crop	Area and level of technique											
	Eastern moist forest						Central moist forest					
	Mixed		Sole				Mixed		Sole			
	Trad	1963	Trad	1963	Rec	Pros	Trad	1963	Trad	1963	Rec	Pros
Maize												
Bush	810	810	1,870	1,870			440	440				
Commercial												
Early					1,700				1,800	1,800		
Late					2,400	4,000					2,400	3,600
Rice					1,900	3,000					1,900	2,800
Swamp	1,310	1,310	940	940			800	800	1,200	1,200	3,800	6,000
Cassava[a]												
Bitter	5,270	5,270	5,260	5,260	10,000		2,000	2,000	5,760	5,760	11,500	
Cocoyam	4,200	4,200	4,620	4,620			3,390	3,390	4,300	4,300		
Yam	4,750	4,750	7,190	7,190	13,700		4,620	4,620	5,200	5,200	14,400	
Cowpea					600		180	180			600	
Melon seed	350	350	430	430			100	100	200	200		
Okra							100	100				
Tomato												
Early												
Late												
Oil palm			2,200	2,200	8,000				2,200	2,200	8,000	
Cocoa			225	225	1,000							
Kola nut												
Rubber			300	300	950				300	300	950	

NOTE: Trad = Traditional; Rec = Recommended Practice; Pros = Prospective Variety. Yields in the traditional methods and 1963 models are the entries in the "Trad" or "1963" columns, respectively. In the recommended practices model they are the entries in both the "Trad" and the "Rec" columns; in the prospective variety model the entries in the "Trad," "Rec," and "Pros" columns are included. The heading "Mixed" refers to yields when a crop is grown by intercropping or mixed cropping.

[a] For these crops the "Trad" data represent the traditional methods of peasant agriculture.

[b] Half of the acre was planted in the current year; half, planted the year before, was harvested this year.

[c] Plus 560 pounds of hay.

[d] There is also an improved variety for mixed cropping that yields 120 pounds of seed and 1,120 pounds of hay.

Table 2A. ***Potential Net Contribution of the Agricultural Sector to Nonfood Income, in Millions of Shillings***

Item	*Techniques employed*			
	Traditional	*1963*	*Recommended*	*Prospective*
N_a Value (at farm) of nonfood income produced by Nigerian agricultural sector	1,348	2,622	14,074	15,509
Hides and skins	224	233	225	237
Cotton	104	160	583	960
Groundnut, seed	36	494	2,940	3,876
Groundnut cake	114	49	82	82
Bean, soya	4	14	14	14
Tobacco	402	948	2,641	2,641
Cocoa	137	167	678	678
Rubber	221	251	960	960
Palm kernel		220	5,587	5,697
Red palm oil	74	60	255	255
Palm kernel oil	32	26	109	109
Palm kernel cake				
E_a Expenditures by the agricultural sector	18	3	1,515	1,415
Fertilizer	18	3	1,054	1,065
Other production expenses			460	353
F_b Expenditures on food or food production by nonagricultural sectors	7,558	1,606	1,038	1,017
Other food producing sectors	1,451	338	423	390
Fisheries	4,663			
Brewing (European-style beer)[1]	708	106	49	64
Food importing[2]	6,822	444	472	454
Total				
The transportation sector	736	1,162	566	563
$N_a - E_a - F_b$				
Net contribution of the agricultural sector to the nonfood income of Nigeria	—6,231	1,012	11,521	13,077
Net foreign exchange earnings	361	2,845	15,086	16,846

NOTE: Hossein Yaghoobi-Rahmatabadi, "The Most Efficient Production Techniques for Providing Nutrition and Income from the Agricultural Sector of Nigeria," Ph.D. diss., Michigan State University, East Lansing, 1971, Table 11, pp. 87-89. The model used for the 1963 methods is not completely comparable with the other three, but the quantitative effects of the differences appear to be small.

[1] The production of palm wine, guinea corn beer, and millet beer is regarded as occurring within the agricultural sector.

[2] Exclusive of fish and the materials needed for the production of European-style beer.

[3] Foreign exchange earnings exceed the farm value of export activities, for the export price includes any tax payment as well as the value of transportation and marketing services rendered after the produce leaves the farm. Likewise, the foreign exchange spent for imported food is less than the value of that food at its destination.

Recommended Practices

The set of recommended practices includes 69 activities, each representing the use of an improved method or variety available in 1969, or soon to become available.[2] No more than two of the new activities in any area are for crops that cannot be used for food within Nigeria. Thirty-one of the new alternatives are in the two savanna areas and 27 in the three rain forest areas; the forest-savanna mosaic has 11. Three activities represent the production of dwarf sorghum (in the two savanna areas) and of mixed cowpeas for seed and hay (in the dry savanna). These three represent varieties expected to be available soon after 1969.

In the model for the recommended practices case the activities from both the traditional practices model and the recommended practices set are available. The solution contains the most efficient activities from the combined set.

Output Available

With the recommended practices available, the potential net contribution of Nigeria's agricultural sector becomes 11.5 billion shillings (a gain of 10.5 billion over 1963 techniques) and the gross value of its nonfood income becomes 14.1 billion shillings (a gain of 11.5 billion). Net foreign exchange earnings rise from 2.8 billion (with 1963 techniques) to 15.1 billion.

The potential gross nonfood income of 14 billion shillings is seven times John Cownie's estimate for the contribution of Nigerian agricultural exports to its 1967 Gross Domestic Product.[3] If all of the gain of 11.45 billion shillings over the potential at 1963 techniques were to be captured it would represent a 36 percent increase in the 1967 Gross Domestic Product at factor cost (£1.6 billion, as estimated in Johnson, Scoville et al.)[4] Agriculture as a whole already provided 56.5 percent of the total GDP at factor cost in 1967, according to the same estimate. If the production estimates available for the recommended

---

[2] For the technical coefficients for these activities see Hossein Yaghoobi-Rahmatabadi, "The Most Efficient Production Techniques for Providing Nutrition and Income from the Agricultural Sector of Nigeria," Ph.D. diss., Michigan State University, East Lansing, 1971, Table 2, pp. 28–31.

[3] Cownie, *Nigerian National Income Accounts*, p. 4.

[4] *Strategies and Recommendations for Nigerian Rural Development, 1969/1985*, Table I.1, p. 19.

practices are correct, the potential for increased income from their adoption is tremendous.

With the recommended practices in use, no income production opportunity need be foregone in order to meet nutritional goals. Every income producing crop appears in the solution at its maximum limit as given in the model. Incomes rise not only because more land can be used for income crops, but also because smaller portions of the exportable food crops need be used for food and because yields of income crops are greater at the new technical levels.

The largest increase is in the income from palm products. This alone totals 6.9 billion shillings when the recommended practices are available. Of this amount, 5.6 billion shillings is the value of the red palm oil exported. With traditional techniques, all the red palm oil produced was required for use as food (842 million kilograms), and 600,000 acres of land that the model allowed for oil palm production could not be used for that purpose because it was required for other food crops. When improved methods are used in oil palm production, yields are nearly 300 percent greater (rising from 2,200 to 8,000 pounds per acre), but because improved food crop methods are also being used, 600,000 extra acres of land can be devoted to oil palm production. In addition, only 536 million kilograms of oil are being used for food.

When traditional levels of technique were employed, all groundnut land in the two savanna areas was used for groundnuts, but almost the whole crop was used as food, either as the nut or as oil. With improved practices, the use of groundnuts for food drops from 457 to 107 million kilograms. In addition, groundnut oil consumption falls from 180 million kilograms to zero. Moreover, yields are higher, and the sole crop takes over the land formerly used for groundnuts mixed with other crops.

Cocoa acreage doubles (from 597,000 to 1,377,000 acres) when improved methods are used for food crops. (Cocoa itself is not used for food within Nigeria to any significant extent.) There are also yield increases of 175 percent (from 400 to 1,100 pounds per acre) in the major producing area.

Compared with traditional techniques, the use of recommended practices makes possible a gain of 12.7 billion shillings in the gross nonfood income produced by agriculture (N_a) and a reduction in nonagricultural expenditures on food and food production (F_b) of 6.5 billion. To accomplish this requires an increase in expenditure on fer-

tilizer and other production expenses (E_a) of 1.5 billion, for a gain of 17.7 billion shillings in the net contribution of the agricultural sector.

The necessary expenditures on fertilizer (one billion shillings) represent the purchase of 1,327,000 long tons, in addition to 97 million shillings' worth purchased for use with oil palm and cocoa.[5] To use 1.5 million tons of fertilizer a year would be perhaps 15 times Nigeria's actual use (probably under 100,000 tons) in the 1967-1968 season.[6]

However, actual fertilizer use has been growing rapidly. Imports for the country as a whole were only 36,000 tons in 1965.[7] Although the government has been subsidizing fertilizer purchases in order to encourage its use, the subsidies may have become a limiting factor. At least it is reported that fertilizer availability in recent years has been limited by the amounts the states are willing (or able) to pay as subsidies.

The use of fertilizer at the rate envisioned in this solution would probably force the states to put an end to subsidization. While the consequent rise in the price the farmer pays for fertilizer might reduce the rate of adoption of these improved techniques, it would not alter our conclusions, for the calculations made in this analysis assume that the farmer pays the full market value of the fertilizer. The levels of application implied by this solution are efficient at full cost, given our emphasis on providing adequate nutrition.

Effects of Limiting Fertilizer

Limiting fertilizer use to some 400,000 tons reduces the potential net contribution of the agricultural sector by 3.3 billion shillings. Permitting the purchase of only 30,000 long tons of ammonium sulphate and 60,000 long tons of single superphosphate, in addition to whatever is used for "commercial" maize, oil palm, and cocoa, which are not

---

[5] Perhaps another 167,000 tons, for a total of 1.5 million tons of fertilizer. For "commercial" maize, oil palm, and cocoa, our data give the amount spent on fertilizer, but do not specify the kinds or quantities purchased.

[6] Consumption in the six northern states was 47,500 long tons in 1967–1968. (C. K. Laurent, *Problems Facing the Fertilizer Distribution Program in the Six Northern States*, CSNRD 27 [East Lansing: Consortium for the Study of Nigerian Rural Development, Michigan State University, January, 1969], Table 1, p. 1.) If the northern states used half of the total for the country, as seems to have been the case in 1965 (ibid.), fertilizer consumption for the country as a whole was below 100,000 tons.

[7] *Nigeria Trade Summary*, December 1965, pp. 46, 68–69.

limited (perhaps 310,000 tons), restricts the net contribution of the agricultural sector to only 8.2 billion shillings. Fertilizer expenditures decline by 820 million shillings, but the net contribution of the agricultural sector declines by four times as much. The net product of 1,000s spent on fertilizer is 4,000s.

Summary

The potential for increasing nonfood income that is embodied in the recommended practices set is very large—equivalent to a 36 percent increase in the 1967 Gross Domestic Product at factor cost. Of course, as in any developing country, the reliability of the estimate is limited by the accuracy of the data available as well as by certain related factors. For example, the data are averages covering very broad areas within the country, and the model imposes maximum limits upon crop expansion that are determined in a rather arbitrary fashion. Furthermore, the nutritional objective upon which this model is based may not be shared by those who make production decisions.

Nor is it to be expected that the whole of the potential gain over 1963 technical levels (11.45 billion shillings) can be captured, at least not all in the form of nonfood income. This is true for several reasons. (1) New practices are adopted slowly, while the population continues to grow, so increased nutrient needs absorb potential gains from new techniques. (2) Marketing board policies keep the farmer from receiving the full market value of his principal export crops. (3) Our calculations assume a perfectly inelastic demand for nutrition, but nutritional levels may rise as incomes rises. In any case, more expensive foods will be purchased. (4) The yields that the average farmer obtains may fall below expectations, perhaps because he cannot provide the capital that the recommended practices require. (5) Finally, the model assumes resources to be used with maximum efficiency. That standard will never be attained.

Prospective Varieties

The set of prospective varieties includes 29 activities representing new varieties that we reasonably may expect plant breeders to have ready for use in Nigeria by 1975 or 1980. New varieties are included for the following food crops: maize, millet, upland rice, swamp rice, sorghum, and the soya bean in the savanna areas; maize, both early and late, in the rain forest areas; swamp rice in the eastern moist for-

est; and early and late maize, millet, swamp rice, sorghum, and groundnut in the forest-savanna mosaic.[8] There are also prospective varieties for two cash crops, groundnuts and cotton, in the two savanna areas.[9] The data are based upon quantitative judgments made by Ray Olson, Department of Agronomy, Kansas State University; George Sprague, Beltsville Plant Industry Station, Agricultural Research Service, U.S. Department of Agriculture; and John McKelvey, Deputy Director, Agricultural Division, Rockefeller Foundation, in interviews with Glenn L. Johnson, Department of Agricultural Economics, Michigan State University. Some modifications have been made in the original estimates.

When these 29 prospective varieties as well as those in the recommended practices set are added to the activities in the traditional practices model, Nigeria's potential production of gross nonfood income rises by another 1.4 billion shillings. The potential net annual contribution of the agricultural sector to nonfood income rises by 1.6 billion shillings and the potential net foreign exchange earnings of agriculture by 1.7 billion shillings (Table 2A). This is a 13.5 percent increase in the potential annual net contribution of the agricultural sector as compared with what is possible when the recommended practices are the only improvements available.

Even the large increases in yield that are expected from the prospective varieties (see Table 1A) have relatively modest effects upon potential nonfood income production as long as the population to be fed is considered constant at the 1967 level. The effects are small because the recommended practices set of improvements permitted releasing enough land from food production to expand every crop producing nonfood income to the maximum limit allowed by the model. As long as the set of nutrients to be provided remains the same and nonfood acreage cannot be expanded, further improvements in food production methods can increase nonfood income only by reducing domestic consumption of foods that could be exported, reducing food purchases from outside the agricultural sector, lowering expenditures on fertilizer and other productive inputs, or reducing expenditures on

[8] In the two savanna areas the model requires that the soya bean be used for food rather than income. Likewise, in the forest-savanna mosaic the groundnut can only be used for food. Significant marketing channels for these crops did not exist in these areas in our base period, 1963.

[9] For the technical coefficients of these activities, see Yaghoobi, "Efficient Production Techniques," Table 3, p. 33.

transporting food within Nigeria. Other mechanisms that operate within the real world are not included within the model: The model does not provide for the release of agricultural labor to nonagricultural uses or for the development of export markets for food crops now consumed primarily within Nigeria. The model also assumes that the income elasticity of Nigeria's demand for food (or nutrition) is zero. In fact, of course, as incomes rise Nigerians will want to consume more—or more expensive—food (but not necessarily more nutritious food).

In this model the additional improvements in food production methods provided by the set of prospective varieties permit domestic red palm oil consumption to drop from 536 to 465 million kilograms. This permits red palm oil exports to expand by 100 million shillings. The improvements also reduce production expenses other than for fertilizer by 100 million shillings and allow negligible reductions in internal transportation expenses and in purchases of food from outside the agricultural sector.

Most of the 1.6 billion shilling increase in potential net nonfood income arises from adopting the prospective varieties of groundnuts and cotton. These increase the gross value of nonfood production by 1.3 billion shillings, 900 million shillings in the farm value of groundnut seed exported and 400 million shillings in the value of cotton sold. All of the increase in cotton sales and practically all of the increase in groundnut exports result from increased outputs. In cotton, these output gains amount to 566,000 pounds. In groundnuts, they amount to 1.9 billion pounds in the two savanna areas and 72 million pounds in the forest-savanna mosaic. In the present model, groundnuts are exclusively a food crop in the latter area,[10] but the increased yield there permits the area to eliminate 64 million pounds purchased as food from the intermediate savanna before the prospective varieties were introduced. This amount becomes an addition to groundnut exports from the intermediate savanna.

While the prospective varieties of food crops would not have added much to Nigeria's capacity to produce nonfood income in 1967, in the absence of larger acreage limits on nonfood crops or the alternatives of industrial employment for agricultural workers or export markets for the food crops, by 1975 or 1980, when those varieties become available, their importance will be many times greater.

Nigeria's population is continuing to grow. By 1985 it may exceed

[10] The model provides no marketing channel for exports from the forest-savanna mosaic.

95 million.[11] In the face of nutrient needs more than 50 percent above the levels specified in this model, the prospective improvements in agricultural varieties are not likely to be sufficient even to keep net nonfood income production at the 11.5 million shilling level that could be reached with the recommended practices set for the 1967 population of 61 million.

Consider only the effect of providing a 50 percent increase in the aggregate caloric supply of the country—from 50,400 to 75,600 billion k calories. To provide the extra 25,200 billion k calories by the consumption of red palm oil would require 6.2 billion pounds of oil, 95 percent of all red palm oil exports in the solution with the prospective varieties available. Converting this much palm oil to consumption use instead of exporting it would reduce the gross value of nonfood income by 5.4 billion shillings, more than one-third below its level in the present solution. The remaining revenues from palm oil exports would amount to only 285 million shillings—little more than the level for the model using 1963 techniques.

Of course the optimal adjustment to a 50 percent increase in the required levels for all nutrients could not be made by a simple adjustment in the quantity of red palm oil consumed. It is probable that an increase in groundnut consumption would occur as well as increases in the consumption of other foods and that less land would be available for crops grown for nonfood purposes. It is also probable that the total reduction in the gross value of the nonfood income that the agricultural sector could produce would be considerably greater than 5.4 billion shillings.

In short, with a population of 95 million, Nigeria's production capacity for nonfood income, even with the use of the improved varieties now in prospect, would be well below the levels indicated by our model using recommended practices (but probably not as low as the levels indicated by our model using 1963 practices).[12] The capacity of Nigeria to feed itself and also produce additional income from agriculture is the prize at stake in the race between population growth and the development and adoption of improved agricultural methods.

Conclusion

Finding a proper measure for the output of an agricultural economy in which production for subsistence is important is a difficult

[11] Caldwell, personal correspondence with Carl K. Eicher.

[12] A more definite estimate would require rerunning the model for the new population level.

matter. Market prices exist only where output passes through the market, but the value relationships that prevail for that food which is produced for the market need not be representative of the relationships that prevail where production is for subsistence.

We can, however, evaluate the output of subsistence agriculture in terms of its contribution to the objective of providing food for the family (or the nation). When there is both production for the market and production for subsistence (generally on the same farm), as in Nigeria, due importance can be given to both kinds of production by treating all production of food that is consumed within Nigeria as a contribution toward attaining specified nutritional levels and by valuing all production that results in nonfood income in terms of the market prices of the products involved. This study requires that a set of nutrients adequate for a population of 61 million people be provided within Nigeria, either by production or by purchase. Agricultural resources not used in order to meet this set of nutritional goals can be devoted to the production of nonfood income.

Improvements in food production methods release agricultural resources for the production of nonfood income. The value of the additional nonfood income thus made possible is an economic measure of the contribution of improved food production, for given nutritional standards and a given population. Improvements in the production of income crops increase nonfood income directly; improvements in food production methods increase it indirectly. The total value of all agricultural improvements (the increase in the net nonfood income that the agricultural sector can produce) includes both; the contribution of improved food production methods is not overlooked.

According to our estimates, the Nigerian agricultural sector had the capacity to produce nonfood income with a gross value of 1.3 billion shillings per year when "traditional" methods were employed. However, to feed 61 million people at the nutritional levels specified, under these technical conditions, the resources of the agricultural sector would have had to be supplemented by contributions of 7.6 billion shillings annually from the other sectors of Nigeria, so the net yearly contribution of the agricultural sector to the nonfood income of Nigeria would have been negative in the amount of 6.2 billion shillings. That is, the resources of the agricultural sector itself fell 6.2 billion shillings a year short of being sufficient to meet the nutritional standard specified.

Improvements in agricultural technology that already had been put

into practice by 1963 were sufficient to reduce this dependence upon the other sectors to 1.6 billion shillings and to increase the gross value of the nonfarm income that agriculture was capable of producing to 2.6 billion shillings per year. With 1963 techniques the sector was able to make a net annual contribution to the nonfood income of Nigeria (after subtracting the contributions from other sectors) of 1.0 billion shillings.

We estimate that general adoption of the agricultural practices being recommended in 1969 (to the extent that they prove to be economically and nutritionally efficient) could increase the net capacity of the agricultural sector to produce nonfood income, after providing the nutrients specified for a population of 61 million, by 17.7 billion shillings a year as compared with traditional methods and by 10.5 billion shillings as compared with the estimate for 1963 methods. The new potential for the production of nonfood income would be 14 billion shillings a year, seven times the agricultural export component of the GDP in 1967. The value of the increase in gross agricultural capacity is 12.7 billion shillings per year as compared with traditional methods and nearly 11.5 billion shillings as compared with the estimate for 1963 methods. The latter figure is equivalent to a 36 percent increase in the 1967 GDP at factor cost. Tremendous opportunities exist for improving agricultural income by the adoption of the improved methods available.

The continued growth of the Nigerian population, however, if it is to be fed at levels equivalent to those specified in these models, is rapidly wiping out these potential gains in nonfood income. Even if the prospective improvements in crop varieties and methods included in this study were to be generally adopted, a population of 95 million would require an expansion of agricultural resources in food production that would cut the capacity of agriculture to contribute to the nonfood income of Nigeria far below the levels indicated for the use of recommended practices with a population of 61 million. Unless the search for improved agricultural methods keeps pace with the growth of population, retrogression will set in.

Appendix B

Nutritional Efficiencies Of Potential Improvements

Nutritional Efficiencies Of Potential Improvements

with Hossein Yaghoobi-Rahmatabadi

One of the most important applications of this book's methods is in determining the nutritional efficiencies of proposed agricultural improvements before efforts are made to encourage their adoption, or, better yet, before large expenditures are made on developing new varieties or methods that have no prospect of contributing significantly to the solution of nutritional problems. To be nutritionally advantageous a proposed improvement should increase the output of those nutrients that are nutritionaly significant, it should do so at low cost, and it should compete economically with alternative ways of providing the same nutrients. To determine which nutrients are significant is itself a serious matter; the casual judgments of even "informed opinion" may be incorrect. Measuring the cost of producing a nutrient also involves complications; unless the values of the other nutrients produced along with it are taken into account correctly, the cost estimate will be in error.

By definition, agricultural improvement implies either greater output or more income. This need not, however, imply an improved nu-

tritional situation, even when the improvement is in the production of food crops. The "green revolution," heralded as a solution for the world's hunger, has had disadvantages. In India it has created new problems by reducing the output of the pulses needed to provide protein in the diet. Not every improvement in food production is equally effective in improving the nutritional situation; some "improvements" actually can worsen the situation, as we shall show. This study demonstrates that the nutritional efficiency of any improved method depends upon what other improvements are in use or available, that some "improvements" should not be used at all, and that traditional practices are sometimes more efficient sources of nutrients than the improvements that agricultural scientists recommend.

In this appendix the model of Part Two is applied to evaluate the nutritional efficiency of two sets of potential improvements in comparison with the varieties and methods included in the "traditional" model. The study asks which potential improvements it would have been beneficial to adopt in 1967, given nutritional allowances for a population of 61 million people that are to be met as economically as possible. The traditional model is named for eleven crops grown in the dry savanna, the intermediate savanna, and the forest-savanna mosaic.[1] For these eleven we have data representing traditional agriculture; for the remaining crops (and for the other three areas) the data represent practices in use in 1963. (There are three instances of more than one level of technique in use in 1963.) Yield data for all three levels of technique were given in Table 1A.

When traditional practices are being considered, the model contains from 16 to 29 cropping activities and from three to six animal production activities in each of its six geographical areas, for a total of 154 production activities. Including activities of all kinds—production, consumption, processing, transportation, and so forth—the model has 550 activities and 638 restraints.

"Recommended practices" covers a set of 69 new cropping activities, each representing the use of an improved method or variety. Almost all of these were available and being recommended for use in 1969. The set of "prospective" practices or varieties covers seven crops (29 activities). These are forecasts of what reasonably may be accomplished by plant breeders within the next five or ten years.[2] The

[1] Maize, millet, rice, sorghum, sweet cassava, yams, cowpeas, groundnuts, soybeans, onions, and cotton.

[2] For the technical coefficients of the activities in both sets see Yaghoobi, "Efficient Production Techniques," Tables 2 and 3, pp. 28–31, 33.

model containing all three sets of activities—traditional, recommended, and prospective—has 655 columns and 685 rows.

Traditional Practices

As one might expect, the production organization that will feed a population equivalent to that of 1967 (61 million people) with the agricultural techniques of 1963 and earlier requires that almost all food crops be produced at the maximum limits permitted in the model. Even then the food provided by the agricultural sector must be augmented from the fishery and commercial brewing[3] sectors and by imports (sugar, wheat, and wheat flour). Expenditures of 6.8 billion shillings annually must be made on food from these three sectors if specified nutritional levels are to be attained in an economical fashion at these levels of agricultural proficiency. These expenditures on products obtained from outside the agricultural sector represent 5.7 percent of the aggregate opportunity-cost value of the nutrients provided by this solution.

The model has 105 cropping activities that can produce only food; only 16 of these are below their maximum levels. In contrast, of the 21 activities producing crops that can be sold for income, 10 are below maximum levels. Moreover, the two most important of the crops that can be sold for income are instead being used largely for food: Almost all the groundnuts and all the red palm oil produced are used thus. (Some crops must be below the maxima permitted in the model, for the maxima for individual crops were set at 120 percent of 1963 levels, while the total arable land available was set at only 109.5 percent of 1963 usage.)

The production pattern that meets nutritional standards most efficiently is shown in Figures 1B and 2B. (See the sections headed "Traditional Practices Available."[4]) The fourth section of Figure 1B identifies each of the areas and provides an indication of comparative sizes. Figure 1B includes the major crops: each crop for which the acreage allowed in the model exceeds 20 percent of the arable land available in the area. Figure 2B includes the remaining crops of the model. The same horizontal distance represents approximately ten times as much acreage in Figure 1B as in Figure 2B.

[3] Which brews European-style beer. The production of palm wine and the cereal beers is regarded as part of the agricultural sector.

[4] For the numerical data on the solution levels at each level of technical practice, see Yaghoobi, "Efficient Production Techniques," Tables 4, 5, and 6, pp. 44–49.

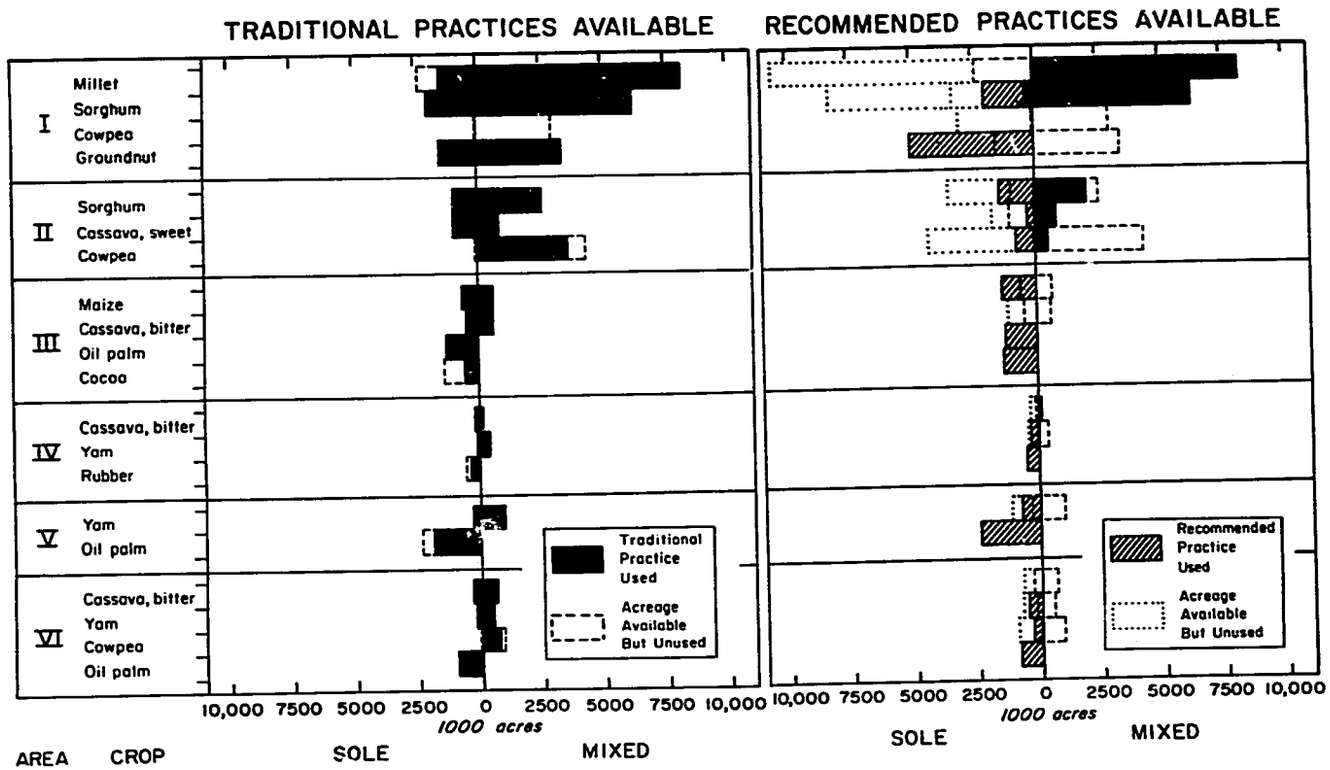
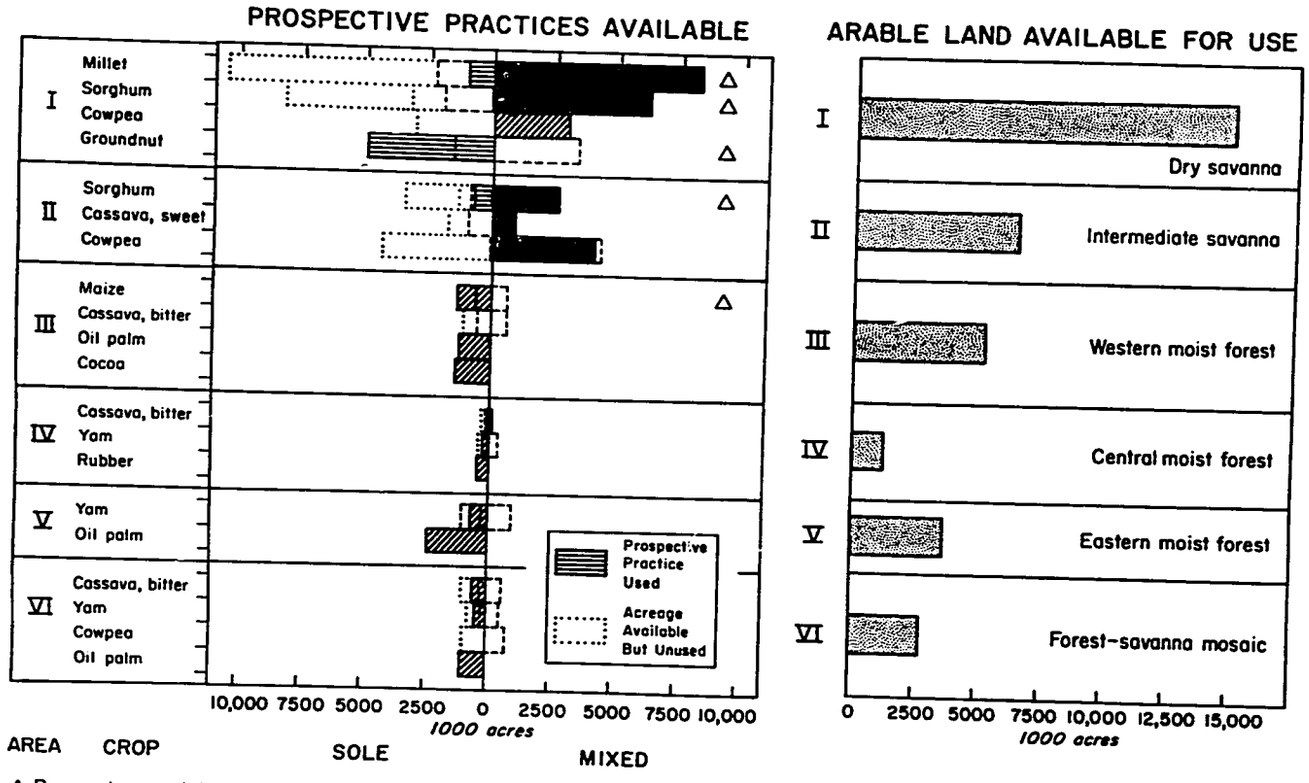


Figure 1B. *Acreages Available and Used: Major Crops*



△ Prospective variety available.

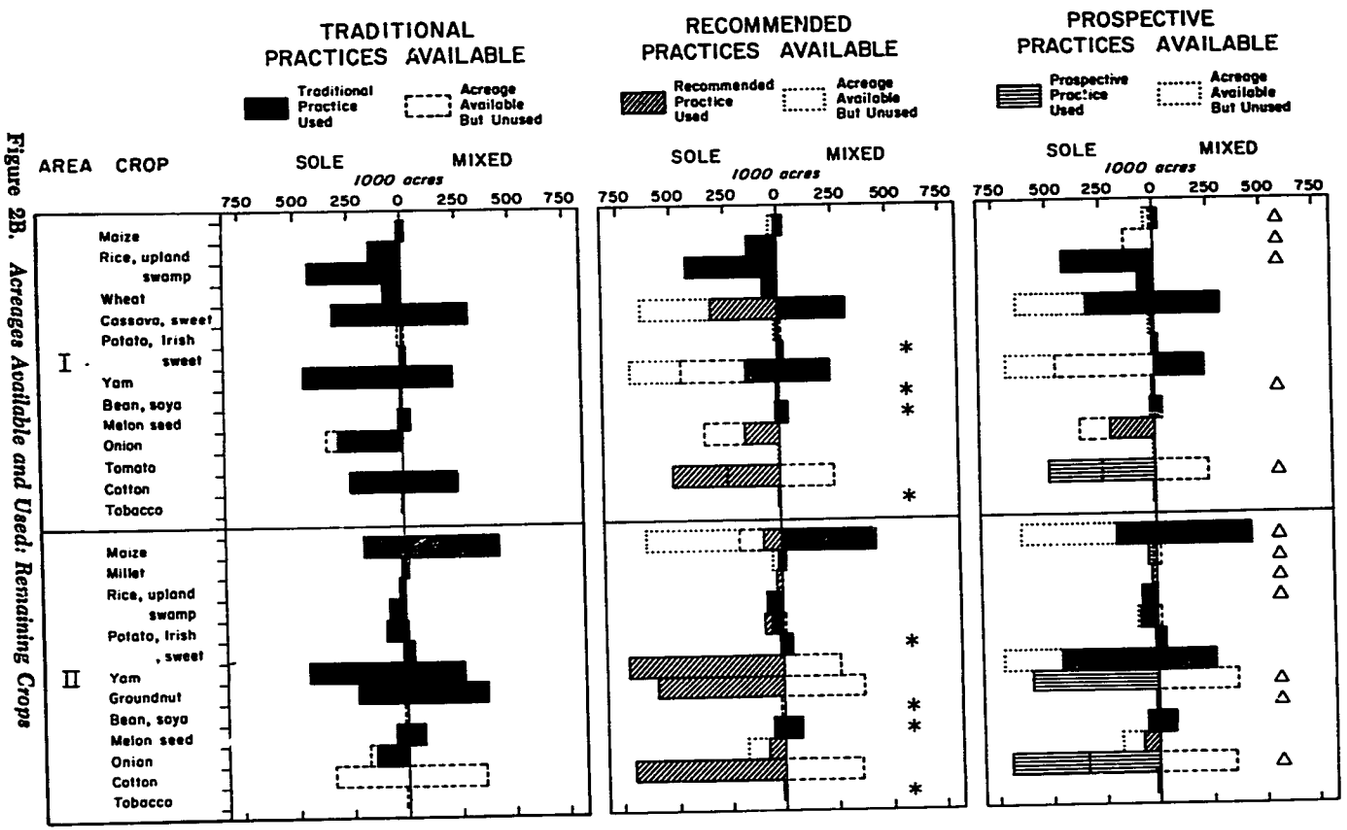
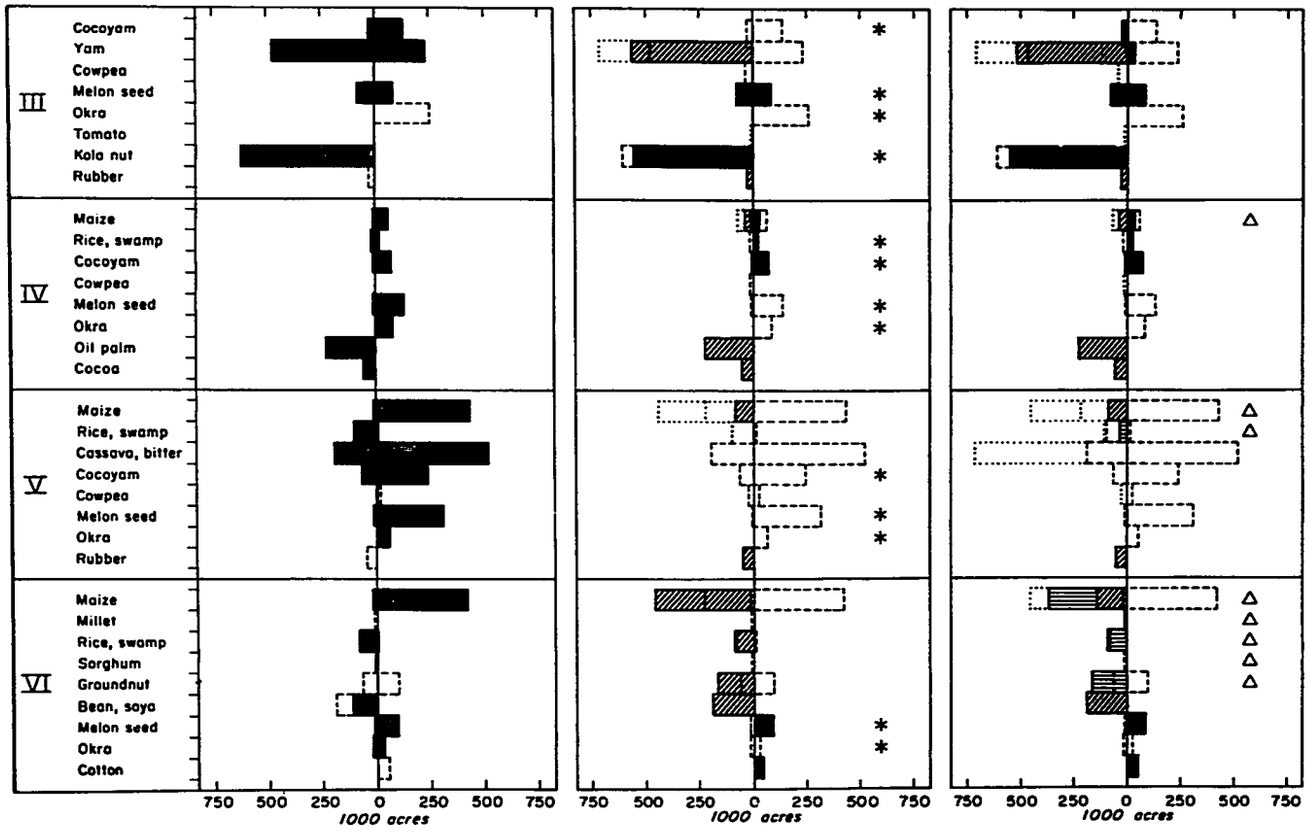


Figure 2B. *Acreages Available and Used: Remaining Crops*



* No improved method available; △ Prospective variety available.

The figures distinguish two types of cultivation for most crops: sole and mixed. In mixed cropping (which we do not distinguish from intercropping) two or more crops occupy the same land. Our acreage figures refer to the harvested acreage of each crop separately. One acre of arable land may support two or three acres of harvested acreage when the crops are grown in mixed cultivation.

Of the 21 potentially income yielding activities in the model, fully ten are kept below the model maxima, and six of these are at zero levels.[5] The groundnut is at its maximum in the important producing areas, but in this solution it is being used almost entirely for food. Only 36 million shillings' worth of groundnut seed is available for export. Oil palm, cocoa, and rubber are below permitted levels in the main producing area for each crop, and rubber is at zero level in the other areas where it can be grown. All the red palm oil produced is used as food; it is not efficient to divert resources to the production of red palm oil for export sale. (The soybean is also used entirely for food, although the model would allow it to be sold for export in the forest-savanna mosaic.) Cotton and tobacco are at their maxima in the dry savanna, but at zero level in the other areas where they are grown.

As the figures show, only two of the major food crops are below their maxima: millet and cowpeas. Millet uses only 74 percent of the acreage allowed it as a sole crop in the dry savanna, but all of the much larger acreage available for the mixed crop. None of the negligible acreage available in the forest-savanna mosaic is used.

Millet is a nutritionally efficient food in every area where it is eaten, but some of the land available for it can be used more effectively for other purposes. In two areas, the eastern moist forest and the forest-savanna mosaic, millet is one of the most efficient foods. It is highly valuable as a source of riboflavin in the former and as a source of calories in the latter. In neither area, however, is it widely consumed, so only small quantities are allowed in the model. Both areas buy millet from the dry savanna in this solution; acreage would

[5] The number of activities in the model is not identical with the number of entries in Figures 1B and 2B. For example, two different production activities (as for maize) may be represented by a single entry in the charts. (Sole and mixed production activities are shown separately, however.) Likewise, although tomatoes and cowpeas are entered in the stub of Figure 2B, in Areas I and III (for tomatoes) and III and IV (for cowpeas) no such activities were included in the traditional practices model.

have been larger there if higher consumption levels had been permitted in the other two areas.

In only one area are cowpeas produced at the maximum level allowed by the model; none at all are produced in the dry savanna, although as many as three million acres could be put to this use in that area. That cowpeas should be below their maxima is surprising since they are a major crop in the two savanna areas and the forest-savanna mosaic. Furthermore, considerable effort is being spent in Nigeria in developing the cowpea as a source of protein. Yet at the technical levels represented by the traditional practices model, cowpeas turn out to be one of the less efficient sources of nutrients.[6]

In two areas the cowpea is definitely inefficient. It does not enter the solution diet in the dry savanna or the western moist forest since to add it would increase the cost in those areas. The principal limiting nutrients in the dry savanna are food energy (calories) and vitamin A (see chapter 9). The cowpea does not provide enough of these nutrients per acre of land to compete effectively with other foods available there. In the traditional practices model the cowpea is not grown in the western moist forest, but it could be purchased from the intermediate savanna. Food energy is the costly nutrient in the western moist forest, but cowpeas are not sufficiently economical sources of calories to be worth purchasing.

In the intermediate savanna and the forest-savanna mosaic the cowpea is as efficient as many other foods, but it produces too few calories per acre to make it worthwhile to use all the land that could be devoted to its production. Food energy is the principal limiting nutrient in both of these areas.

Only in the two areas where riboflavin is one of the costly nutrients (the central and eastern moist forests) does the cowpea have a special nutritional advantage. In these areas it is one of several foods so efficient as sources of nutrients that they are consumed at the maximum levels that the model allows. It is that maximum limit on consumption—a low one, reflecting low customary consumption in the area—that limits cowpea production in the eastern moist forest. In the traditional practices model no production is permitted in the central

[6] As are two other commonly recommended sources of plant protein in some areas: groundnuts and soybeans in the forest-savanna mosaic and soybeans in the intermediate savanna. Groundnuts are an efficient source of nutrition in the intermediate savanna, however, as are both groundnuts and soybeans in the dry savanna.

moist forest, but cowpeas are purchased from the intermediate savanna.

The emphasis commonly placed on the nutritional promise of the cowpea results from concentration on the protein problem to the exclusion of the remainder of the nutritional picture. Cowpeas do contain a high percentage of protein, but whether they are economical as a source of protein depends upon what quantities of the other significant nutrients they also provide. Traditional measures of the cost of protein mislead because they fail to take these other nutrients into account. Furthermore, the protein for which cowpeas are usually so highly valued is not a limiting nutrient in this solution. The protein allowances specified by the model can be met economically without sending cowpea production to its maxima. The outputs of the traditional animal industries, supplemented with vegetable protein from millet, sorghum, groundnuts, and other sources (including cowpeas), plus the purchase of dried freshwater fish from the fisheries sector, provide more than the quantity of protein specified by the allowances, and no extra expenditure is necessary. The opportunity cost of protein in this solution is zero. When sufficient quantities of the limiting nutrients are provided, more than enough protein is also present in the diet—without heavy dependence on the cowpea.

If the protein allowance were to be set much higher in proportion to the other nutrients to be provided, it is probable that cowpeas would appear more efficient, but it is still an open question whether they would be as efficient as a number of other foods.[7] They contain twice as much protein as sorghum or millet (22 percent in contrast to 10 or 11 percent),[8] but for the Nigerian diet the composition of cowpea protein is inferior to that of sorghum. The cowpea is high in lysine (6.78 percent of its total protein), but lysine is not the limiting essential amino acid in the Nigerian diet. Both by our calculations and by dietary intake studies,[9] the limiting one is one or another of the sulfur-containing amino acids. The cowpea is not particularly strong in this respect. The sulfur-containing essential amino acids con-

---

[7] Not until the set of prospective varieties becomes available does the cowpea become nutritionally efficient in the dry savanna, but even in this case it is not the protein content that earns it a place. Protein is not a limiting nutrient in that area in any of these solutions. Yaghoobi, "Efficient Production Techniques," Table 14, p. 106.

[8] The groundnut has 27 percent protein.

[9] Idusogie, "A Critical Review," pp. 158, 174, 192–93, 229.

stitute 2.95 percent of the total weight of cowpea protein. This is about the same as in groundnut protein (2.72 percent), and better than for millet (2.15 percent), but it is distinctly inferior to sorghum protein, which has 3.59 percent by weight of the sulfur-containing amino acids.

In summary, the cowpea is nutritionally efficient only in areas where riboflavin has a high opportunity cost. Where meeting the food energy requirement is the dominant consideration, the cowpea lags in nutritional efficiency.

Other food crops produced at less than permitted levels in the solution for traditional practice techniques are okra (at zero level in the western moist forest), Irish potatoes in the dry savanna, onions in the intermediate savanna, and groundnuts and soybeans (at zero level) in the forest-savanna mosaic and the intermediate savanna, respectively.[10] In all, 16 food crop activities are below maximum levels, and 10 of these are at zero levels.

Animal production activities have not been mentioned. The traditional animal industries are, of course, an important source of high quality protein. All of them are at maximum levels except native cattle production in the dry savanna. For that the optimal level is 81 percent of the maximum allowed in the model, partly because there is less bush pasture available in the dry savanna than was used in 1963 and partly because goat and she p production is nutritionally more efficient than cattle production.

No "modern" technique for animal production is nutritionally efficient, given the nutritional goals of this model. This is significant in view of the expenditures currently being made on the development of modern forms of animal and poultry husbandry. The modern animal industries do not make efficient use of resources when the traditional set of agricultural practices is being employed. The calories (and other nutrients) diverted from direct human consumption are more valuable than the nutrients obtained from the animal products received. However, if we were to increase the protein allowance in proportion to the other allowances, or if the cost of producing calories could be lowered sufficiently, at some point one or more of the modern animal industries might appear as an efficient productive activity.

[10] The model requires groundnuts in the forest-savanna mosaic and soybeans in the two savanna areas to be used as food, not sold for export.

Recommended Practices

Making the 69 recommended practices available as well as the practices included in the traditional model increases nutrient productivity so much that 19 food crops can go to zero level (compared with 10 in the previous case), and 20 more can produce below their maximum levels (compared with 6 in the previous case). Every income crop goes to its maximum level.

At this new level of productivity the opportunity cost of producing the nutrients required drops by more than 90 percent in most areas.[11] The recommended practices are particularly effective in raising productivity for calories and riboflavin. The latter remains a limiting nutrient only in the eastern moist forest. Calories remain significantly limiting in all areas; protein *becomes* limiting in all areas but the dry savanna.

The sections headed "Recommended Practices Available" in Figures 1B and 2B show the optimal pattern for efficient production of nutrients when the recommended practices are available. Nutritionally efficient activities are represented by black or diagonally-hatched bars, the former representing traditional methods and the latter representing improved methods. Activities that are not sufficiently efficient to be used to the limit of the acreage allotted for the particular crop are shown by the white bars. A white bar bordered with dotted lines shows acreage available for an improved activity that was uneconomical to use. A white bar bordered with a dashed line shows acreage available for a traditional activity, but not used. Because the acreage available for an improved practice is the sum of the acreage allowed for the sole and the mixed forms of cultivation using traditional methods, the dotted bars normally extend beyond the dashed bars. That is, the acreage to the right of the center line in the figure, which could only be used for mixed cropping in the traditional methods model, becomes available for use with the sole crop if improved methods are used. It therefore is added to the left-hand bar in the models for recommended and prospective practices. If mixed cropping continues to be used, however, the acreage cannot also be used for the sole crop.

An improved method replaces sole crop production by traditional methods when a black bar at the left of the center axis is replaced by a diagonally hatched bar of the same length. An improved method re-

[11] Yaghoobi, "Efficient Production Techniques," Table 14, p. 106.

places traditional mixed crop production when a black bar at the right is replaced by a white bar and a diagonally hatched bar of equal length is added on the left side of the axis. If a black bar persists, either the traditional practice is more efficient than the improvement, or no improved method was available in the model for this crop.

The most important cases in which no improved method was available are the kola nut (in the western moist forest) and melon seed (in all areas). There are 34 such cases altogether, mostly unimportant. In addition to the kola nut and melon seed, they are swamp rice in the central moist forest, sweet potatoes, cocoyams, and soybeans in the two savanna areas, okra, and tobacoo. All of these will be found (identified by an asterisk) in the "Remaining Crops" diagram, Figure 2B.[12]

In general, improved methods take over much of the sole crop acreage and some of the mixed, but in some cases traditional methods persist despite the availability of improvements. Some improved methods are nutritionally inefficient, traditional mixed cropping often remains efficient in the face of competition from improvements, and some traditional methods are more efficient than the improvements that are available.

Of the 72 improved practices available in this solution,[13] 30 are nutritionally inefficient. In 10 of the 30 cases, some other improved practice is more efficient. In 8 instances, no other improved practice is more efficient, but traditional sole or mixed cropping is (or both). In 5 cases another improved practice is more efficient as well as at least one of the traditional methods. Finally, there are 12 cases in which the crop itself is nutritionally inefficient in the area under consideration; none of the methods available is nutritionally efficient. Table 1B gives the details.

A glance at Figures 1B and 2B shows that the largest proportion of inefficient food production activities is in the eastern moist forest (Area V), where yields are relatively low and oil palm and rubber provide profitable alternative uses for the land. Yams and maize are

---

[12] The number of crops in the figure is less than the number of activities. If both sole and mixed production are available, that makes two activities, but only one crop.

[13] The 72 consist of the 69 new production activities in this model plus three improved activities ("commercial" maize production) that were already present in the traditional practices model.

Table 1B. ***Improvements Not Used, Recommended Practices Solution***

Improvement: Crop	Area	Reason for nonuse: Traditional practice used: Sole	Traditional practice used: Mixed	Another improved practice used	Optimal crop level zero
Maize					
Commercial	3,6			x	
	4	x	x	x	
	5			x	
Rec. practice	1	x	x		
Western White 1					
Late	4	x	x	x[a]	
Early	5			x[b]	
Millet	1		x		
	6				x
Rice					
Upland	1	x			
Swamp	1,2	x			
	5				x
Sorghum					
Rec. practice	1	x	x	x	
	2		x	x	
	6				x
Wheat					
Irrigated	1	x			
Cassava					
Bitter	3,5,6				x
Potato					
Irish	1	x			
Yam	1	x	x		
Cowpea					
Rec. practice	1				x
	2		x	x	
New variety	1,4,5				x
Mixed, improved	1				x
Tomato					
Irrigated	1				x
Early	3			x[c]	
Number of instances	30	10	8	10	12

[a] Western White 1, early.
[b] Western White 1, late.
[c] The late crop.

the only food crops that continue in the solution, and neither of these uses all the land available for it. When the recommended practices are available, efficient nutrient production for Nigeria as a whole has the eastern moist forest drawing upon other areas for significant portions of its nutrients in order to carry on its income production activities at their maximum levels. (Of course, oil palm production in the east provides calories and vitamin A as well as income.)

Table 2B. ***Efficient Improvements when Recommended Practices Are Employed***

Improvement *Crop*	*Area*	*Replaces* *All other practices*[a]	*Traditional sole cultivation, but not mixed*	*Special cases; notes*
Maize				
Rec. practice	2		x	
Western White 1				
Early and late	3,6	x[d]		
Early	4			b,d,f
Late	5	x[c,d]		
Millet	2		x	
Rice				
Upland	2	x		
Swamp	6	x		
Sorghum				
Dwarf	1			e,g
	2			e,i
Cassava				
Bitter	4		x	
Sweet	1,2		x	
Potato				
Irish	2			h
Yam	2,4–6	x		
	3			i,m
Cowpea				
New variety	2			e,i
	3			j
	6	x		
Onion	1,2	x		
Tomato				
Late	3			j,k
Groundnut	1,2,6	x		
Soybean	6	x		
Cotton	1,2	x		
Oil palm	3–6	x		
Cocoa	3,4	x		
Rubber	3–5	x		
Number of instances	42	29	5	8

[a] This usually comprises both sole cropping and mixed cropping, but in some cases only one type of cultivation was included in the traditional practices model.
[b] The late crop of Western White 1 is at zero level in Area IV.
[c] The early crop of Western White 1 is at zero level in Area V.
[d] "Commercial" maize is also available, but is at zero level.
[e] There is also a recommended practice, which is at zero level.
[f] Replaces part of the mixed crop.
[g] Replaces part of the sole crop.
[h] Replaces all of the mixed and part of the sole crop.
[i] Replaces all of the sole and part of the mixed crop.
[j] The crop was not previously available in this area.
[k] The early crop is at zero level.
[m] The amount of mixed cropping that remains is too small to be seen on the scale of Figure 2B.

The most important cases of improved methods that are nutritionally inefficient in one or more areas are bitter cassava (Areas III, V, and VI), sorghum (Areas I and II), cowpeas and yams in the dry savanna, millet (Areas I and VI), and rice (Areas I, II, and V). In these cases traditional methods were efficient nutritionally, although the recommended practice was not, for rice, yams, and millet. Traditional mixed sorghum in the two savanna areas is more efficient than sorghum grown as a sole crop using the recommended practices. It is also more efficient than the new dwarf variety in the dry savanna, but not in the intermediate savanna. The cowpea and bitter cassava were not worth growing by any method in certain areas where they are normally important crops.

Even with improved methods, cowpeas are nutritionally inefficient in the dry savanna. This is true, moreover, despite the fact that in the recommended practices solution the protein allowance is costly to meet in most parts of the country. It is not costly, however, in the dry savanna. Food energy, calcium, and vitamin A are the allowances that are difficult to meet in that area.

The low valuation of bitter cassava may be somewhat misleading, for this crop performs two important functions in the Nigerian food economy that are not taken into account in this model. It is particularly helpful in moderating the strong seasonal pattern in food availability since cassava is available during the hungry season just before the new harvests come in. At this time most other foods are very scarce, partly because they cannot be stored satisfactorily. Cassava also can be grown on poor land with more success than most other crops; it is useful at the very end of the rotation period just before the land is left to lie fallow.

As long as there are differences among crops and methods we must expect some to be more efficient than others. Table 2B lists the 42 instances of efficient improvements, by crop and area. For food crops, the test is nutritional efficiency; for cash crops it is efficiency in the production of income. In the case of a crop that can be used for either food or income, the portion of the output used as food within Nigeria is valued in terms of its nutritional content. Thus such a crop is tested both for income and nutritional efficiency.

In most cases an efficient improved practice replaces whatever other methods were employed—usually both sole and mixed cropping using traditional methods. There are few instances, however, in which traditional methods persist along with the improved practice, in particular, nine cases in which the sole crop is replaced by mixed cropping

persists. (See the next-to-the-last column of the table, plus the four cases identified by the letters "i" and "f" in the last column.)

Combining the information in Tables 1B and 2B and eliminating overlapping cases yields 22 instances in which activities from the traditional set are efficient as sources of nutrition or income even though improved practices are available. Why should this be, in the face of competition from improved methods with larger yields?

Part of the answer lies in the fact that direct competition between a given method of production and other methods of producing the same crop in the same area is only a small part of the total competition involved. Indirect competition, that between a given activity and the whole set of other activities available for the production of this crop in other areas or other crops anywhere in Nigeria, may be even more important. The direct competition between two methods of producing the same crop in the same area is evaluated by comparing the value of the improved yields provided by the improved method with the added costs that the improved method usually involves. As adopting a single improvement will have little effect upon the unit value of the crop, whatever value existed before the improvement may be used for this comparison. The effect of indirect competition is much less easily estimated because it will be manifested primarily in its effects upon the opportunity-cost values of the nutrients provided by each method. The added expenditure per acre of land may be warranted by the additional nutrients obtained when they are valued at the opportunity-cost values that prevail before there is widespread adoption of the improved methods; they may not be warranted when the new methods being adopted for other crops or in other parts of the country have reduced the opportunity-cost value of the added nutrients to be obtained.

Both traditional and improved methods must bear the opportunity costs of the land and labor they employ, but only the improved methods have additional charges to bear for fertilizers, seed, chemicals, and so forth. The opportunity costs of land and labor are determined largely within the system; they tend to fall, in general, as the opportunity costs of the nutrients fall. Expenditures for inputs purchased from outside the agricultural sector, on the other hand, are determined for the most part outside that sector. They do not respond to the new pattern of internal valuations created by general adoption of improved methods, so it should not be surprising that the general decline in the opportunity-cost value of the nutrients provided may be more prejudicial to the competitive position of the improved

method, with its externally determined components of costs, than to the traditional method, in which factor costs are determined simultaneously with the values of the nutrients they produce. In short, the extra costs of the improved methods may be worth assuming when the value of the extra nutrients they provide is high. When general adoption of improved methods reduces the value of the extra nutrients without reducing the extra cost required, the improved method may lose its advantage.

The effect of the availability of the set of recommended practices upon the opportunity costs of providing the nutrients called for by the allowances specified in the model is massive. Table 3B compares the costs of meeting these allowances, in shillings per capita per day, in each of the six areas, under the technical conditions of the traditional model and with the recommended practices that were available. No wonder some of the traditional methods are nutritionally efficient along with, or even instead of, recommended practices that were thought to be superior.

In some cases neither the traditional nor the improved method can survive the indirect competition. As the opportunity-cost value of the nutrient output declines, some crops are reduced to zero level so that the land and labor they employ can be shifted to more rewarding uses. The number of food crops at zero production has increased from 5 in the traditional practices solution to 19 in the present case (see Table 4B). In the traditional practices model, the 5 included one major crop (cowpeas in the dry savanna), okra in the western moist forest, groundnuts in the forest-savanna mosaic, and two crops that could only have been produced on a very small scale in their areas anyway (soybeans in the intermediate savanna and millet in the forest-savanna mosaic). In the present instance, 9 of the 19 involve 4 crops (cocoyams, melon seed, okra, and soybeans) for which no improved practices were available in the model. Of the 19, 6 are in the eastern moist forest.

When the production of a certain crop goes to zero (or drops below its maximum level—see Table 5B), the explanation may lie partly in the fact that, while the opportunity-cost value falls for nutrients in general, it does not fall proportionally for all nutrients. Some nutrients may even become more costly, as protein, vitamin A, and calcium do in some areas when the recommended practices become available. Food energy (calories), however, and riboflavin (in the central and eastern moist forest areas) fall drastically in value.

Table 3B. ***Costs of Daily Nutrient Allowances, in Shillings per Capita***

Area	*Traditional practices*	*Recommended practices*
I	1.14	.245
II	6.43	.298
III	6.42	.494
IV	8.01	.428
V	10.34	.846
VI	6.53	.607

Table 4B. ***Food Crops at Zero Level in the Recommended Practices Solution***

Crop	*Area*					
	I	*II*	*III*	*IV*	*V*	*VI*
Millet						x
Rice, swamp					x	
Sorghum						x
Cassava, bitter			x		x	x
Cocoyam			x[a]		x[a]	
Cowpea	x			x	x	
Bean, soya		x[a]				
Melon seed				x[a]	x[a]	
Okra			x[a]	x[a]	x[a]	x[a]
Tomato, irrigated	x					

NOTE: The underscored items are crops that were at zero level in the traditional practices solution. Groundnuts were also at zero level in Area VI in the traditional practices solution, but they are at their maximum level in this one.

[a] No recommended practice available.

It follows from these changes in the relative difficulty of satisfying the various nutrient goals that nutritionally efficient crops in the recommended practices solution are being chosen for their effectiveness in meeting a differently weighted set of standards than was the case in the traditional practices solution. So it should be. Agricultural development affects the relative abundance of the several nutrients differently, so wise planning for nutritional needs must be based on the relations between nutrient supplies or productivity in the new situation, not the old.

Of the 22 instances in which activities from the traditional set are efficient as sources of nutrition or income even though improved practices are available, 13 are mixed cropping activities: maize, millet, sorghum, cassava (both bitter and sweet), yams, and cowpeas. Ten of the 13 are in the two savanna areas. The remaining 9 are sole crop-

Table 5B. ***Efficient Food Crops Produced at Less than Maximal Levels in the Recommended Practices Solution***

Crop	*Area*					
	I	*II*	*III*	*IV*	*V*	*VI*
Maize		x			x	
Millet	x					
Rice, swamp				x[a]		
Cassava, bitter				x		
Cassava, sweet		x				
Potato, Irish	x					
Yam	x		x	x	x	x
Cowpea		x	x			x
Melon seed						x[a]
Onions	x	x				
Tomato			x			
Kola nut			x[a]			

NOTE: The underscored items are crops that were at less than their maximal levels in the traditional practices solution.
[a] No recommended practice available.

ping activities for maize, rice, sorghum, Irish potatoes, and yams. Seven of the 9 are in the dry savanna.[14] It is likely that the comparative frequency of efficient traditional activities in the two savanna areas reflects the fact that the opportunity costs of nutrients are much lower there (Table 3B) than in other areas. Of course, these opportunity costs would have fallen less rapidly with technical progress if the model had not both provided that the bill of nutrients was a fixed one and set maximum limits on the acreage devoted to cash crops. As the population grows, more nutrients are needed, so improved methods that are not nutritionally efficient for a population of 61 million may become efficient in time.

Similarly, if there were no limits on the expansion of export crops, the opportunity costs of nutrients would fall less rapidly as technical improvement took place. If alternative uses for resources in export crop production were unlimited, the opportunity costs of nutrients would be based on the continuing high values of resources in export production. As a consequence, more improved methods and, presum-

[14] One of the other two is probably an error of nomenclature. The traditional practices model includes a small acreage of sole "bush" maize in the central moist forest for which a yield of 1,870 pounds per acre was reported. This is probably an improved activity that has been mislabeled. It is contained in the solution along with Western White 1 grown as an early crop.

ably, fewer traditional methods would be nutritionally efficient. Of course, there are real limits on the expansion of cash crop production. We represent such limits by setting absolute maxima at 20 percent above 1963 acreage levels. This is an arbitrary device, necessitated by the absence of data that would permit a more sensitive representation, but one that does bring out the relationship between export opportunities, the technical levels employed in food production activities, and the problem of providing adequate nutrition for the population at low cost.

The frequency with which mixed cropping activities appear in the list of efficient traditional methods suggests that mixed cropping may be more efficient in the Nigerian situation than the Western scientist has been inclined to believe. Unfortunately, our mixed cropping data were much less dependable than those available for sole cropping, so these calculations can provide only tentative evidence in support of the practice.

Prospective Varieties

The prospective practices examined in this study include 29 activities, covering seven important crops. These represent estimates of what plant breeding research might make possible within Nigeria by 1975 or 1980. The data are based upon quantitative judgments made by Ray Olson, Department of Agronomy, Kansas State University; George Sprague, Beltsville Plant Industry Station, Agricultural Research Service, U. S. Department of Agriculture; and John McKelvey, Deputy Director, Agricultural Division, Rockefeller Foundation, in interviews with Glenn L. Johnson, Department of Economics, Michigan State University. Some modifications have been made in the original estimates.

Only 15 of the 29 activities are efficient. (See Table 6B.) Among the efficient food crops, the most important are millet in the dry savanna, sorghum in the intermediate savanna, and early maize, groundnuts, and swamp rice in the forest-savanna mosaic. Cotton and groundnuts are efficient in the two savanna areas, but cotton is an income crop, and the groundnut is essentially that in the two savanna areas, in both the recommended practices and the prospective varieties solutions. (Neither the groundnut nor groundnut oil is consumed in the two savanna areas in either of these solutions, but the intermediate savanna does ship modest quantities of groundnuts to the

Table 6B. ***Prospective Varieties***

Improvement Crop	*Area*	*Efficient*	*Inefficient* Crop grown in area but by method indicated	*Optimal crop level zero*
Maize				
Single crop	I		TM	
	II	x[a]		
Early and late	III		WW1:E,L	
	IV		WW1:E; TS; TM	
	V		WW1:L	
Early	VI	x		
Late	VI		WW1:L	
Millet	I	x[b]		
	II	x		
	VI	x		
Rice				
Upland	I			x
	II		R	
Swamp	I		TS	
	II		TS	
	V	x		
	VI	x		
Sorghum	I		TS; TM	
	II	x[b]		
	VI			x
Groundnut	I	x		
	II	x		
	VI	x		
Soybean	I	x		
	II	x		
Cotton	I	x		
	II	x		
Number of instances	29	15	12	2

NOTE: TM, traditional mixed cropping; TS, traditional sole cropping; WW1:E, Western White 1, early; WW1:L, Western White 1, late; P:E, prospective variety, early; and R, recommended practice.

[a] Traditional sole and mixed cropping are also efficient. The acreage in the prospective variety is too small to be visible in Figure 2B.

[b] Traditional mixed cropping is also efficient.

eastern moist forest in both solutions and to the forest-savanna mosaic in the recommended practices solution. When the prospective varieties are used in the forest-savanna mosaic it becomes uneconomic to bring in groundnuts from the intermediate savanna.)

Only two of the ten activities involving prospective varieties of

maize prove to be nutritionally efficient, and for one of those (in Area II) the optimal cropping pattern consists almost entirely of traditional sole and mixed cropping. In five out of eight cases in which the prospective variety of maize is inefficient, however, the somewhat older improved variety, Western White 1, is efficient. (Our data for Western White 1 do not indicate that commercial fertilizer must be used to obtain the yields postulated in the model. The larger yields from the prospective varieties turn out not to be worth the extra fertilizer required to obtain them.) In addition, the recommended practice for upland rice in the intermediate savanna proved to be efficient, although the prospective variety is not.

Examination of Figures 1B and 2B reveals two other interesting consequences of the availability of the prospective varieties. When the efficient ones are in use, the cowpea becomes nutritionally efficient in the dry savanna for the first time, despite the fact that the model includes no prospective variety for cowpeas. An improved variety for the production of seed and hay as a mixed crop (the hay being fed to sheep) was available for use in the recommended practices model, but was not efficient under those conditions. Now it is. When the efficient prospective varieties are in use, food energy is much less expensive in the dry savanna than it was before. Evidently the reduced weighting given to calories allows the cowpea to join the list of efficient crops because the reduced weighting lowers the nutritional significance of other crops more than it does that of the cowpea. In the intermediate savanna, where a similar mechanism is operating, cowpea acreage expands considerably from its level in the recommended practices solution. It is the traditional mixed crop (for seed) that is expanding, however; the sole crop acreage of the new variety, although present in the former solution, is gone entirely from this one. (See Figure 1B.)

Another consequence of the adoption of efficient prospective varieties is the elimination of the recommended practices for the production of sweet cassava, maize, and yams in the intermediate savanna and of sweet cassava and sorghum in the dry savanna. Instead of using these improved methods it is more efficient to go back to customary ones for maize and yams in the intermediate savanna and sweet cassava in the dry savanna and to let the sole crop production go entirely (the mixed crop is grown in both solutions) in the other two cases. The reason seems to be again that calories are much less expensive in the present solution, so the extra yield obtained by the improved methods

is simply not worth the extra cost of employing them. We see again the consequences of declining opportunity costs for nutrients, while the added expenses associated with using improved methods remain constant.

The reduction in the opportunity cost of calories in the two areas occurs because the extra output of the prospective varieties for sole sorghum in the intermediate savanna and sole millet in the dry savanna makes it unnecessary to use the recommended practices for maize, yams, and sweet cassava in the first case and for sweet cassava and sorghum in the second. There is substitution between the more efficient prospective varieties of millet in the dry savanna and sorghum in the intermediate savanna (complemented by traditional sweet cassava in the former and maize and yams in the latter) and the less efficient recommended practices for sweet cassava, maize, and yams in the intermediate savanna and for sweet cassava and sorghum in the dry savanna. Reverting to traditional methods eliminates the fertilizer purchases that the recommended practices required. To insist upon using these recommended practices would make adequate nutrition more rather than less expensive. A small expansion in the output of calories would cost less in the present solution, with its reversion to some traditional practices, than it would if the recommended practices, with their accompanying expenditures for fertilizer, were employed to obtain it. (Aggregate expenditures on fertilizer fall by 35 million shillings in each of the two savanna areas when the prospective varieties become available.)[15]

The importance of balancing the correct opportunity-cost value of the added nutrient output from "improved" methods of production against the cost of the extra fertilizer and other industrial products these methods require becomes even more clear at a time like the present, when the dramatic rise in world petroleum prices is forcing a similar sharp rise in fertilizer prices. In this new situation we can expect even more instances in which traditional production methods not only are feasible but also preferred in comparison with the more energy-intensive "modern" methods.

The data available to us concerning the prospects attainable through plant breeding were related mostly to cereal crops. We had no data on root crops, despite their importance in Nigeria. The primary effect of the improved cereal production was to lower the cost of calories in certain areas (not including the central and eastern

[15] Yaghoobi, "Efficient Production Techniques," Table 11, p. 88.

moist forests), so it seems likely that breakthroughs in root crop productivity might have been equally significant for Nigeria. A comparison of the benefits to be expected from root crop as compared with cereal research should be made in order to point plant breeding programs in the right direction. The present study does indicate that meeting the protein allowance becomes one of the limiting requirements of the problem as meeting food energy goals becomes easier. Therefore, a useful comparison between root crops and cereals will have to be made in terms of the whole nutritional situation, not simply in terms of calories alone.

Another characteristic of the prospective varieties solution is that for the first time one of the modern animal industries becomes nutritionally efficient. Commercial cattle production in the intermediate savanna is now worth carrying on at a low level, the result of the lower opportunity-cost value in this solution of the arable land that commercial cattle production diverts from crop production.[16] As the production of food energy becomes less costly, it finally becomes efficient to devote a small amount of land that could be used for crop production to the production of an animal food. This is true despite the fact that the protein content of that food is no more significant in this solution than when only the recommended practices were available.

One further comment about the prospective varieties solution: As Appendix A pointed out, the continuing growth of the Nigerian population demands continually expanding levels of nutrient production. Thus prospective varieties not efficient in this solution may well become efficient as the opportunity costs of meeting nutrient needs are driven up. In this setting, however, modern methods of animal production are likely to become less, not more, efficient nutritionally.

Conclusion

Unsophisticated efforts to increase food production without distinguishing between efficient and inefficient sources of nutrients may worsen the nutritional situation rather than improve it. Concentrating on the protein problem without examining the relationship between providing adequate quantities of protein and adequate quantities of the other nutrients may lead to expanding the animal industries when the feeds eaten by animals that the well-to-do will consume can ill be spared from the diets of the poor, or to encouraging the production of

[16] Ibid., Table 8, p. 78.

cowpeas in situations when meeting food energy needs is so important that millet, sorghum, or groundnuts are more efficient. Large increases in yields do not always mean efficient production of nutrients. As we have seen, to replace traditional practices by certain of the recommended or prospective practices would raise the cost of nutrition for the nation, not lower it.

It is possible, with methods now available, to measure the nutritional efficiencies of various crops and techniques. We do not have to wait until the "green revolution" has occurred to discover that too much acreage in the improved cereals may mean an excessive reduction in the protein content of the diet. We do not need to wait until improvements have been put into effect to determine their results; we can anticipate some of their consequences if we make the effort.

To be sure, the data available are not always adequate, and methods for prediction can be improved. Predictions cannot be perfect, but they can be better than no predictions. Examining the nutritional efficiencies of food crops and methods and concentrating development programs on production activities that promise the greatest nutritional efficiencies can significantly improve the effectiveness of food production programs and help make possible the well-fed, alert, and healthy population that is an essential precondition to rapid economic development.

Biblioaraphy

L'Association pour l'Étude Taxonomique de la Flore d'Afrique Tropicale. *Vegetation Map of Africa South of the Tropic of Cancer.* Oxford: the University Press, published with the assistance of UNESCO, 1959.

Belli, Pedro. "The Economic Implications of Malnutrition: The Dismal Science Revisited." *Economic Development and Cultural Change* 20 (1971): 1–23.

Caldwell, John C. Demographic Research and Training Unit, Faculty of the Social Sciences, University of Ife. Personal correspondence with Carl K. Eicher, 6 April 1969.

Cameron, Margaret E. "Amounts of Nutrients Required by Humans in Their Diet." *Review of Nutrition and Food Science,* no. 1 (October 1965): 15–20.

Centre of Advanced Study in Economics. *Wage Policy and Wage Determination in India.* Papers and Proceedings of the Seminar held by the Centre of Advanced Study in Economics, University of Bombay, March 1969. Bombay: University of Bombay, 1970.

Cownie, John. *Nigerian National Income Accounts: Historical Summary and Projections to 1985.* CSNRD 14r. East Lansing: Consortium for the Study of Nigerian Rural Development, Michigan State University, August 1968.

Davidson, Stanley, and Passmore, Reginald. *Human Nutrition and Dietetics.* 4th ed. Edinburgh: Livingstone, 1969.

Fonseca, A. "The Need-Based Wage in India: A Computerized Estimate." In Centre of Advanced Study in Economics, *Wage Policy and Wage Determination in India,* pp. 181–97.

"Food vs. People." *War on Hunger* 5, no. 9 (September 1971): 10–11.

Godden, W. "Notes on Certain Edible Earths and Native Salts in Nigeria." *West African Medical Journal* 2 (1929): 187–89.

Gurney, J. M. "Considerations in Agricultural Planning." *Nutrition Reviews* 29 (1971): 50–52.

Hartsook, E. W., and Mitchell, H. H. "The Effect of Age on the Protein and Methionine Requirements of the Rat." *Journal of Nutrition* 60 (1956): 173–95.

Helleiner, Gerald K. *Peasant Agriculture, Government, and Economic Growth in Nigeria.* Homewood, Ill.: Richard D. Irwin, 1966.

Idachaba, Francis Sulemanu. "The Effects of Taxes and Subsidies on Land and Labour Utilization in Nigerian Agriculture." African Rural Employment Paper no. 7. East Lansing: Department of Agricultural Economics, Michigan State University, April 1973.

Idusogie, Ephraim Osabor. "A Critical Review of the Role of Cash Cropping on the Nutrition of Nigerian Peoples." Ph.D. diss., University of London, 1969.

Johnson, Glenn L.; Scoville, Orlin J.; Dike, George K.; and Eicher, Carl K. *Strategies and Recommendations for Nigerian Rural Development, 1969/1985.* CSNRD 33. East Lansing: Consortium for the Study of Nigerian Rural Development, Michigan State University, July 1969.

Keay, R. W. J. *An Outline of Nigerian Vegetation.* 3d ed. Lagos: The Federal Government Printer, 1959.

Latham, Michael. *Human Nutrition in Tropical Africa.* Rome: Food and Agriculture Organization of the United Nations, 1965.

Laurent, C. K. *Problems Facing the Fertilizer Distribution Program in the Six Northern States.* CSNRD 27. East Lansing: Consortium for the Study of Nigerian Rural Development, Michigan State University, January 1969.

May, Jacques M. *The Ecology of Malnutrition in Middle Africa (Ghana, Nigeria, Republic of the Congo, Rwanda Burundi, and the former French Equatorial Africa).* Studies in Medical Geography, volume 5. New York: Hafner, 1965.

Mahadevan, P. Speech before the International Conference on Nutrition, National Development and Planning, Massachusetts Institute of Technology. Cambridge, Massachusetts, 19–21 October 1971.

Mengesha, Melak. Faculty of Social Science, Haile Sellassie I University, Addis Ababa, Ethiopia. Speech before the Tropical Studies Group, Michigan State University. East Lansing, Michigan, 14 February 1973.

Miller, D. S. "A Procedure for Determination of NPU Using Rats: Body N Technique." Appendix C, pp. 34–36, of "Biological Assay Methods for Protein Evaluation," in National Research Council, *Evaluation of Protein Quality.* Washington, D.C.: the Council, 1963.

_____ and Payne, P.R. "Problems in the Prediction of Protein Values of Diets: The Use of Food Composition Tables." *Journal of Nutrition* 74 (1961): 413–19.

_____. "A Theory of Protein Metabolism." *Journal of Theoretical Biology* 5 (1963): 398–411.

National Academy of Sciences/National Research Council. Food and Nutrition Board, Committee on Protein Malnutrition. *Evaluation of Protein Quality; Report of an International Conference.* Publication no. 1100. Washington, D.C.: the Academy and the Council, 1963.

Nigeria, Federal Office of Statistics. *Nigeria Trade Summary.* Lagos: the Office.

———. *Review of External Trade, Nigeria, 1968.* Lagos: the Office, 1969.

———. *Rural Economic Survey of Nigeria,* including *Farm Survey,* 1963/64, RES/1966/1, 28 February 1966; *Livestock Enquiry,* 1963/64 and 1964/65, RES/1966/2, no date; and *Farm Survey,* 1964/65, RES/1966/5, no date. Lagos: the Office.

Nigeria Year Book, 1966. Lagos: Times Press Limited, n.d.

Nigeria Year Book, 1973. Lagos: Daily Times Magazine Division, n.d.

Norman, David W. *An Economic Survey of Three Villages in Zaria Province: 2. Input-Output Study, Vol. 1, Text.* Samaru Miscellaneous Paper 37. Zaria, Nigeria: Institute for Agricultural Research, Samaru, Ahmadu Bello University, 1972.

———. *Economic Analysis of Agricultural Production and Labour Utilization among the Hausa in the North of Nigeria.* African Rural Employment Paper no. 4. East Lansing: Department of Agricultural Economics, Michigan State University, January 1973.

———. "Initiating Change in Traditional Agriculture." *Proceedings of the Agricultural Society of Nigeria* 7 (1970): 6–14. Also in *Agricultural Economics Bulletin for Africa* 13 (1971): 31–52.

———. "Intercropping of Annual Crops under Indigenous Conditions in the Northern Part of Nigeria." Paper presented at a conference on Factors of Agricultural Growth in West Africa, organized by ISSER, University of Ghana. Legon, Ghana, March 1971.

———. "The Rationalization of a Crop Mixture Strategy Adopted by Farmers under Indigenous Conditions: the Example of Northern Nigeria." Mimeographed, n.d.

Ojomo, Olatunde A. *Cowpea: Production and Research in Western State of Nigeria.* Ibadan: Research Division, Ministry of Agriculture and Natural Resources, Moor Plantation, September 1967.

Oke, O. L. "Chemical Studies on the Nigerian Foodstuff 'Ogi.'" *Food Technology* 21 (1967): 202–204.

Oram, P. A. "The Technical Advisory Committee (TAC) of the Consultative Group on International Agricultural Research." *PAG Bulletin* 3, no. 1 (Spring 1973): 20–23.

Orr, M. L., and Watt, B. K. *Amino Acid Content of Foods.* Home Economics Research Report no. 4. Washington, D.C.: (Household Economics Research Division, Institute of Home Economics, Agricultural Research Service, U.S. Department of Agriculture) U.S. Government Printing Office, December 1957.

Payne, Kenyon. Department of Crop and Soil Sciences, Michigan State University, East Lansing. Personal communication.

Phillips, Tom Alan. *An Agricultural Notebook, with special reference to Nigeria.* 2d ed. Ikeja: Longmans of Nigeria, 1964.

Platt, B. S. *Tables of Representative Values of Foods Commonly Used in Tropical Countries.* Privy Council, Medical Research Council Special Report Series no. 302. London: Her Majesty's Stationery Office, 1962.

République du Mali. Mission Socio-Économique du Soudan, 1956–1958. *L'Alimentation des Populations Rurales du Delta vif du Niger et de l'Office du Niger.* Paris: Service des Statistiques, Chargé des Relations et de la Coopération avec les États d'Outre-mer, 1961.

Schickele, Rainer. "Critical Issues in the Economics of Development." Privately circulated, 1971.

Rice, Harold L., and Pettifor, Andrew H. "The Probyte: A New Protein Unit System." *Journal of Agricultural and Food Chemistry* 20 (1972): 509-18.

Schmidt, Donald R. Agronomy Department, Cornell University, Ithaca, New York. Personal correspondence, 22 April 1969.

Scoville, Orlin J. "The Twelve States of Nigeria: Background and Current Issues." Mimeographed, November 1968.

Smith, Victor E. "Agricultural Planning and Nutrient Availability." *Nutrition Reviews* 28 (1970): 143–50.

———. "A Diet Model with Protein Quality Variable." *Management Science* 20 (1974): 971–80. An earlier version appeared as Michigan State University Econometrics Workshop Paper no. 7007. East Lansing: Department of Economics, April 1971.

———. *Electronic Computation of Human Diets.* MSU Business Studies. East Lansing: Bureau of Business and Economic Research, Graduate School of Business Administration, Michigan State University, 1964.

———. "A Model of Nigerian Agriculture: Programming for Nutrition as Well as Income." Michigan State University Econometrics Workshop Paper no. 6811. East Lansing: Department of Economics, April 1969.

———. *Optimal Resource Allocation for Income and Nutrition.* Working Paper no. 11. East Lansing: Consortium for the Study of Nigerian Rural Development, Michigan State University, June 1969.

Sukhatme, P. V. "Size and Nature of the Protein Gap." *Nutrition Reviews* 28 (1970): 223–26.

Tollens, Eric. Agricultural Economist. Personal communication, 31 March 1971.

United Nations. Food and Agriculture Organization. *Agricultural Development in Nigeria, 1965–1980.* Rome: FAO, 1966.

———. *Monthly Bulletin of Agricultural Economics and Statistics.* Rome: FAO.

———. *Energy and Protein Requirements: Report of a Joint FAO/WHO Ad Hoc Expert Committee.* FAO Nutrition Meetings Report Series no. 52 (WHO Technical Report Series no. 522). Geneva: WHO, 1973.

———. *Protein Requirements: Report of a Joint FAO/WHO Expert Group.* FAO Nutrition Meetings Report Series no. 37 (WHO Technical Report Series no. 301). Rome: FAO, 1965.

———. *Report of the FAO/WHO Seminar on Problems of Food and*

Nutrition in Africa South of the Sahara. Lwiro, Bukavu (Congo), 18–29 May 1959. FAO Nutrition Meetings Report Series no. 25. Rome: FAO, 1961.

———. Nutrition Division, Food Consumption and Planning Branch. *Amino Acid Content of Foods (Provisional).* Rome: FAO, July 1963.

——— and U.S. Department of Health, Education and Welfare, Public Health Service, Health Services and Mental Health Administration, National Center for Chronic Disease Control, Nutrition Program. *Food Composition Table for Use in Africa.* Bethesda, Md.: U.S. Department of Health, Education and Welfare, 1968.

United Nations. Protein Advisory Group. *PAG Bulletin.* New York: United Nations.

———. "PAG Guideline (No. 14) on the Preparation of Defatted Edible Sesame Flour." *PAG Bulletin* 3, no. 1 (Spring 1973): 10–14.

United States. National Institutes of Health, Office of International Research, Nutrition Section. *Republic of Nigeria: Nutrition Survey, February–April 1965.* Washington, D.C.: Public Health Service, U.S. Department of Health, Education and Welfare, 1967.

Watt, Bernice K., and Merrill, Annabel L. *Composition of Foods . . . raw, processed, prepared.* Rev. ed. December 1963. Agriculture Handbook no. 8. Washington, D.C.: (Consumer and Food Economics Research Division, Agricultural Research Service, U.S. Department of Agriculture) U.S. Government Printing Office, 1963.

Whitney, John. Personal communication, May 1969.

Woodroofe, R. B. Chief Agricultural Officer, Kano State Ministry of Natural Resources, Kano, Nigeria. Personal communication.

World Health Organization. *Requirements of Vitamin A, Thiamine, Riboflavin and Niacin; Report of a Joint FAO/WHO Expert Group (September 1965).* WHO Technical Report Series no. 362. FAO Nutrition Meetings Report Series no. 41. Geneva: World Health Organization, 1967.

Yaghoobi-Rahmatabadi, Hossein. "The Most Efficient Production Techniques for Providing Nutrition and Income from the Agricultural Sector of Nigeria." Ph.D. diss., Michigan State University, 1971.